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RISK MANAGEMENT IN THE MAINTENANCE OF RADIOLOCATION SYSTEMS

MANAGEMENTUL RISCULUI ÎN MENTENANȚA SISTEMELOR DE RADIOLOCAȚIE

SUMMARY

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CUPRINS

LIST OF ABBREVIATIONS

AR	Augmented Reality
ATM	Air Traffic Management
BBN	Bayesian Belief Network
BITE	Built-in Test Equipmen
CAST	Causal analysis using STAMP
CBR	Case-based reasoning
CFA	Contributory Factor Analysis
CI	Competitive Intelligence
CIMO	Context, Intervention, Mechanisms and Outcome
COTS	Commercial Off-The-Shelf
CREAM	Cognitive Reliability and Error Analysis
CT	Cognitive Tools
CVPC	Body Worn Video Camera
EIF	Error Influencing Factors
ETA	Event Tree Analysis
FAA	Federal Aviation Administration
FAHP	Fuzzy Analitic Hierarchical Procces
FLIR	Forward Looking Infra Red
FMEA	Analysis of failure modes and effects
FMECA	Failure Mode, Effects & Criticality Analysis (FMECA)
FRAM	Functional resonance analysis method
FTA	Fault Tree Analysis
HAZOP	Hazard and Operability Analysis
HEP	Human Error Probability
UNHCR	Human Cognitive Reliability
HEART	Human error assessment and reduction technique
HFACS	Human Factors Analysis and Classification System
HRA	Human Reliability Analysis
IA	Artificial Intelligence
INDICATE	Identifying Needed Defences In the Civil Aviation Transport Environment
IoT	Internet of Things
KBS	Knowledge Based System
LDA	Latent Dirichlet Allocation
MA	Machine Aiding
MBF	Reliability Based Maintenance
MCDA	Multiple Criteria Decision Analysis
MCDM	Multiple Criteria Decision Making
MCH	Hybrid Monte Carlo Method
MCI	Military Critical Items

MEDA	Maintenance Error Decision Aid
MP	Machine Proposal
MTTR	Mean Time to Recovery
NLP	Neuro Linguistic Programming
WMO	World Meteorological Organization
EMP	Psychological Error Mechanism
IP	Prioritization Index
PCA	Principal Component Analysis
PRA	Probability of Risk Assessment
QRA	Quantitative Risk Analyses
RIF	Risk Influencing Factor
ROG	Real Option Game
SAM	System-Action-Management
SAPOE	Seafarers Assessed Proportion of Effect
SADT	Structured analysis and design technique
SCM	Swiss Cheese Model
SEAP	Electronic Public Procurement System
SHELL	Software, Hardware, Environment, Liveware
SIC	Safety Information Cognition
SICAM	SIC - based Accident - causing Model
SICHFA	SIC - based Human Factor Analysis
SIF	Safety Information Flow
SLIM	Success Likelihood Index
SLR	Systematic Literature Review
SMM	Safety Management Manual
SMS	Safety Management System
SRM	Safety Risk Management
STAMP	Theoretical systems crash Model and process
THERP	Technique for human error rate prediction
ICT	Information and Communications Technology
VR	Virtual Reality
VUCA	Volatility, Uncertainty, Complexity, Ambiguity

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ABSTRACT

The PhD thesis, **Risk Management in the Maintenance of Radiolocation Systems,** was a challenge to identify, interpret and associate the inherent risks and to seek viable solutions to mitigate and limit the causes of occurrence as well as their effects, represented by personal injury, loss of life and/or property loss. The essential purpose of radiolocation systems is the 24/7 surveillance of the airspace in the area of responsibility. These areas of responsibility overlap so that this complex architecture can be analysed as a system of systems. Operational availability is the main desideratum, the lack of which causes breaches in the area of responsibility, which is identified as a vulnerability of the air surveillance system. Therefore, once these possible shortcomings have been identified, aspects covering the whole range of situations from the basic level represented by the radiolocation system to the higher level represented by the decision maker responsible for the system of systems architecture, system design, acquisition, operation and decommissioning have been analysed and addressed in the pages of the thesis. The personal contributions have been translated into proposals to improve risk management so that the working environment becomes safer, the stress component decreases, with the ultimate goal of maintaining the operational status of the radiolocation systems in service with minimum resources.

The topic addressed was based on the importance and topicality of the field and the interest of decision-makers in solving practical problems specific to technological change and formulating associated strategic and tactical managerial decisions. This set of research has been addressed in the subject area by going through the stages of the thesis architecture, the efficient use of research methods and methodologies harmonised with the research objectives. Given the relatively small number of bibliographic references and data available, the focus was also on elements of originality and innovativeness in dealing with maintenance issues and aspects of in-depth understanding of multiple risks (technological, change, project management implementation, macroeconomic risks, etc.) in modern radiolocation systems.

In the first chapter, which is the **introduction of** the thesis, the approach of the topic in the current context was justified, the delimitation of the topic and the fields of the research project was carried out, the importance and topicality of the topic was exposed and the current scientific context was presented, the objectives of this first chapter being the identification of the need for adequate treatment of potential risks in the territory using questionnaires and analyzing institutional requirements of various ministries/departments of defence of NATO member countries), as well as the establishment of the research methodology and the design of the thesis architecture, in relation to the current concrete situation in Romania. The proposed objectives have been fully achieved, being materialized through the design of case studies, the centralization of answers, their analysis and interpretation as well as the constitution of concise and eloquent schemes, based on some innovative methods from the governing literature of strategic management and project management (the use of the paradigm of real options was a bold approach, which can give decision makers a tool with major impact in the flexibility of specific projects and dynamic adaptation to the changing external environment especially in conditions of uncertainty and high volatility.

In the second chapter entitled **Analysis of the operational environment and the current state of research in the literature,** the objective was to gain an in-depth understanding of the

current state of knowledge in the field, the gaps and overlaps in the contributions of relevant authors. Using the questionnaire method applied to a relevant sample of specialists in the field, the technical-managerial problems in the territory were identified and a first classification of problems and risks according to the perception of the respondents resulted. In this chapter, elements concerning the maintenance management of radiolocation systems identified in open sources were highlighted. Using the Web of Science and Scopus tools, filtering and selection of relevant documents for the field of interest were carried out, categorized by authors, techniques and methods, and areas of applicability. The main objective was to browse and classify the methods and techniques used in risk management in radiolocation maintenance, an approach successfully achieved and justified based on the identification of items of interest and relevant correlations between common themes treated by authors dedicated to the field.

The architecture of an aerial surveillance system and the methods/models used in the maintenance of radiolocation systems is the title of the third chapter. The objective is to highlight the evolution of the human-machine relationship (from system requirements design, selection, procurement, training, operation, maintenance and decommissioning to environmental compliance and exploitation) and how to adapt the human factor as a key element in maintenance risk management. Highlighting the role of human resources in the architecture of radiolocation systems was carried out in the context of technological change and the turbulent external environment strongly impacted by multiple crises post 2020. Also in this chapter the PhD student presents tools, methods/models used in the maintenance of radiolocation systems, conventional and innovative. The interest in this chapter is the filtering and in-depth understanding of methods able to identify the need for intervention and to perform availability prediction of an element (antenna, ECU rotor) in continuous motion through vibration monitoring, thermal imaging - FLIR or BiTE (Built-in Test Equipment). Methods, tools and IT components with measurement, analysis, interpretation and prediction capabilities have been identified for this area, suitable for the research topic with impact in minimising the period of operational downtime and thus reducing the risks of damage to personnel and radiolocation equipment. At the same time, an innovative 13-step implementation concept has been proposed that integrates the presented methods with the objective of achieving optimal management of maintenance and inherent risks.

In chapter four entitled **Risk analysis and risk management process in radiolocation systems**, specific aspects of some conceptual elements - risk, scenario types, how to classify specific risks, risk management and risk analysis - are highlighted. One of the objectives of this chapter is to outline the specific elements of the research topic and it is materialized by the process of active risk analysis and management in the subject area. The objective has been met by highlighting some classifications of risk events specific to the radiolocation domain in the context of disruptive technological change. Prevailing causal factors were highlighted and a research direction focused on minimising related risks and potential incidents was proposed. The specific risks of radiolocation systems in the context of technological change in a turbulent environment were also presented. A version of a risk sheet was presented with the risk level highlighted by colour legend.

In the fifth chapter entitled **Performance Management of Complex Socio-technical Systems (SSTC): Human Factors Behaviour in Radiolocation Systems,** the proposed main objective is to integrate reliability engineering in the maintenance of radiolocation systems and to define the specific features of the research approach. A second objective concerns the identification of the gap between regulations and the reality on the ground, in the context of technological change and human factor specificities. From the research carried out, conclusions were drawn regarding the limits of the regulation of risk management elements linked to incomplete harmonisation with practice in the field. Human errors (errors of commission and errors of omission), were also complemented by errors in the decision-making system which, despite having increasingly sophisticated tools, does not always manage to capture the solutions for adaptation through flexibility.

Chapter six entitled **Applicable holistic methods and socio-technical implications of digitization in the maintenance of radiolocation systems** presents some methods of interest with applicability to the research field. The BCG matrix provides the recipient with a framework for evaluating the success of each product to help them determine which they should invest more in and where to withdraw. From the research conducted, it emerged that the AHP provides a rational framework for a necessary decision by quantifying criteria and alternative options and relating these to the overall objective. The application that used multi-criteria analysis for the purpose of selecting the learning/training platform in the context of the pandemic crisis is an eloquent guide and will support stakeholders in making decisions in their field. The section on analysing the impact of turbulent and crisis environments on the operation and maintenance of radiolocation systems highlights the need for quality management, which through the decisions taken manages to keep the system they manage viable. The chapter also identifies the socio-technical implications of digitisation in the field of interest, represented by the difficulties in recruiting suitably trained staff and the weight with which the human factor responds to technological expansion.

Chapter seven entitled **Case studies, practical applications and real options games with impact on risk management in the maintenance of radiolocation systems,** is a defining element of the thesis, in which a series of studies with impact on the researched field are carried out. An essential objective of the thesis, dealt with in this chapter, is focused on case studies on the identification of the events produced, the causes and factors that led to their occurrence and the necessary intervention measures (failure of the rolling bearing, pedestal breakage under the influence of strong or gusty winds, radom destroyed by lightning).

Two practical applications were carried out on vibration monitoring as a predictive method for optimised management of inherent risks (a 2D study under laboratory conditions on the experimental bench with the SkyRadar teaching radar, the complete set produced by IFM Germany consisting of VSA004 acceleration sensor, VSE002 data acquisition and processing unit, signalling lamp, and a laptop unit where the software for data interpretation and establishment of damage and major fault limits was installed; the second 3D study under real flight conditions using an Arduino UNO assembly for vibration monitoring, powered from a 12V power supply, with a series of sensors attached: GPS with antenna, 6DOF sensor, barometer, RTC Real Time Clock) and a logger (recorder) equipped with a memory (SD card). A proposal for using AR in remote maintenance is included in the chapter.

The results from the analysis of the use of flexibility as a tool to increase the implementation capability of projects associated with technological change impacting on the maintenance (technical and human component) of radiolocation systems are spectacular. They highlight that today's decision makers can leverage more advanced analytical procedures to make strategic investment decisions in radiolocation system architectures. By integrating the real options paradigm, a novel way of evaluating and understanding how to formulate strategic decisions is highlighted. The application of the real options approach has revealed strategic solutions to increase the value of a project while managing risks; expansion and abandonment options have been considered in the study.

Human factor risk modelling for anticipating and predicting the evolution of risk factors involved in radiolocation maintenance is proposed to be achieved by integrating BodyCam or Augmented Reality (AR) glasses in the process of maintenance work execution. This can be used to provide assisted training for less qualified personnel, as well as to record the maintenance work performed in order to create a database (BigData) that can be uploaded to a government cloud where it can be technically audited by teams of specialists in a first phase and, in the future, can be used as input for an Artificial Intelligence (AI) model. This last proposed solution is at this point idealistic and represents **a bet with the future**. At the moment AI is only able to relate to text and incipient voice databases. But its evolution is spectacular. It is expected that in the not too distant future, based on an analogy with the STEM cell sampling model, video recordings of radiolocation operations will represent the already collected data base necessary for the development of an Artificial Intelligence engine dedicated to the maintenance of radiolocation systems and implicitly their risk management. The creation of a digital register in which each element involved in maintenance is categorised for the purpose of human reliability analysis. By tracking the execution of maintenance operations and by periodical evaluations of the level of training, the categories of personnel are classified by degree of training (of expertise/competence, evaluated by tests of various complexities such as STANAG 6001 linguistic), equipment by degree of complexity and risks by probability of occurrence and potential impact. All these lead to increased accountability of personnel involved in the execution of radiolocation maintenance by decreasing errors of commission and omission.

The **conclusion** chapter highlights the contributions made through the research topic focused on the development and integration of risk management models adapted to radiolocation maintenance, the personal contributions and participations in the projects the PhD student has been involved in as well as future research directions resulting from the limitations of the research conducted.

From the point of view of application contributions, the solutions for the management of specific maintenance problems and the vibration analysis of the radar electronic platform, the roll bearing and the radiolocation equipment mounted on board the airborne vectors stand out. The results of the experimental test bed measurements and simulations are scalable and can be implemented from a pilot programme and in a second phase can be integrated into all national and NATO alliance radiolocation systems.

It also proposed a novel way of using the hardware and software tools that contribute to RA, both for staff training, experience enrichment, increasing self-confidence and technical performance with major effects in risk management. Increasing the database with records of maintenance operations and the use of flexibility as a tool to increase the ability to implement projects associated with technological change with an impact on the maintenance (technical and human component) of radiolocation systems supports the creation of a complete picture, as real and especially current as possible, of the phenomena that are triggers of failures and accidents, on the basis of which decision-makers can impose specific regulations and measures to be followed to optimise processes and reduce risks. The way the information is presented is succinct, colloquial and at the same time permissive and elevated, succeeding in clarifying concepts from the fields of Engineering and Management with applications in the field under consideration.

1. INTRODUCTION

Justification of the approach in the current context

The maintenance of radiolocation systems has always been an area of interest for me as the proper execution of this depends on the fulfilment of the airspace surveillance mission in the area of responsibility. The approach to the issue of risk management from the perspective of the maintenance of radiolocation systems is a continuous challenge, since we are dealing with a socio-technical system composed of the human factor as a first component, and the technical system complementary to the first component, must be treated in its entirety, implicitly with the related internal processes, to achieve the management of potential risks depending on the operational status of the radiolocation technique, namely the physical integrity and even the life of the personnel.

With these concerns in mind, I set out to bring together in a unified concept the defining elements of the life of radiolocation specialists, their operational working environment and the specific risks of their activities. The personal contributions were also translated into proposals for improving risk management so as to make the working environment safer and reduce the stress component, with the final objective of maintaining the operational status of the radiolocation systems in service with minimum resources.

Delineation of the theme and areas of the research project

The proposed research topic fits into the general picture of risk management at the level of socio-technical systems that concern flight safety. In a detailed search we found research on the human factor and the performance of pilots and air traffic controllers respectively, but we did not find any relevant analysis of the risk management of the maintenance of radiolocation systems, and therefore of the personnel performing it.

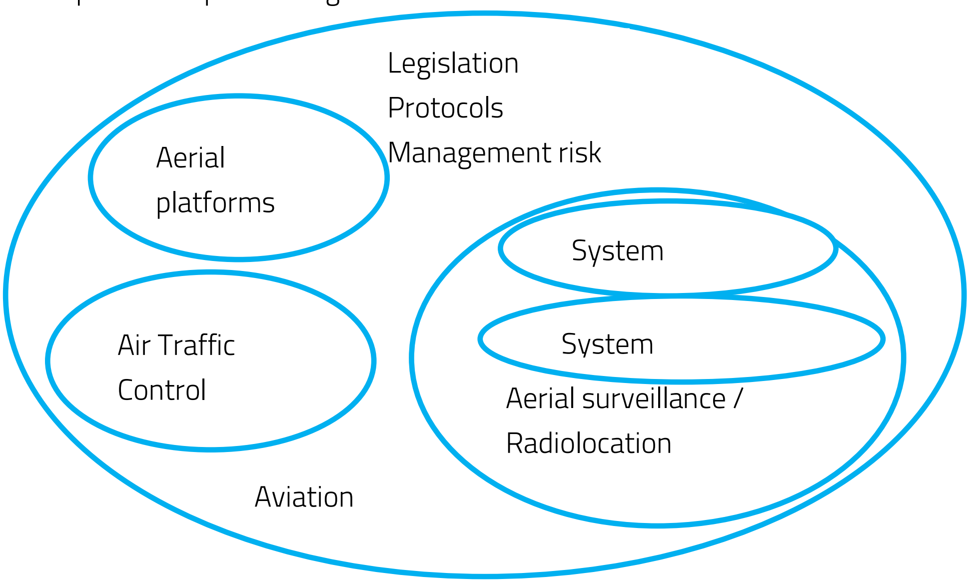


Figure 1.1: Delimitation of the aviation research topic

In aviation (Figure 1.1), the aerial surveillance component is clearly determined, and is mainly carried out with radiolocation systems. From our research we have identified that risk management is dealt with and analysed at the level of corporations and multinational companies at a fairly high level. However, the analysis from this perspective of risk management in specialised, niche areas, such as the maintenance of radiolocation systems, is not sufficiently addressed, which has aroused my intense interest.

Importance and topicality of the theme

The theme of the research project took shape in 2017-2019 (a period of relative calm in the national, regional and international context) during the coordination of my students' dissertations, projects and degree works at the Air Force Academy "Henri Coandă" in Brasov. The subject became more and more captivating and materialized into a research topic for the present PhD thesis. At that time the importance was given by the personal concern and the concern of the teams I was coordinating to identify and analyse potential risks and to find and propose viable solutions to manage them, the aim being to maintain the operational availability of the radiolocation systems. To the elements of that time were added some complementary ones, at least two, materialised in Figure 1.2 (the pandemic crisis 2020-2022, the Ukraine-Russian Federation inter-state conflict, manifested with fierce violence as a long-lasting war, and the crisis of resources, human and energy)

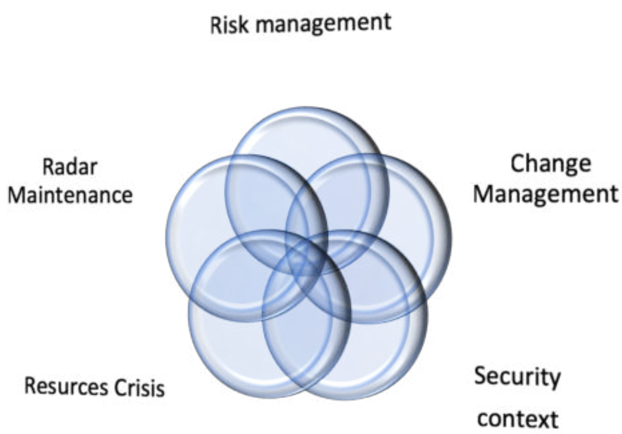


Figure 1.2 Convergence of current interdisciplinary fields

The PhD thesis entitled **Risk Management in the Maintenance of Radiolocation Systems** is highly topical and important due to the interest in a thorough understanding of the issue of risk management especially its implications from the perspective of radiolocation maintenance, such a unique and particular field. The thesis deals with current risk management issues in the context of multiple crises (resource crisis, supply chain crisis, generation change crisis, semiconductor crisis) by addressing the use of flexibility as a tool for real options in the process of deployment and maintenance of radiolocation systems. Throughout, the thesis arouses interest, with the way the case studies are treated reinforcing this belief. The approach is progressive, from integrated implementation of preventive maintenance in radiolocation systems, to database implementation and enrichment solutions, to sampled technical auditing of the actions of maintenance staff, culminating in the use of innovative AR (Augmented Reality) and IoT (Internet of Things) tools. The formulations are concise and bring increased conceptual clarity. The multidisciplinary and interdisciplinary nature of the thesis makes it stand out in the literature as a good tool for personnel performing maintenance as well as those implementing solutions for risk reduction in radiolocation systems.

Current scientific context

Whichever way we look at a given field, it comprises the academic/academic area, the fundamental research, development and innovation area and obviously the practical/applied area, which is close to industry. These areas do not have clear demarcations, but coexist in an ecosystem that aims at stability and continuous operational availability on the one hand, and scientific progress and continuous development of the field on the other. The academic area, that of training future radiolocation specialists, has a clearly determined role to motivate and train young people, to put all material and knowledge resources at the service of those who represent the future pioneers of radiolocation. The research, development and innovation area uses specific methods, techniques and tools to respond to contemporary and future challenges. The practical/application area provides the material and technological resources to implement the products of research and innovation.

Today's scientific context, as in any field, is in constant flux. A clear picture, by conducting the literature review in the second chapter of the thesis, highlighted authors with interest in the field of risk management, methods and tools used in risk management in industrial processes and in the maintenance of equipment, systems, as well as the fields in which they are applied (aviation, marine, nuclear, etc.). The conclusions of the chapter propose that reactive or corrective methods should be abandoned in risk management and that the most appropriate methods for the current context should be adopted, namely predictive and interactive methods.

Also, in order to achieve a picture as close as possible to reality, to narrow the gap between the theoretical component of the literature and the practical component of the operational working environment, I have developed, applied and analysed a questionnaire whose products have directed my research to identify and propose solutions that can improve the maintenance of radiolocation systems and thus optimize risk management in the field of interest. Again, the identification from open sources of the maintenance needs of equipment in radiolocation systems is without doubt the most truthful and current resource and impetus for research. We have identified that there are launched public tenders seeking partners for the supply of spare parts and sub-assemblies of the composition of the TPS-79(R) - Gap Filler radars in the amount of $ 82,060.00 (January 2016), for the provision of repair service type Repair and return of defective equipment specific to the TPS-79(R) - Gap Filler radars (January 21, 2019) with an estimated price of 201,898,153.94 lei, equivalent at that time to $ 48,000 (**Error! Reference source not found.**

Spatially and temporally we are in an area that is in a continuous dynamic. Every moment brings news, an important event for knowledge and development, but also challenges for regional and international security. Crises of all kinds, of resources, of supply chains, of generational change, more recently of semiconductors, highlight the ability to adapt to the new, to be resilient, to be flexible and to manage leverage, design and simulate scenarios appropriately.

Justification of the choice of the title of the thesis and formulation of the proposed objectives in relation to the current state and the need for research

As I have also referred to in the previous sections, the personal concern about the maintenance of radiolocation systems, and hence their safe implementation through appropriate risk management, was the initial impetus (Figure 1.3) This was constantly fed by the answers to the research carried out in the field, from discussions with specialists in the field, from the products of the questionnaire completed by them, as well as the identification at institutional level both at national level and at the level of the partner army within the North Atlantic Alliance of the need to implement modern, innovative solutions. The choice of a more refined and concise final title for the thesis than its predecessor was made after the presentation of the third scientific research report. The chosen research topic elegantly brings together the technical component represented by maintenance and the leadership component represented by the decision making process to achieve effective risk management.

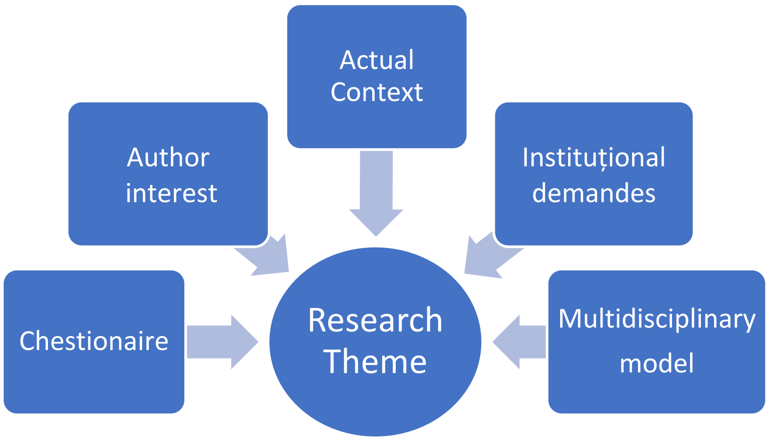


Figure 1.3Convergence of ideas and items towards the chosen research topic

The **proposed objectives** include the research needs identified in the field, in the radiolocation units, to fill the gaps identified in the literature. In my thesis I have proposed a panoramic, overall approach characteristic of leadership, but where I considered that the situation required it I have made it concise. The **overall objective of** the thesis is to determine effective and feasible solutions to improve risk management from the perspective of radiolocation systems maintenance in the context of disruptive technological change and the current multiple crises, which translates into: reducing the number of events causing injury or even death to staff, reducing the effects of risks, implementing new solutions in radiolocation systems and making the most appropriate decisions by decision makers.

In order to adequately cover the general objective, I have proposed a breakdown by operational objectives for the step-by-step treatment of the research topic as follows. The **first** proposed **objective** is to identify/map through the products of a dedicated questionnaire, the situations and needs of specialists in the operational environment and the systems they frame. At the same time I aimed to verify the visibility of radiolocation systems, to identify from open sources, the specific aspects of radiolocation maintenance reported by dedicated institutions. Subsequently I foresee a **second** very important **objective** to be addressed, namely the analysis of the literature and implicitly the identification of works with specific applicability to the chosen research topic. Following the model of the analysis of aviation events, I propose as a **third objective**, the identification of specific events produced in and at radiolocation systems, highlighting the causes that led to their occurrence, the latent conditions, the enabling environment, as well as the identification of measures drawn as lessons learned.

From the integration of the 3 objectives (Figure 1.4) proposed I believe that there will be sufficient data and information to answer the **fourth objective** proposed, to identify the gap between the specific regulations in the technology sheets, operation, operation and maintenance manuals on the one hand and the reality of the operating environment on the other hand (where the pressure of the situation and logistical shortcomings create the prerequisites for accidents) once this gap or gap is highlighted I believe that the need for effective risk management will become evident.

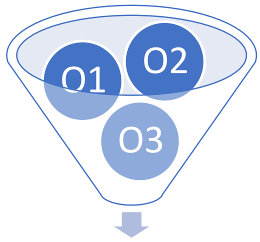


Figure 1.4Basic outline of the proposed objectives

This objective will create the basis for interesting analyses from both technical and socio-human points of view. The **fifth objective** is to improve the technical component by integrating predictive maintenance at the level of the rotating elements by carrying out a case study on the introduction of devices capable of analysing vibrations for the bearings on the electronic platform-antenna and the bearings in the ECU systems. For this objective, I proposed the realization of two mounts on an experimental test stand (specific to ground-based radiolocation systems) and another on a 3D airborne vector (to simulate the effects of flight on radar equipment on board aircraft). The proposed objective provides the necessary elements for implementation/transfer to the beneficiary through a pilot programme.

The modelling of human factor risks is the **sixth** proposed **objective**, for the achievement of which the following are proposed: recording of maintenance work using BodyCam/AR Glasses, constitution and development of a database of maintenance operations footage, classified by system, saved in the government cloud with privileged access to technical audit teams. Based on this and other indicators I believe that elements of human reliability analysis can be scalably and modularly integrated. The integration of flexibility as a tool to increase the implementation capability of projects associated with technological change impacting the maintenance (technical and human component) of radiolocation systems is the **seventh** proposed **objective** and is addressed using the real options paradigm. This together with the **eighth objective** represented by the development of an integrated set of decision tools based on directions/steps to be followed to achieve best practices in the maintenance of radiolocation systems. The focus will be permanently on moving from static (cause-effect) models to dynamic (adaptive, resilient, cyclic) IT-assisted models, making an analogy with the STEM cell model (betting on the future) and taking steps towards the adoption of Artificial Intelligence.

Research methodology and development of the thesis architecture

The thesis integrates conventional techniques and methods specific to the field under consideration, but also innovative models that make up for the lack of data or elements at the confluence of the technological and human factors. The proposed studies are scientifically relevant because of their bold approach to specific concepts of change management, maintenance management and project management under uncertainty. The proposal of mechanical component upgrade, vibration analysis on two platforms, flexibility analysis as a tool for real options and implementation of innovative technologies, give value elements to the present thesis.

The results obtained through the analysis of flexibility as a tool to increase the implementation capability of projects associated with technological change have a significant impact on the efficiency of the maintenance processes of radiolocation systems. Adaptation through increased flexibility is analysed using the real options of expansion and abandonment, respectively, and provides insight into the decision-making process, i.e. advantages related to risk reduction under conditions of technological change and multi-crisis environments. Also the results obtained from the acquisition and processing of vibration data as well as best practice proposals make substantial contributions to the operational environment. The treatment of the objectives in the described manner gives the thesis originality and innovative character, succeeding in arousing the interest of specialists as well as researchers in the field.

We used modern tools in the study of the research topic: VOSviewer for literature filtering, specific devices used in industrial engineering and autonomous airborne vector systems, software for data analysis and interpretation, comparative analysis useful to be integrated in the field of maintenance of radiolocation systems.

The information obtained from the case studies, the applications and the analysis of the questionnaire and the literature was presented in an easy to interpret and understand manner. These results can be a starting point for future studies as the proposed methods are scalable. Both the literature, transparent information from open sources, and the basic interests and needs in the operational environment were explored in depth and formed the basis for personal studies and contributions.

Dissemination of research results (Annex) includes the publication of 5 BDI articles and 1 ISI Proceedings article at 35th IBIMA 2020 on the topic of the research area. In the thesis I used my practical experience, methods from engineering and management as well as methods from statistics. The thesis is organized in 8 chapters and related appendices with the role of completing the picture made in the chapters. The approach of the thesis is interdisciplinary but also multidisciplinary and the objectives are anchored in the specificity of the treatment of radiolocation systems in Romania.

1 ANALYSIS OF THE OPERATIONAL ENVIRONMENT AND THE CURRENT STATE OF RESEARCH IN THE LITERATURE

We have devoted this chapter to the analysis of the operational environment by interpreting the results of a questionnaire, as well as reviewing the current state of research in the literature. The objective proposed in this chapter is to identify/map, through the products of the dedicated questionnaire, the situations and needs of specialists in the operational environment. The analysis of the visibility of radiolocation systems is based on the identification from open sources, of specific aspects of radiolocation maintenance reported by dedicated institutions.

Products of the questionnaire applied to operational staff

The objective of the questionnaire **on** "Risk management in the maintenance of radiolocation systems" is to deepen the spectrum of risks in radiolocation systems from the perspective of the factors directly involved in the maintenance activity. The questionnaire was distributed to the target area represented by personnel specialised in the operation and maintenance of radiolocation systems. A total of 24 respondents from all categories of personnel (Figure 1.1), graduates of the classes of 1995-2021, as follows: 1 engineer officer, 17 specialist officers, 3 military majors, 2 non-commissioned officers, 1 SGP (professional soldier).

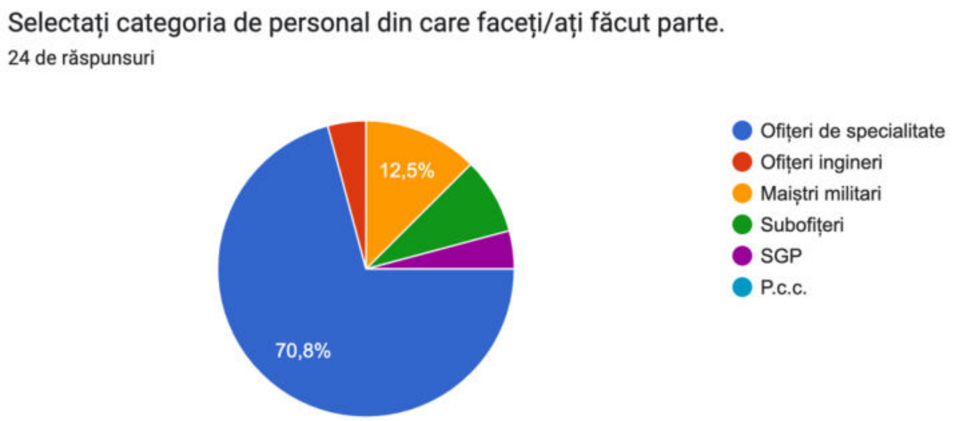


Figure 1.1: Distribution of respondents by staff category

Due to the unique niche area, the radiolocation systems responsible for the surveillance of national airspace are relatively few in number and therefore the staffing of these systems is limited. The number of graduates in a class is between 10-20 graduates in a context dominated by the exit of experienced specialists from the system.

Details of the questionnaire products can be found in **Annex 2** of the thesis. Of particular importance is the fact that 83.3% of respondents selected that they were NOT aware of or had NOT participated in such a project addressing the issues addressed by this thesis (Figure A2 2).

Open source data analysis

The environments in which radiolocation systems operate are, in principle, closed, conservative. The problem is that they cannot be self-sufficient, or at least not self-sufficient without massive expenditure. It has been shown that outsourcing services is often a highly effective measure for all industries. There are various advertisements or tender openings where specific services for radiolocation systems are outsourced. Among those seeking these services are the military structure dedicated to airspace surveillance in Romania (Annex 3) and the US Department of Defense Navy (Annex 4). An analysis of the documents identifies the need for a predictive maintenance programme, i.e. the procurement of sub-assemblies and maintenance services, in particular for rolling bearings and air conditioning units. The sums involved are not negligible, so optimal management can achieve spectacular savings.

Review of the current state of research in the literature

Assessment of the current state of research

Planning phase

Research questions

Development of research protocols

Search databases and keywords

Exploitation phase of the selection criteria

Selection criteria

Classifications

Results and applications

Analysis and discussion. Possible contributions

Partial conclusions

Reactive methods are not suitable for application in the field of radiolocation maintenance. Pro-active methods could however be used in hybrid architectures. Risk analysis may be incomplete and inconsistent and may not capture all potential undesirable conditions due to the complexity of the system. [LOF, 10] shows the need to improve risk management through proactive and predictive countermeasures.

The analysis presented contributes to a better understanding of predictive and interactive approaches. Predictive methods are still under development, while interactive methods exploit the value of the active interface between system users and designer.

Predictive-interactive methods could be a combination of proactive performance measurement, using timely data collection and analysis, development of predictive methods, involving an active interface with system and process designers, managers and operators. This provides a prioritisation of actions in the decision-making process, and a greater efficiency in finding latent conditions and proactively reducing risks.

Several automation strategies to reduce human error were considered. Operators learn from experience by solving daily problems in the system and automation reduces the ability of the operator to continuously learn and provide corrective actions in unusual situations. Automated systems also involve significant investment in human operator training. Through human-machine integration, the innovative ability to implement abstract ideas and the ability to process data are exploited. It reduces the operator's workload and simplifies his decisions. There is an interest in the design of artificial intelligence-based strategies that offer the prospect of reducing the risks associated with human factors.

2 ARCHITECTURE OF RADIOLOCATION SYSTEMS AND METHODS/MODELS USED IN THEIR MAINTENANCE

This chapter dedicated to the architecture of radiolocation systems and the methods and models used in their maintenance has as its main objective to provide a clear picture of the specific architecture, environment and processes within the system, highlighting the essential role of maintenance in reducing vulnerability. At the same time it is proposed to identify the maintenance processes from implementation to decommissioning of the system, as well as to identify the methods and models used. The merging of all these objectives is achieved by proposing the implementation of a 13-step programme. The chapter is completed by the vision of maintenance in the context of the Industry 4.0 technological change.

Objectives and description of the paradigm

Chapter 3 presents the architecture of radiolocation systems and the methods/models used in their maintenance. The proposed objective is to highlight the role and importance of radiolocation systems, the constituent components as well as the processes involved in the integrated system throughout the radiolocation system design, acquisition, deployment, operation and decommissioning chain. A second objective of the chapter is to highlight the importance of the human factor in the radiolocation system which is itself a complex socio-technical system. The chapter also highlights the types of maintenance that technically contribute to the proper functioning of radiolocation systems.

Sub-systems in aerial surveillance architectures

Analysis of OPS (Organisations-People-System) relationships, human factors and organisational processes typical of radiolocation systems

Methods and models used in the maintenance of modern radiolocation systems

Conventional methods used in maintenance analysis of industrial equipment

AD method (fault trees)

Markov chain method

MC (Monte Carlo) method

Considerations on the use of methods in the maintenance of radiolocation systems.

Limitations of conventional methods.

2.1.1.1.1 The conventional methods presented were initiated in the years of the Second World War

Methods of carrying out maintenance work

Method of performing individual maintenance

Method of performing maintenance on sub-assemblies

The method is effectively applied to the maintenance of modern radiolocation systems due to the existence of spare parts (equipment, blocks, cabinets) in the radar inventory. Replacement of defective parts or parts that no longer function within the specified parameters can be done directly by the operators, without the need for outside intervention by specialised personnel. Repairs to defective sub-assemblies can be carried out at a later date at the premises of the specialised maintenance facilities.

A disadvantage of the method may result in situations where the radiolocation system operator (the human factor) causes other failures during the replacement of the faulty block or the replacement of the sub-assembly was not necessary and did not lead to the radar being returned to service.

Method based on the use of back-up equipment

In the event of more complex maintenance work on the radiolocation system (transceiver block, antenna system, etc.) which requires a long period of downtime and thus rendering the radar inoperative, back-up equipment shall be used. The maintenance of dismantled equipment shall be carried out, also in this case, at the premises of specialised maintenance facilities, in the same way as for the method of carrying out maintenance on sub-assemblies.

The advantage of this method is the reduced time required to take the radar system out of operational status, which includes only the time needed to dismantle certain blocks and the time needed to install spare equipment. In this situation, the duration of repairs to the maintenance structures does not affect the operation of the radar.

Loop/flow maintenance method

The method assumes the existence of maintenance lines in the flow for the repair of spare parts and component sub-assemblies of the radiolocation system. The personnel in the maintenance facilities have a high degree of specialisation and have acquired extensive experience in the field. Maintenance work is carried out in the order required by the technological process and follows a precise algorithm of operations for repair, assembly or mounting of component parts.

Innovative methods for maintaining modern radiolocation systems

Maintenance in the context of technological change Industry 4.0

Objectives and description of the Industry 4.0 paradigm

Aerial surveillance systems (especially radars) have evolved with technological progress. To benefit from Industry 4.0 features, systems and their maintenance management need to be rethought, reinterpreted and updated. The article aims to highlight, on the one hand, the current state of play in addressing the topic of maintenance management of aerial surveillance systems and, on the other hand, the need to implement the Industry 4.0 concept to increase efficiency and keep systems operational.

Airborne surveillance systems, in all the forms in which they are designed, built and optimised, are special electronic equipment in the defence system which, when operated effectively, are the main source of information on airborne platforms in flight. Detection and location of targets, as well as target identification, is the primary objective. This would be almost impossible without proper maintenance to keep systems operating 24/7, as any disruption could cause security breaches in one's own airspace, a vulnerability that can be exploited with dire consequences.

Evolution of maintenance management

The number of scholarly articles that have addressed the evolution of maintenance of systems used in industry with the development of communication and information technologies has shown an increasing trend (Figure 2.1).

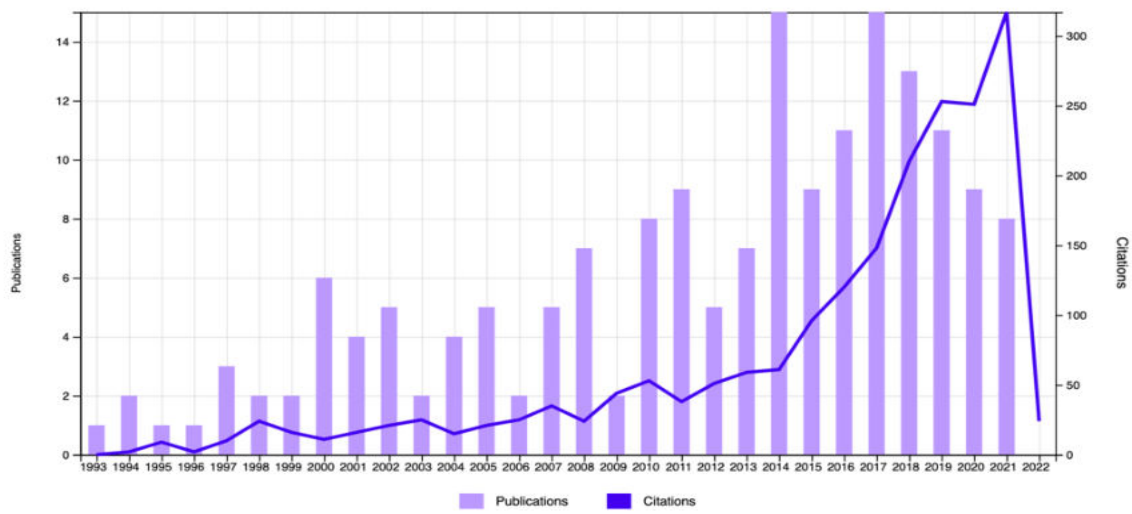


Figure 2.1 Trend of interest in the evolution of maintenance management

Concepts used in the past, such as corrective maintenance, preventive maintenance, electronic maintenance and intelligent maintenance systems [GUI, 16], have been further developed by Industry 4.0 and related key technologies (IoT - Internet of Things, cyber physical systems, etc.). Currently, the focus of the scientific literature is on elements such as condition-based maintenance and PHM (Prognostics and health management), [BAU, 20], [LEE, 11], [MOO, 06], [JAR, 06] . Even under these conditions, in the existing literature we have identified a lack of understanding of what it means to achieve digitised production for maintenance organisations along the hard (technical) and soft (social) dimensions [BOK, 17], [PEL, 16].

Identifying and highlighting the need to research the subject

Following the search of bibliographic resources found in the Web of Science [wCLA, 21] and interpretation of the results using the VOSviewer software [wVOS, 21], available online in the browser. Using the keywords "aerial surveillance", "management", "maintenance" we identified that the proposed topic is not adequately addressed in the scientific literature. Based on research conducted in the scientific literature, in Figure 2.2 a. identify the links between the most commonly used concepts of maintenance and aerial surveillance. The lack of the concept of Industry 4.0 draws our attention. On the other hand, in Figure 2.2 b. we tried to associate Industry 4.0 with the topic of maintenance in aerial surveillance, the latter term was not found in the search list.

It is obvious that aerial surveillance systems are special, dedicated systems that require special maintenance both in terms of hardware, software and the level of training of the human factor operating and maintaining them. The implementation of the Industry 4.0 concept in aerial surveillance systems is a challenge, as stability and 24/7 operation are major objectives.

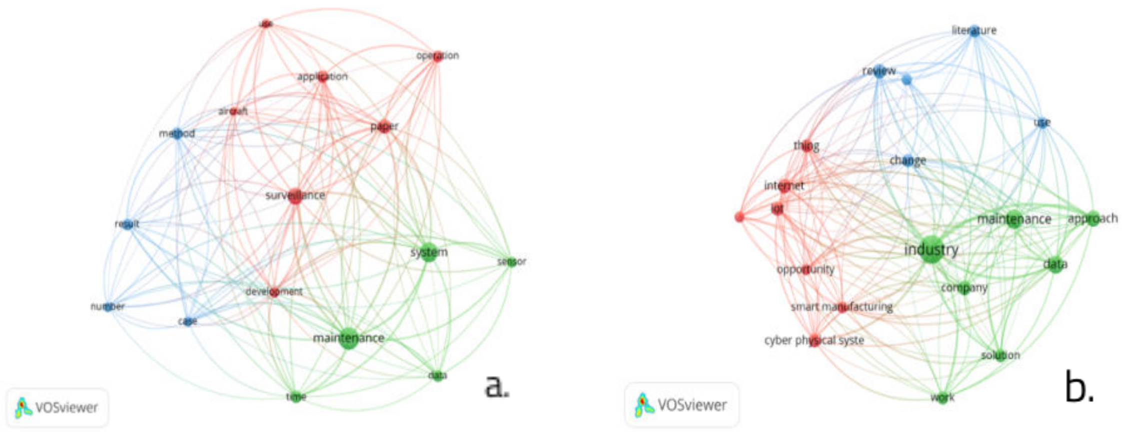


Figure 2.2 Links between elements of interest

The evolution of aerial surveillance systems architecture

It is easy to understand that in order to address the topic of aerial surveillance systems maintenance, it is extremely important to understand the evolution of their architecture. The first aerial surveillance systems with significant technological advances that proved effective were used during the conflicts of World War II to defend England [wWIK, 21] from German air raids. We identify in the past, in step with the evolution of technology at the time, analogue radars that used high transmitting powers, with high resource consumption, whose protection against interference was limited. Data links were also non-automated, with data transmission via telephone links with significant delays from the observation point to the decision point. Technological developments have also had an impact on aerial surveillance systems, so that digital and analogue digital radars are now in operation, processing signals using high-performance processors. The latter, using the features of phased array antenna systems, have the advantage of using low power and high sensitivity receivers. These systems benefit from interference protection - RF bandwidth modes, networking (automatic data links/transmissions) and secondary radar features with IFF. The future is expected to be great for aerial surveillance systems, using the advantages of networking multiple sensors and using artificial intelligence to identify threats and make cognitive radar targeting decisions.

Contributions to industrial systems maintenance, industrial revolutions and the emergence of Industry 4.0

The evolution of industrial systems maintenance is directly related to the typology of systems architecture. In the past, equipment was rugged, with few checkpoints, with excessive, costly, mainly corrective maintenance. Today, multiple sensors (stroke, vibration, lubrication quality, etc.), system computers equipped with fault display software make it possible to carry out mainly preventive maintenance. For the future, the evolution of maintenance leads to the use of systems for data acquisition, processing and display using multiple sensors, contextual, artificial intelligence, optimisation, reliability-oriented maintenance, so-called predictive maintenance.

Man and society in terms of needs have evolved, with stages being called industrial revolutions [wGRE, 21]. These have been classified as follows:

I - mechanisation using water and steam power;

II - mass production using electrically driven conveyor belts;

III - the digital one, with the use of electronic and IT products to automate production;

"4.0" - Software (programs), which are usually called a new version in major changes, the first digit of the version number is incremented by one and at the same time the second digit starts from zero. The basic organisational principles of Industry 4.0 [wWIK, 21] are well known: interconnection, information transparency, technical support, decentralised decisions.

Implementation and effects of Industry 4.0 on modern radar logistics and maintenance

Logistics, in general, and maintenance processes, in particular, stand to gain immensely by implementing the organisational principles of Industry 4.0. I would like to draw your attention to a few aspects related to the optimised organisation of logistical elements (storage, maintenance, transport, etc.), the identification of degradation/wear of system components and those requiring repair. IoT can automatically report system degradation and generate reports for maintenance needs. Respectively automatic generation of orders for spare parts.

The evolution of technology has brought ease of maintenance processes. Thus, modern radars use high-performance components and redundant systems that are less expensive due to miniaturisation (solid state technology). Interconnected software components (operation, identification and reporting of out-of-tolerance parameters, mission parameters) are also identified [LIZ, 16] and the possibility of updating is provided. The organisational chart distinguishes between team members [GAL, 20] and outlines clear tasks (software operation/engineer software intervention/maintenance) with the possibility of remote intervention. Staff training through e-learning methods, with the possibility of distance learning via AR [MAS, 17]. It is clear that trends in the use of AI are leading to a reduction in downtime.

The vulnerability of radiolocation systems and their security in the face of technological change Industry 4.0

The integration of aerial surveillance systems into the network brings with it an exposure to data and information flows and creates security vulnerabilities. In Industry 4.0 via IoT, the challenges are the same, with the possibility of data transmitted over the network being affected by cyber attacks. This challenge requires securing: the physical communication channels used and the electronic ones by encrypting the data packets transported between the IT systems used.

Discussions and future directions

In order to benefit from technological progress, it is important to keep pace, to achieve development on the essential condition of maintaining the stability of the system. In order to achieve this goal, it is necessary to address the challenges identified: adapting the human factor to technological change, acquiring systems/interfaces that allow the use/integration of current aerial surveillance systems into the Industry 4.0 compliant IoT platform and reducing system vulnerability by securing the system.

Methods to identify the need for intervention (vibration, thermal imaging - FLIR, BITE (Built-in Test Equipment)

The development of the technique has been due to society's continuous desire to evolve, to create better models, to respond to society's demands and obviously to be the best in the market.

Mechanical elements could be made with ever smaller tolerances and electronic elements were miniaturised (**Error! Reference source not found.**These two essential elements allowed to create and develop answers to other problems arising in technological systems. The need to measure dimensions, accelerations, temperatures, etc. was satisfied by developing sensors capable of monitoring all these quantities.

To optimise the maintenance processes of technological and industrial systems, it is necessary to correctly diagnose faults that occur due to normal wear and tear, normal thermal and mechanical shocks or due to improper operation. In order to acquire conclusive data for analysis, sensors or transducers are used in industrial processes as follows:

- Vibration sensor capable of measuring displacements and accelerations on one or more axes;
- Individual temperature sensors;
- Individual or system-integrated elements with self-diagnostic capability and the ability to highlight modules/components that are faulty or out of tolerance - BITE,
- Thermal imaging system using IR (infrared infrared) technology that has the ability to highlight different heated areas in colour,

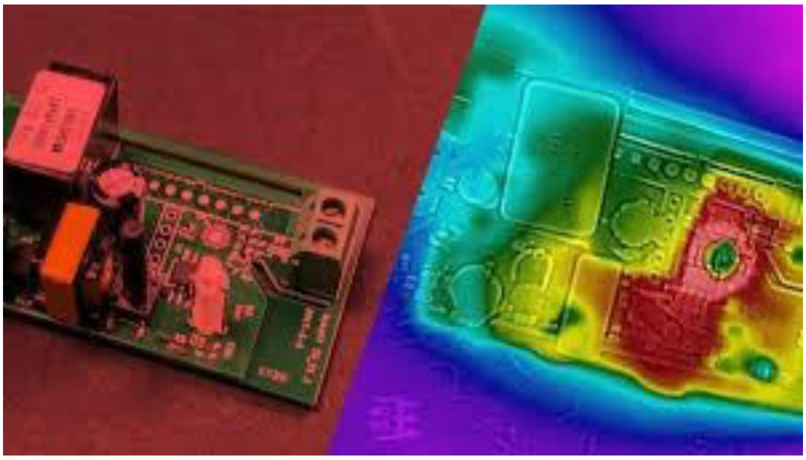


Figure 2.3Image of an electronic circuit captured with FLIR technology

Personal contributions

The chapter created the opportunity to properly map the architecture of radiolocation systems, the environment and processes within the system, with emphasis on the essential role of maintenance in reducing vulnerability. We have highlighted the importance of identifying maintenance processes from implementation through to system decommissioning, as well as identifying commonly used methods and patterns in technical systems. Within the chapter we proposed the implementation of a 13-step maintenance programme integrating classical and innovative maintenance methods. We completed the chapter with the vision of maintenance in the context of the technological change Industry 4.0. highlighting the essential role of the human factor as well as the vulnerabilities that need to be secured in the new context of the Industrial Revolution 4.0.

Partial conclusions

The architecture of radiolocation systems is complex and its analysis has shown that methods and models dedicated to systems of systems can be used, in which the technical and human components are closely linked, with emphasis on the human factor as a key element in risk management in maintenance (from the design of system requirements, selection, acquisition, training, operation, maintenance and decommissioning with respect to environmental regulations and its exploitation).

In order to ensure the operational availability of the radiolocation system, continuous adaptation to the context is required and can only be achieved through an appropriate management system. One option proposed is to implement a 13-step programme that takes into account all the factors involved.

In the context of the Industry 4.0 technological change, in order to benefit from the technological advance, it is important to keep pace, to achieve development with the essential condition of maintaining system stability. In order to achieve this goal, it is necessary to address the challenges identified: adapting the human factor to technological change, acquiring systems/interfaces to enable the use/integration of current aerial surveillance systems into the Industry 4.0-compatible IoT platform, and reducing system vulnerability by securing the system.

3 RISK ANALYSIS AND RISK MANAGEMENT PROCESS IN RADIOLOCATION SYSTEMS

This chapter focuses on the essential concepts and terms related to the topic to be researched, risk, risk factors and the process by which they are best managed. It introduces risk and chance analysis and management and gives a first impression of general ideas before going into details during the following chapters. It also shows how the analysis is divided into steps.

Overview of risk management issues

This chapter defines basic concepts and notions of risk analysis: event risk (chance), event frequency, exposure, hazard propagation, consequences and damage analysis. The classical literature introduces the notion of proportional risk as the product of measuring the probability of events and measuring the consequences of an event. This distinguished between calculating, visualising, comparing and evaluating risks. In particular, different sampling risk criteria are discussed.

In his paper *Risk, Uncertainty and Profit*, economist Frank Knight drew the important distinction between risk and uncertainty: "Uncertainty must be taken in a radically different sense from the familiar notion of risk, from which it has never been properly separated [...]. The essential fact is that 'risk' means in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of that character; and there are far-reaching and crucial differences in the directions of phenomena, depending on which of the two is really present and functioning. It will seem that a measurable uncertainty, or 'risk' proper, as we shall use the term, is so different from an immeasurable one that it is not an uncertainty at all." [KNI, 1921]

Definition of fundamental concepts

This section is an essential part that defines the fundamental concepts: hazardous event and threat scenario.

Type of threat scenario, dangerous events

We mainly consider risk scenarios where either impact or strong explosive events are involved, can be used for sufficient modelling or can play a major role in the analysis. The focus will be broadened to include terrorist threat scenarios as well as natural disasters. High-intensity explosive events are characterized by a very rapid and localized energy release[KLO, 97] . In the case of powerful explosions, a fast moving detonation separates the initial material and the detonation products. Examples for high explosives are dynamite or TNT. High explosions are explosions with rapid combustion and transformation of pyrotechnic products. An impact is a "sudden time-dependent charge"[BAN, 09] . Impact events involve fragments generated by powerful explosions. Impact events also include events with projectiles launched from tubes, events where debris is generated by explosions or where system components impact the ground surface.

Risk, an essential component in any process

Classification of specific risks

Risk can be classified according to different risk attributes. Examples of classifications are:

- risks per event, in the event of an event (conditional risks), per time interval or per life cycle,
- source of risk: man-made, technical, natural, natural-technical,

- objects, persons or parts of the body exposed to risk: risk to machinery, personnel, third parties, health of lungs affected by the risk, etc., e.g. Proske distinguishes between natural risks, technical risks, health risks and social risks[RRO, 04] .

  Other examples of risk classifications in opposition:

local	relocated
on request	ongoing risks,
individual	collective (group)
voluntary	involuntary
perceived or subjective	targets
statistical history	model-based
based on (semi)quantitative estimates	Quantitative calculations

Examples of risks corresponding to these classifications are:

- annual individual local risk of injury from terrorist explosions,
- the total average annual collective fatal risk of a given scenario,
- Total collective risk expressed using a frequency-number curve (F-N curve): frequency of one or more injuries per year, frequency of ten or more injuries per year due to an explosives magazine.

Risk management and analysis

Definition of risk analysis: **Risk analysis** is the determination of risks in a given situation, context. Definition of risk management: **Risk management** is the analysis of risks and the management (mitigation) of risks, including changing the context. Definition of risk analysis and risk management process: Risk analysis and risk management can be divided into different steps. The iterative or incremental stage execution of these stages together with communication between stages is the risk analysis/risk management process.

Risk management scheme (5-step approach)

A standard scheme for the risk management process is the 5-step risk management scheme. It can be found in many applications. Versions vary slightly, but essentially look like this scheme, based on[ALE, 09] :

1. Setting the context: Describe the initial situation, define objectives such as safety or health.
2. Identifying hazards/risks: Define damage scenarios. This involves describing the source of the hazard and the exposure of people or objects.
3. Analyse/calculate risks: Estimate or specify probabilities and consequences of events.
4. Risk assessment/classification/prioritisation/assessment: Assess whether or not risks are acceptable. This may involve a comparison of risk levels against predefined criteria or a comparison of costs and benefits.
5. Treat/externalize risks: For risks that are not acceptable, change the initial situation or find external solutions such as insurance.

Figure 3.1Risk management process steps diagram

The steps are linked together by an iterative monitoring (optimization) or incremental process. Consultation and communication take place between stages. See Figure 3.1 for a graphical version of the 5-step risk management scheme.

Risk analysis and management process

The following provides a more detailed description of the risk analysis process that will be used in the following chapters. It is divided into 9 steps that are connected with the iterative or incremental optimisation and monitoring process. We start listing with step (2) to add another step in front of it when dealing with the risk management process.

(2) Initial situation with no source of hazard: All information needed to apply is collected in hazard and damage schemes. This includes geometric data, geographical, metrological and topological data, and information on materials and meteorological conditions.

(3) Description of the source of danger: The description includes the geometry, mass, position, orientation and velocity of the hazard source, and mitigation measures in the vicinity of the hazard source.

(4) Hazard propagation/hazard analysis: This includes the potential dispersion, distribution and distribution of the impact load of the physical hazard.

(5) Damage/consequence analysis/modelling: Here the effects of the potential hazard to objects such as vehicles, buildings and infrastructure or people are determined.

(6) Analysis of the frequency of hazardous events: Analyze how often the source becomes active in producing the hazard. This is determined by considering, for example, the frequency value of the presence of the hazard source, the frequency of an unintentional accident occurring within the hazard source and the frequency of a failure of the containment system. This step also covers the frequency of events by location.

(7) Distribution of objects: The distribution describes how many and where in the area objects of interest are located. Exposure describes whether they are actually exposed to harmful effects.

(8) Frequency of successful avoidance of consequences of hazardous events: This stage considers the success frequency of organisational and training measures, spontaneous reactions (e.g. flight), and success rates of placing passive, reactive or active physical barriers.

(9) Calculation and visualisation of risks: This involves calculating the different risk categories. Visualisation options include risk maps, tables and F-N charts.

(10) Comparison of risk with criteria: Risk quantities are compared with the risk of the assessment criteria, e.g. risk matrix, critical values and F-N criteria. For example, it is checked whether the individual annual non-local risk is lower than the de minimis risk.

Table 3.1: Complementary attributes of analysis processes and risk and opportunity management

Implicit	**Explicit**
With software support	No software support

Graphical description/visualisation	Textual description
Coarse process steps	Refined process steps
Standardized, formalized	Ad hoc, situation/scenario-based
Described from the decision-maker's perspective	Described from an end-user perspective
Time-critical process steps	Process steps that are not time-critical
Real-time risk analysis, risk management for decision support	Preventive risk analysis, ex-post risk analysis, forensic risk analysis
Virtual environment for information exchange	Information exchange in person
Multidisciplinarity	One discipline
More stakeholders	One stakeholder
Multinational	National
By virtue of the existing database	Data collection by oneself
Threat assessment with a focus on Consequences or probabilities	Threat assessment based on risk (i.e. consequences) and probability
Considering only first order effects (health effects and first actions)	Considering also second and third order effects (effects on society, economy and politics)
Scenario-based	Covering several scenarios
Focusing on the worst-case scenario	Consider a wider range of scenarios
Application to real scenarios (ex-post for validation purposes)	Application to fictitious scenarios (Preventive analysis)

To describe the risk management process, the following steps are added.

(1) Context: This includes information about the country where the event is located, the cultural and ethical context, the legal and technical context, the requirements and the types of scenarios that are considered.

(11) Risk assessment: The risk assessment is a combination of the previous step and other steps to produce a final risk assessment. In particular, legal, social and psychological effects on risk assessment are considered.

(12) Risk communication focuses on communicating risks to experts, respondents, the public and third parties. For example, comparable risks are mentioned with the risks to be assessed. These should be risks to which the persons concerned can refer. An emotional link to the risk should be created.

(13) Risk assessment: Taking into account steps (10)-(12), decide whether the risks are acceptable or not.

(14) Mitigation measures: There are mitigation measures that reduce frequency, mitigation measures that reduce physical hazards, mitigation measures that reduce the consequences of events, and mixed mitigation measures. We also count feasible background changes among mitigation measures.

The risks of injury specific to radiolocation systems are:

As the questionnaire products showed, the specific risks of radiolocation systems are: electrocution, RF (Radio Frequency) irradiation, cardiac arrest, asphyxiation, acute poisoning, burns, lightning accidents, sprains, strains, fractures, wounds.

The risks of occupational disease are:

- Chronic laryngitis - can affect radar operators on combat duty due to prolonged strain on the vocal cords;
- Accommodative Asthenopia or worsening of pre-existing myopia - may affect radar operators performing combat duty due to prolonged straining of vision through continuous tracking of IOC (cathode ray tube) or display (LCD, OLED) systems
- Heart disease: ischaemic heart disease, hypertension - due to stress as well as increased mental and physical demands, high temperature, vibrations, radiation;
- Cataracts - intense and prolonged action of radiant energy: IR, hyperfrequency, ionizing radiation;
- Respiratory ailments - due to predisposition to inhalation of irritant gases or dusts.

In Table 3.2 a risk management variant of a radiolocation system is presented. The table contains the risk factors, the level of risk calculated according to the level of impact and probability of occurrence of that factor, the measures proposed to avoid the risk, the personnel responsible for the management of that risk factor as well as the timeframe for implementation.

Table 3.2Risk management variant of a radiolocation system

No. crt.	Risk factors	Risk level	Proposed measures	Responsible	Term
1.	Moment of carelessness that can result in staff being subjected to electric shock	Moderate	1.Station personnel must remain alert to potential hazards at all times. 2. The head of the maintenance work must carry out regular training of staff on safety rules at work.	Radio operators	Permanent
2.	Maintenance on antenna equipment when storms are imminent or ongoing.	Picked up	Interruption/delay of maintenance work	Maintenance works manager	Permanent
3.	Radiofrequency/non-ionising radiation	Very high	1. Keeping the safety distance 2. Personnel working with the station to follow the recommendations in the technical manuals 3.The antenna should be positioned in azimuth so that during maintenance it does not emit abnormal radiation.	Station staff	Permanent

No. crt.	Risk factors	Risk level	Proposed measures	Responsible	Term
4.	Detonation of electro-explosive devices	Moderate	1. Keep the distance specified in the table, specific to the type of device. 2. Avoid moving devices without express orders or without notifying the head of maintenance work.	Responsible for electro-explosive devices.	Permanent
5.	Exceeding safety limits for pacemaker personnel	Moderate	A distance of approximately 500 meters from the antenna at any elevation angle must be maintained during transmission.	Staff concerned.	Permanent
6.	Use of toxic materials	Low	1. Work only in well-ventilated areas. 2. Keep a fresh water source nearby with a flexible nozzle to remove corrosive chemicals from any part of the body 3. Follow and observe all precautions, warnings and procedures on containers for solvents, paints and cleaning chemicals.	Staff concerned.	Permanent
7.	Radar station deployment and maintenance	Picked up	1. Use extreme caution when moving, placing and assembling radar components. 2. Use extreme care to avoid slipping when servicing antenna equipment if surfaces are wet or covered with ice or snow.	Station staff.	The Order
8.	The occurrence of a fire or explosion	Low	1. Do not use paints, thinners and cleaners near flames or electrical sparks. 2. Check terminal polarity markings. 3. If such an event occurs, shut down the station immediately.	All staff	Permanent

Partial conclusions

The chapter outlined risk, scenario types, how to classify specific risks, risk analysis and risk management. The intended objectives of this chapter to outline the defining elements of the topic to be researched was materialized through the process of risk analysis and management. The specific risks of radiolocation systems were also presented and a variant of their management was graphically captured in a table with a colour legend highlighting the risk level.

4 PERFORMANCE MANAGEMENT OF COMPLEX SOCIO-TECHNICAL SYSTEMS (SSTC). HUMAN FACTOR BEHAVIOUR IN RADIOLOCATION SYSTEMS

"People are subject to mistakes and even the best can make mistakes"

This chapter argues why the radiolocation system is treated as a complex socio-technical system, what its performance is, how it can be quantified and how it is managed. The chapter highlights the behaviour of the human factor in radiolocation systems.

Objectives and problem description

In the previous chapter, the major components on which risk can manifest itself were highlighted. In the man-machine assembly it is desired to achieve maximum results with minimum risk. In order to achieve this goal we have identified the items to be taken into account and we have elaborated the objectives to be achieved, as follows:

- Definition of socio-technical system and the difference between it and a computer-based system
- Delineating and defining the concept of emerging system properties such as reliability and security
- Explain the processes for systems engineering and systems procurement, and how the organisational context of a system affects its design and use.
- **Views** on legacy systems and why they are critical to many economic systems

What defines us as individuals in society is unique. In order to survive and evolve, we need to perceive events, understand them and adapt so that they do not surprise us in the future. Yes, we have the ability to learn from the events we have experienced, and the product of these abilities is defined as lessons learned. Over time it has been found that human error is generated in a variety of conditions:

- individual behaviours
- management and leadership practices
- organisational processes and values.

All of these can be reduced or even avoided; reducing the likelihood and consequences of human-caused events through various means and methods of prevention will reduce the risk to personnel, the environment, and not least national security. This constitutes the paradigm of psychophysiological engineering.

Thesis vision from the perspective of the complex socio-technical systems paradigm

The central component of the thesis is represented by the human factor on whose skills depends the proper functioning of the technique represented in this case by the radiolocation system, a perfect binomial man - machine. This homogenous system is by no means simple, but complex, in which each of the two components is essential, each being complex in itself. The machine seen in isolation from man, or without well-trained personnel, is nothing more than an inadequately exploited tool. All the more so, this technical system, although designed, built and constantly improved by specialist engineers, is all the more dangerous. That is why in the regulations specific to each radiolocation station it is strictly forbidden to employ and put into operation technical systems personnel who have not been trained and checked on their knowledge and practical skills on such a system.

Radiolocation systems belong to the category of complex socio-technical systems and this is justified by the nature and uniqueness of the systems. whether analogue or digital, they require in-depth knowledge and special practical skills both for their operation/operation and especially for their maintenance. Radiolocation systems are systems whose design required the integrated implementation of mechanical, electrical, electronic, hydraulic and pneumatic subsystems.

Typology and characteristics of SSTC

In order to better understand the SSTC, it is necessary to draw the line between the two determining systems. On the one hand we have computer-based technical systems in which we have hardware and software components. Operators and operational processes are not analysed and considered as part of the system, and the system is not self-aware.

On the other hand, we find socio-technical systems that include technical systems (control apparatus), include standard operating processes and procedures and the people who operate, use, exploit and interact with the technical system. SSTC are governed by policies, regulations and organisational rules and its defining characteristics are:

- It has emergent properties and is non-deterministic;
- It is in complex relationships with organisational objectives;
- It has 'whole system' properties that depend on the components of the system and the relationships between them;
- It does not always produce the same output for the same set of inputs because the behaviour of the system is partly dependent on human operators;
- The extent to which the system supports organisational objectives is not solely up to the system.

Analysis of emerging domain-specific properties

Reliability engineering elements in SSTC with application in maintenance of radiolocation systems

Reliability engineering and its impact on SSTC performance management

Faults can propagate quickly in the system due to inter-dependency between components, and system faults often occur due to unforeseen inter-relationships between components. It is probabilistically impossible to predict all possible relationships between components, and the results of software reliability measurements can give a false picture of system reliability.

The influence on hardware reliability is given by the likelihood of a hardware item failing and the duration of its repair. Software reliability is given by the probability that a software component has a software bug/error and produces an incorrect output. Operator reliability is given by the probability that the system operator makes a mistake.

Critical reliability aspects and prohibition properties

A hardware fault can generate false signals that are outside the range of inputs expected by the software. Software errors can cause alarms to be triggered which cause **operator stress** and lead to operator-generated errors. The context in which a system is installed can affect its reliability.

There are properties that are expressed as prohibitions:

- Safety - the system must not behave in an unsafe manner;
- Security - the system must not allow unauthorised use.

Practice shows that it is difficult to measure or evaluate these properties, but in contrast, there are properties that can be measured more simply:

- Performance can be expressed in terms of how well you meet previously set items or by measuring results against the time allocated to the task. Involvement and initiative can be items whose assessment gives value to performance;
- Reliability is another quantifiable technical item and can be judged in relation to the number of interventions in the period of time or the period of time the system has not needed to be intervened.

SSTC engineering process in radiolocation systems

SSTC engineering refers to: specification, design, implementation, validation, deployment and maintenance of socio-technical systems. SSTC engineering also deals with: the services provided by the system, the constraints on the construction and operation of the system and the ways in which the system is used.

The process usually follows the "waterfall" model because of the need to develop different parts of the system in parallel. Restricted conditions for iterations of phases because hardware modifications are very expensive. Software may have to compensate for hardware problems. The process inevitably involves engineers from different disciplines having to work together: There is a high possibility of misunderstandings occurring. Different disciplines use different vocabularies so lengthy negotiation is required. Engineers may also have their own agendas to achieve.

Inter and multi-disciplinary approaches specific to applications in radiolocation systems maintenance

There are three types of requirements in this regard. Abstract functional requirements in which system functions are defined in an abstract manner. On the other hand system properties where non-functional system properties are defined. Undesirable characteristics are identified by specifying unacceptable behaviour for the system. Another aspect is the overall organisational objectives of the system

Human performance issues in the maintenance of radiolocation systems

Errors of commission versus errors of omission

There are two ways in which people can be very simply wrong. Either they do something they shouldn't have done, or they fail to do that something they should have done. The former are errors of commission, and the latter are errors of omission. Here we consider the evidence that shows that omissions - failure to perform required actions or tasks, usually during installation - are the largest category of maintenance errors. Indeed, in nuclear power generation, and probably elsewhere, errors of omission during maintenance represent the largest category of system-wide human performance problems, which includes errors made during operations normal control operations as well as during recovery from an emergency or abnormal condition. An analysis of 200 significant event reports from nuclear power plants identified that the omission of functionally isolated acts accounts for 34% of recorded errors - the largest category. The same study also found that the activities most often associated with these omission errors were repairs and modifications (41%), testing and calibration (33%), inventory control (9%) and manual operation and control (6%).

Incidence of errors of omission.

Comparable figures are found in the field of aviation maintenance. In one study, based on an analysis of 122 maintenance errors recorded by a major UK airline over a three-year period, omissions accounted for 56% of the total, 30% involved incorrect installations of one kind or another, while 8% involved the use of the wrong parts. When these errors of omission were examined in detail (Figure 4.1), the following subcategories were found:

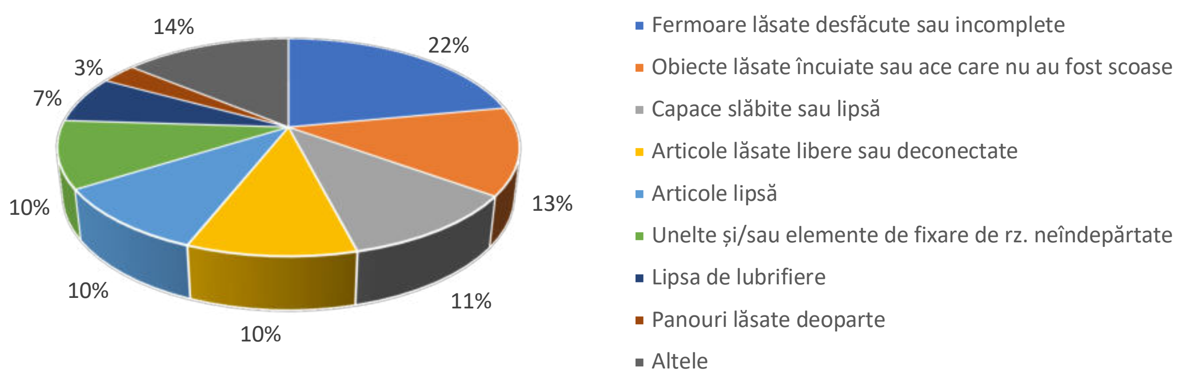


Figure 4.1: Incidence of errors of omission

Personal contributions

In this chapter we have highlighted the roles of the SSTC components with an emphasis on the human factor whose errors of commission or omission, over time, become habits and affect the smooth running of the system with an impact on risk management.

Partial conclusions

The chapter started with the negative side of the situation by pointing out that maintenance is an error-prone activity. It attracts a large - perhaps the largest - proportion of human factors problems in a wide range of hazardous technologies. The upside is that maintenance errors are not random. They fall into systematic patterns related both to the nature of the activity and the types of errors involved. There is considerable evidence to show that reassembly and installation are associated with the bulk of errors committed. In addition, omissions - failure to perform the necessary operations, usually when putting things back in place - constitute the largest category of maintenance errors. Finally, most of these errors were considered by experienced maintenance operators to have already occurred and were also considered likely to recur. The fact that the same errors continue to happen to different people in different organizations strongly suggests that we should focus our remediation attention more on the task and the workplace than on the alleged psychological inadequacies of those making the errors. This has very important implications for managing maintenance errors. .

5 Applicable holistic methods and socio-technical implications of digitization in the maintenance of radiolocation systems

This chapter presents holistic methods applicable to management and outlines how to use the multi-criteria analysis method in a specific case of selecting a distance learning/instruction platform in an unfavourable context. The chapter also highlights the socio-technical implications of digitisation in the maintenance of radiolocation systems.

Holistic methods applicable in risk management

In the literature, in order to explain phenomena in various fields (industrial, agricultural, medical, economic, financial, etc.), specialists have tried and succeeded in creating mathematical models and methods for analysing processes. Among the best known are:

- BCG Matrix (Boston Consulting Group);
- Paradigm developed by Timothy A. LUEHRMAN, described as Tomato Garden;
- Multicriteria analysis;
- Real options - taking advantage of flexibility opportunities.

BCG matrix with application in the maintenance of radiolocation systems

The Boston Consulting Group has created a matrix, called BCG for short, which is a well-known and widely used marketing tool. It is developed in the form of a 2X2 matrix, based on the premise that economic performance is determined by two very important factors:

- relative market share ;
- relative growth rate of the market.

The BCG Matrix is a model used to analyse a company's products to help with long-term strategic planning. The matrix helps companies identify new growth opportunities and decide how they should invest for the future.

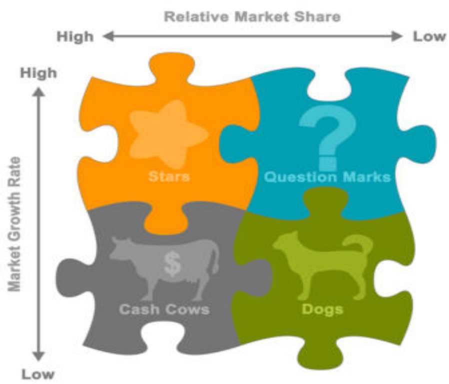


Figure 5.1The 4 elements of the BCG matrix

Most companies offer a wide variety of products, but some offer higher returns than others. BCG matrix (

Figure 5.1) provides the company with a framework for evaluating the success of each product to help the company determine which they should invest more money in and which they should eliminate altogether. It can also help companies identify a new product to bring to market. The matrix is divided into four quadrants based on market growth and relative market share.

The products are graded in an extremely colourful way:

- **STARS** - high market share/high market growth (cash neutral - does not generate cash);
- **Cash Cows** - high market share/low market growth (cash generators);
- **QUESTION MARKS** - low market share / high market growth (cash drain)
- **DOGS** - low market share/low market growth (cash neutral - does not generate cash).

AHP as a method of prioritising efficiency criteria

Analytic Hierarchy Process (AHP) is a method of organising and analysing complex decisions using mathematics and psychology. It was developed by Thomas L. Saaty in the 1970s and has been refined ever since. It contains three parts: the end goal or problem you are trying to solve, all possible solutions, called alternatives, and the criteria by which the alternatives are judged. The AHP provides a rational framework for a necessary decision by quantifying the criteria and alternative options and relating these to the overall objective.

Stakeholders compare the importance of the criteria, two at a time, through pairwise comparisons. For example, they want to find out what matters more, job-related benefits or having a short commute? And a second iteration, how much more? AHP converts these ratings into numbers, which can be compared against all possible criteria. This quantification capability distinguishes AHP from other decision-making techniques.

In the final step of the process, numerical priorities are calculated for each of the alternative options. These numbers represent the most desired solutions, based on the values of all users.

Multicriteria analysis used in the selection of the distance learning/instruction platform in the context of the CoViD-19 pandemic

The current pandemic context is perhaps the most serious challenge for all working environments, including education. Students and teachers alike are unwittingly deprived of the natural encounter of learning in a lecture hall or laboratory, and thus put in the challenging situation of having to continue their efforts to achieve their goals by making efficient use of the online environment in all its complexity (hardware infrastructure, educational platforms, accessibility to internet connection). The article addresses the issue of distance learning platform selection by using a mathematical model of multi-criteria analysis of the factors involved. It is essential that education does not stop its journey and continues to evolve, thus adding value to society. Moreover, our future, all of ours, depends on our ability to meet the challenge of distance learning to the highest standards. By linking the skills of teachers and instructors, the potential of students and the optimisation of IT resources, this is possible provided that each of the elements involved contributes to the ultimate goal: preparing generations of young people for the uncertain future. The resilience of the public and private education system depends on the use of tools that are appropriate to the goals set.

For the whole spectrum of corporations, from the most varied fields, as well as for educational institutions, in the pandemic context governed by social distancing measures that have forced activities to be carried out at a distance, the choice of a working platform, i.e. distance learning, has become a particular socio-technical challenge. The topicality of the subject is evident in the pandemic context, but we would like to emphasise the importance of selecting the distance learning platform, as this decision represents an essential node in the implementation of the act of education, with strong influences on the actors involved, the way in which content is constituted and formatted, the methods of objective evaluation and, obviously, the way in which information is structured and the skills of future members of society are acquired.

The selection of the distance learning platform was based on personal empirical findings in the process of developing students' competences and was a major challenge that required a carefully documented analysis.

Environment and factors involved in distance learning

Distance learning has become an extraordinary challenge for education systems as it involves a multitude of factors. In the research carried out, we found that the factors involved are both technical and human in nature, in a close relationship that constitutes the typical architecture of an e-Learning system[FIN, 10] . Their disparate analysis is difficult to achieve, the interdependence of the technical and human factors involved led us to start from the assumption that the identified factors meet the requirements of a socio-technical system[MAR, 21] . A socio-technical system often describes a "thing - an interconnected, systems-based mix of people, technology and their environment"[MUM, 01] . Achieving the final goal of attaining the desired competences requires that all the requirements of the system are met at least satisfactorily. We would like to point out that in the field of e-Learning there have been previous concerns about the interest in establishing educational resources complementary to face-to-face learning[DOB, 10] . In a research report[LEA, 20] we identified the factors involved in the distance learning process and their problems and tried to offer generic solutions outlined in Table 5.1 .

Table 5.1 Factors involved identified and proposed solutions

Factors involved identified	Proposed solutions
Access to equipment	Involvement of institutions to identify gaps in their own infrastructure - for teachers, instructors and students + establishment of minimum number of critical equipment
Internet connectivity	Provide broadband internet connectivity, on at least 2 connectivity solutions, enabling online activities with synchronous capabilities (video, audio, streaming, simulation) and redundancy
Stakeholder involvement	Unified training of trainers and students alike
Dedicated online educational platforms/applications*	Case study through multi-criteria analysis for the choice of e-learning platform
f2f (face to face) translation - online	Designing/adapting activities for the online environment and structuring online learning activities with a balance between synchronous and asynchronous;

Educational resources (syllabus, content, etc.)	Identification/use/development of educational resources, especially educational resources open (REDs);
Activity on learning platforms;	Development of tutorials and training webex for stakeholders
Evaluation/feedback	Use and operation of digital tools in formulation of feedback/evaluation;
Interaction, collaboration	Activating, motivating and empowering learners to participate in online activities

The topic is wide-ranging and could be the subject of future research. We have chosen to address at a detailed level the issue of distance learning platform selection. Once the desired objective was identified, it was necessary to use a tool that would allow us to deal with the topic in a comprehensive way. Analysing the alternatives proposed by the authors of the Creativity and Inventiveness course, we chose to use the multi-criteria analysis method[PRE, 14] .

According to the survey "on the educational activities carried out in Romania during the period of face-to-face school suspension"[LEA, 20] problems regarding participation in the learning process were highlighted, sometimes real, sometimes only invoked to excuse the lack of involvement of the actors involved, caused by the lack of equipment (institution server and terminals: PC, laptop, tablet, smartphone) or internet connectivity (non-existent or narrowband). Solving these desiderata are constituted as requirements/resources required by the learning platform.

Case study - selection of distance learning/teaching platform using multi-criteria analysis

The current pandemic situation has created and continues to create challenges in all areas including education, teaching and research. In order to adapt to the new climate, tools must be used in education to continue the process of transmitting knowledge and acquiring skills, which can only be achieved by using an online e-learning platform capable of responding individually to the requirements of each institution.

A. Competitive e-learning platforms

In a world where information and ideas spread at breakneck speed thanks to the online environment, companies are creating tools that try to meet market demand. From a larger list, following an initial selection made through successive testing of competitive platforms, we have chosen five e-learning platforms that meet the needs identified in our working group:

- Moodle developed by Moodle Pty Ltd Australia[BOB, 19] ;
- ILIAS also used by UNAp[BOS, 18] ,[PRE, 20] ;
- Teams unbundled by Microsoft[wMOO, 22] ;
- Zoom developed by Zoom Video Communications, Inc. San Jose, California, U.S.[wWIK, 22] ;
- G_Suite aka Google WorkSpace /ClassRoom developed by Google[wILI, 22] .

The steps of the multi-criteria analysis of these products represent the case study, the result of which is the opinion of the authors of the study in order to choose the product to be used in the distance learning process.

From the five proposed platforms, we expect that the platform developed by Google will achieve the best result, since through the experimental use of the products, we found that the human factor performance (HPE) is put in the foreground, an element that is otherwise quite neglected in the Romanian culture in general and in the military organizational environment in particular. We believe that the justification for this desire is that logistics requires generous funds and conservative institutions are reluctant and slow in allocating funding. On the other hand, we must bear in mind that the human factor requires a long-term investment through education and research, and understandably through innovation and creativity.

Solving the problem involves taking the following steps:

- the establishment of objective, determining criteria;
- choice of variants;
- approaching the problem as a multi-criteria decision;
- solving the multi-attribute problem using different methods;
- finding the set of methods that lead to a reduced set of variants.

B. Brainstorming[PRE, 14]

The Brainstorm Technique is used as it is suitable for generating new ideas after defining the problem and analysing significant data. The members of the working group set up to choose the platform were not informed in advance of the topic of the meeting, in order to keep the ideas spontaneous. The variety of ideas was achieved by chaining ideas. Two sessions were held with an average duration of 35 minutes, the location being non-formal. The facilitators set out the problem, i.e. nominating criteria for choosing an e-learning platform to be used in a uniform way across the institution. They then presented the collected information and the criteria analysis, after the presentation gave the floor to the members of the group in the order they announced themselves. The group members wrote down their ideas and the results were translated into the following list of easy to analyse criteria:

- The existence of templates for learning modules and the possibility of customisation;
- Creating and using institutional accounts;
- Ability to run applications on all types of low-resource devices (desktop, laptop, tablet, smartphone);
- Possibility of video call with the minimum of actors involved (teacher and 30 sd);
- Possibility to record activities and play them back later;
- IT administration at cloud server level;
- Easily translate F2F courses into online mode;
- Integration of the attendance list and catalogue;
- Pragmatic and objective assessment of students with the possibility of identifying fraud;
- Possibility of integrating data collected from previously used or complementary systems;

- Interactivity with other services (calendar, activity reporting, forum, ranking, etc.);
- Feedback loop from one series to another and Remodelling the training system after introducing feedback elements;
- Resolving the challenges encountered and recalibrating the system;
- Human factor performance;
- Costs involved, budget allocation;
- Easy maintenance and update.

Development, implementation and maintenance of distance learning platforms

At this stage, the following challenges were achieved: critical processing, filtering variables, combining them, modifying ideas from brainstorming sessions. The mathematical apparatus will show us which criteria are decisive and require special attention in the valorisation of the aspects that contribute to the performance management of distance learning. The elements resulting from the brainstorming sessions have been taken into account and the following criteria have been analysed[BOB, 19] :

Table 5.2: Criteria analysed

Crt. no.	Criteria analysed
1	The existence of templates and the possibility of customisation
2	Creating and using institutional accounts
3	Ability to run applications on all types of low-resource devices
4	Possibility of video call with a minimum of actors involved (teacher and 15 students)
5	Ability to record activities and play them back later
6	Cloud server level IT administration
7	Easy translation of F2F courses online
8	Integration of the attendance list and catalogue
9	Pragmatic and objective assessment of students, with the possibility to identify fraud
10	Possibility to integrate data collected from systems used so far or from complementary systems (compatibility)
11	Interactivity with other services (calendar, activity reports, forum, ranking
12	Series-to-series feedback loop and reshaping the training system after the introduction of feedback elements
13	The Human Performance Envelope (HPE) - stakeholder involvement in improving learning
14	Costs involved, budget allocation
15	Easy maintenance and upgrade

After establishing the criteria to be analysed, they were compared against each other and then we calculated the score and determined the level of their importance ranking. We used formula (6.1) to calculate the Weighting Coefficients (Cpi). and the results were then used in determining the most appropriate educational platform.

$$Cpi \quad = \frac{p+\Delta p+n+0,5}{-\Delta p'+\frac{Ncrt.}{2}} \qquad (5.1)$$

where:

p is the sum of the scores obtained (per line) by the item under consideration;

Δp the difference p between the score of the item under consideration and the score of the item on the last level; if the item under consideration is the one on the last level, Δp is 0;

n the number of criteria outperformed (overscored) by the criterion under consideration;

$N_{crt.}$ the number of criteria considered;

p' the difference between the score of the item under consideration and the score of the first item (resulting in a negative value); if the item under consideration is on the first level, Δp' results in a value of 0.

Table 5.3 Score matrix, ordination level and weighting coefficients

Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Points	Level	Cpi
1	1	0	0	1	1	1	0	1	1	1	0	1	1	0	1	9,5	6	2,24
2	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	13,5	2	4,71
3	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	11	4,5	2,91
4	0	0	0	1	1	1	0	1	1	1	0	1	1	0	1	8,5	7	1,85
5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0,5	15	0,05
6	0	0	0	0	1	1	0	1	0	0	0	1	1	0	1	5	10,5	0,82
7	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	12,5	3	3,89
8	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	3	12,5	0,42
9	0	0	0	0	1	1	0	1	1	1	0	1	1	0	1	7	8,5	1,33
10	0	0	0	0	1	1	0	1	1	1	0	1	1	0	1	7	8,5	1,33
11	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	11	4,5	2,91
12	0	0	0	0	1	0	0	1	0	0	0	1	0	0	1	3	12,5	0,42
13	0	0	0	0	1	1	0	1	0	0	0	1	1	0	1	5	10,5	0,82
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14,5	1	5,73
15	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1,5	14	0,20

In Table 6.4a, the four platforms proposed for testing were given contribution scores for one criterion (scale 1-10), and then in Table 6.4b the products of the N scores and the weighting coefficients were calculated, which when added together will show which of the educational platforms are worth exploring and exploiting by the actors involved.

Table 5.4(a) Platform scores (b) Initial scores

	A	B	C	D	E
Criteria	NiA	NiB	NiC	NiD	NiE
1	7	2	9	2	8
2	9	9	10	3	9
3	9	6	10	9	10
4	1	1	6	9	9
5	1	5	9	9	8
6	8	8	9	8	9
7	9	6	9	1	8
8	10	3	9	1	9
9	7	9	8	1	8
10	8	7	10	2	9
11	8	8	10	8	9
12	7	8	8	5	7
13	8	7	8	6	8
14	9	8	1	9	1
15	7	8	10	8	9

		A - Moodle		**B - ILIAS**		**C - Teams**		**D - Zoom**		**E - G Suite**	
Criteria	Cpi	NiA	***CpiA**	NiB	***CpiB**	NiC	***CpiC**	NiD	***CpiD**	NiE	***CpiE**
1	2,24	7	**15,68**	2	**4,48**	9	**20,16**	2	**4,48**	8	**17,92**
2	4,71	9	**42,35**	9	**42,35**	10	**47,06**	3	**14,12**	9	**42,35**
3	2,91	9	**26,18**	6	**17,45**	10	**29,09**	9	**26,18**	10	**29,09**
4	1,85	1	**1,85**	1	**1,85**	6	**11,11**	9	**16,67**	9	**16,67**
5	0,05	1	**0,05**	5	**0,23**	9	**0,42**	9	**0,42**	8	**0,37**
6	0,82	8	**6,59**	8	**6,59**	9	**7,41**	8	**6,59**	9	**7,41**
7	3,89	9	**35,05**	6	**23,37**	9	**35,05**	1	**3,89**	8	**31,16**
8	0,42	10	**4,21**	3	**1,26**	9	**3,79**	1	**0,42**	9	**3,79**
9	1,33	7	**9,33**	9	**12,00**	8	**10,67**	1	**1,33**	8	**10,67**
10	1,33	8	**10,67**	7	**9,33**	10	**13,33**	2	**2,67**	9	**12,00**
11	2,91	8	**23,27**	8	**23,27**	10	**29,09**	8	**23,27**	9	**26,18**
12	0,42	7	**2,95**	8	**3,37**	8	**3,37**	5	**2,11**	7	**2,95**
13	0,82	8	**6,59**	7	**5,76**	8	**6,59**	6	**4,94**	8	**6,59**
14	5,73	9	**51,60**	8	**45,87**	1	**5,73**	9	**51,60**	1	**5,73**
15	0,20	7	**1,37**	8	**1,56**	10	**1,95**	8	**1,56**	9	**1,76**
			237,74		**198,76**		**224,83**		**160,25**		**214,64**

C. Interpretation of results

We found that due to the affordability differences (free of charge vs. acquisition and maintenance costs) mentioned earlier in our case study, platforms C and E although scored well compared to the other platforms, received the minimum score on criterion 14 (costs involved, budget allocation) and thus the final score was lower than that of platform A. During data processing and analysis, two of the selected vendors in the study (G_Suite and later Microsoft, platforms C and E respectively) offered facilities to users if the platforms of these developers are used by an educational institution, the use of the platforms with all modules being facilitated free of charge with no costs involved (at least for a period). Thus we submitted to the group it was decided to reanalyse the data in the new context, i.e. the group members a re-evaluation and scoring of this criterion. This criterion being re-evaluated with the maximum score (highlighted in the centraliser in Table 6.5a) resulted in an increase of the final score (highlighted in Table 6.5b) and the outranking of the contender platforms.

Table 5.5 (a) Platform scores (b) Final scores (when costs are not taken into account

	A	B	C	D	E
Criteria	NiA	NiB	NiC	NiD	NiE
1	7	2	9	2	8
2	9	9	10	3	9
3	9	6	10	9	10
4	1	1	6	9	9
5	1	5	9	9	8
6	8	8	9	8	9
7	9	6	9	1	8
8	10	3	9	1	9
9	7	9	8	1	8
10	8	7	10	2	9
11	8	8	10	8	9
12	7	8	8	5	7
13	8	7	8	6	8
14	9	8	10	9	10
15	7	8	10	8	9

		A - Moodle		B - ILIAS		C - Teams		D - Zoom		E - G Suite	
Criteria	Cpi	NiA	***CpiA**	NiB	***CpiB**	NiC	***CpiC**	NiD	***CpiD**	NiE	***CpiE**
1	2,24	7	**15,68**	2	**4,48**	9	**20,16**	2	**4,48**	8	**17,92**
2	4,71	9	**42,35**	9	**42,35**	10	**47,06**	3	**14,12**	9	**42,35**
3	2,91	9	**26,18**	6	**17,45**	10	**29,09**	9	**26,18**	10	**29,09**
4	1,85	1	**1,85**	1	**1,85**	6	**11,11**	9	**16,67**	9	**16,67**
5	0,05	1	**0,05**	5	**0,23**	9	**0,42**	9	**0,42**	8	**0,37**
6	0,82	8	**6,59**	8	**6,59**	9	**7,41**	8	**6,59**	9	**7,41**
7	3,89	9	**35,05**	6	**23,37**	9	**35,05**	1	**3,89**	8	**31,16**
8	0,42	10	**4,21**	3	**1,26**	9	**3,79**	1	**0,42**	9	**3,79**
9	1,33	7	**9,33**	9	**12,00**	8	**10,67**	1	**1,33**	8	**10,67**
10	1,33	8	**10,67**	7	**9,33**	9	**12,00**	2	**2,67**	9	**12,00**
11	2,91	8	**23,27**	8	**23,27**	10	**29,09**	8	**23,27**	9	**26,18**
12	0,42	7	**2,95**	8	**3,37**	8	**3,37**	5	**2,11**	7	**2,95**
13	0,82	8	**6,59**	7	**5,76**	8	**6,59**	6	**4,94**	8	**6,59**
14	5,73	9	**51,60**	8	**45,87**	10	**57,33**	9	**51,60**	10	**57,33**
15	0,20	7	**1,37**	8	**1,56**	10	**1,95**	8	**1,56**	9	**1,76**
			237,74		**198,76**		**275,09**		**160,25**		**266,24**

Case study conclusions and discussion

By quantifying the criteria, ordering and evaluating them, using multi-criteria analysis, we were able to determine which of the proposed educational platforms represents the best solution to meet the requirements and needs of the actors involved in the educational process at the institution level. Without fail the subject matter has ramifications and connections in all fields and is a good example to follow in choosing any online and offline products. Having addressed the socio-technical system issue by selecting the educational platform, a small part of distance learning performance management has found its solution. We believe that the present study is an eloquent guide and will support the approach of other institutions in the selection of the respective distance learning platform.

It should be borne in mind that each of the identified factors involved is closely interrelated, their interconnection leading to dependency throughout the whole educational process. Each criterion requires/allows for further analysis with implications for managerial decision making which will be the subject of future research.

Analysis of the impact of turbulent and crisis environments on the operation and maintenance of radiolocation systems

Turbulent environments are defined as environments that have a high degree of volatility, uncertainty, complexity, ambiguity. Radiolocation systems run continuous operational service, so the pressure is constant on the crew. In a turbulent environment, this pressure increases and must be managed appropriately. The crew is trained to cope with these challenges but it is very important that these pressures are not added to by additional pressures.

In order to prevent overcrowding, it is recommended that when the workload of the crew increases, the team should be supplemented by the required number of people. In extreme cases, systems that are not adequately staffed should be supplemented with qualified, trained and certified personnel designated by the relevant echelon.

Socio-technical implications of digitisation in the maintenance of aerial surveillance systems

We survived what we considered to be a tumultuous period, in which the pandemic was for each of us a challenge, a challenge to adapt to a completely new environment, with the redefinition of inter-social relationships. Megginson wrote in 1963, "According to Darwin's Origin of Species, it is not the most intellectual of species that survives; it is not the strongest that survives, but the species that survives is the one that is best able to adapt and adjust to the changing environment in which it finds itself." [MEG, 63] The current period is by no means more relaxed but a particularly unstable one, with the military conflict in Ukraine a catalyst for the European and global energy crisis. We are struggling to cope, adapting ourselves, our behaviours, our relationships to the environment.

Aerial surveillance systems are a particular facility with their early warning component. It goes without saying that they need to be operational 24/7 and this can only be achieved with optimal maintenance. Digitisation, in successive stages, comes as a response to the challenges, i.e. a tool with which each of the daily processes that take place can be made easier. Digitisation must be seen not only as a component of information technology with its hardware and software components, but in direct connection with information and communication technology specialists and operators trained to operate technical systems.

The analysis of the socio-technical implications of the digitization of airborne surveillance system maintenance processes, sediments into a very important and topical topic. In order to identify the aspects that contribute to the fragility of air surveillance systems and the extent to which their resilience can be improved, I have chosen to go one by one through the aspects related to digitisation at European Union level by treating the topics related to the integration of digital technology and human capital from the perspective of digitisation and ending with a SWOT analysis of the socio-technical relationship on the digitisation of air surveillance maintenance processes.

Challenges of digitisation at EU level - implications for the human factor

In order to better visualise the components involved, we have turned to several reports carried out at EU level. In Figure 5.2, it can be seen by component the index of the digital economy and society[wDIG, 22] in 2021. We can see at the top of the ranking with percentages between 60 and 70% countries such as Denmark, Finland, Sweden, Netherlands and at the bottom with a level between 30 and 40% countries such as Bulgaria and Romania. The EU average for the Digital Economy and Society Index is 50%.

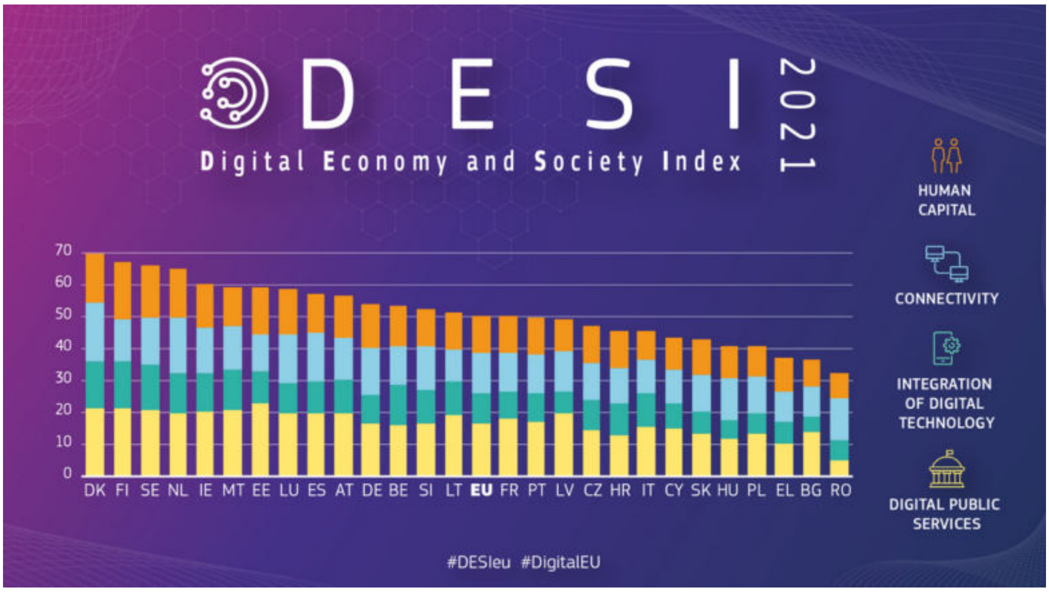


Figure 5.2: Digital Economy and Society Index 2021

Romania, although with minor developments[wPRO, 22] in its score (Table 5.6), it fails to outperform any of the EU countries and for the fourth consecutive year remains at the bottom of the ranking. This is partly due to political instability and poor governance.

Table 5.6: Romania's digitisation situation

	Romania		EU
	place	score	score
DESI 2021	27	32,9	50,7
DESI 2020	26	40,0	52,6
DESI 2019	26	36,5	49,4
DESI 2018	26	35,1	46,5

Another very important aspect to take into account is that Romania scores relatively well in terms of the infrastructure needed for digitisation, i.e. connectivity. Romania ranks 10th in terms of connectivity. In 2020, it has improved its performance in terms of coverage, but stagnated in terms of overall usage. Broadband coverage has increased to 87%, reaching the EU average. Strong infrastructure-based competition in Romania, especially in urban areas, is reflected in the Very High Capacity Fixed Network (VHCN) coverage indicator of 76%, well above the EU average of 59%. On the other hand, the components of human capital, digital technology integration and digital public services are at an extremely low level compared to the results recorded by other EU countries.

The role of human capital from a digitalisation perspective

At EU level we can see from Figure 5.3 in the number of employees specialising in information and communication technology (ICT) has remained relatively constant the graph showing the percentage of these employees according to the size of the enterprise given the total number of employees.

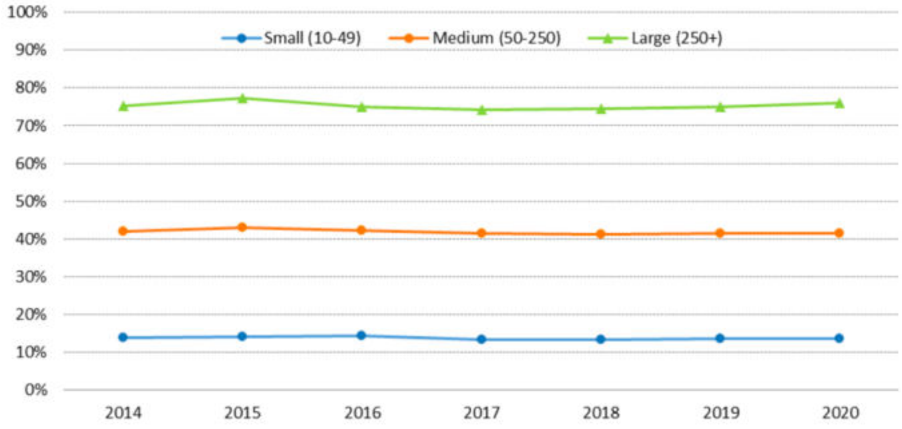


Figure 5.3: Enterprises employing ICT specialists (% of enterprises), 2014-2020

An ICT specialist designs, maintains and services the systems used to store, retrieve and send data. A wide range of careers are available in this field, from supporting a library collection to managing technology used in military operations. Professional qualifications can vary depending on the specific industry and job, but may include a degree in computer science or a related field.

Using the simulator on the European Union DESI platform we extracted data (Figure 5.4) on the number of graduates with studies in information and communication technology from which we can see that in the last 4 years there has been a more pronounced increase than in other countries in the percentage of these graduates although Romania has a large number of graduates in ICT (4th place), the shortage of specialists keeps the country's capacity to create innovation and take advantage of the benefits of digital transformation at a low level.

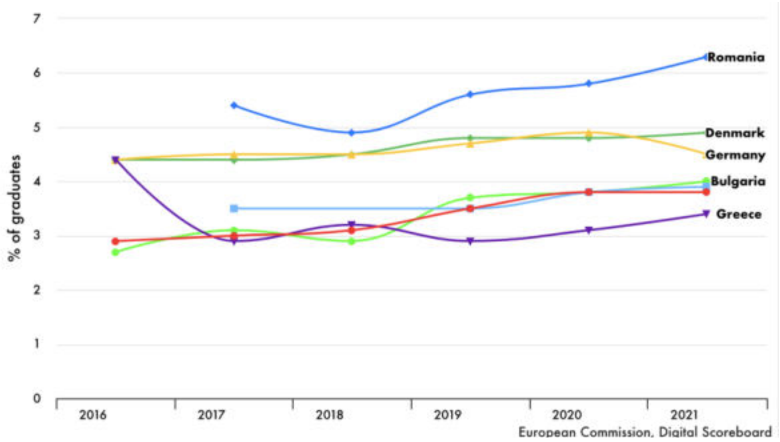


Figure 5.4: Percentage evolution of ICT graduates

Solutions for integrating digital technology into the maintenance of specialised systems

For the Digital Economy and Society Index in the chapter on digital inclusion (Figure 5.5Source: DESI 2021, European Commission.), three elements were taken into account, namely the intensity of digitisation of digital technologies for making and e-Commerce.

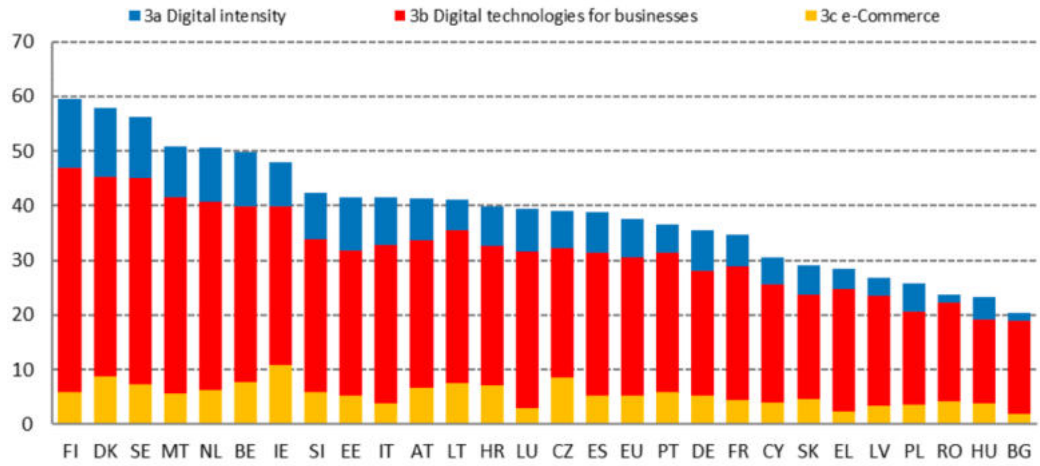


Figure 5.5: Digital Economy and Society Index (DESI) 2021, Digital Technology Integration.

Romania ranks 25th in the EU in terms of integrating digital technology into business activities. Most indicators in this dimension are well below the EU average. Only one third of SMEs have at least a basic level of digital intensity, compared to the EU average of 60%. Although 17% of Romanian SMEs take advantage of the opportunities offered by online trade, more cross-border sales could be recorded. Only 17% of businesses issue e-invoices, well below the EU average of 32%. Around 8% of businesses use social media platforms (low compared to the EU average of 23%), 13% use cloud services (EU average: 26%) and only 5% of businesses analyse large volumes of data. At the same time, 31% of businesses use artificial intelligence, well above the EU average of 25%. The percentage of businesses using ICT for sustainability is 68%, slightly above the EU average of 66%.

Implementation of digitisation in the maintenance of aerial surveillance systems

Logistics at the level of aerial surveillance systems has developed more and more since it had to align the interoperability and capabilities of the structures of which Romania is part. Maintenance as part of logistics increasingly needs the benefits of digitisation in the sense that the costs involved are extremely high and need to be optimised. Maintenance has evolved from scheduled and corrective maintenance to predictive and reliability-based maintenance. Maintenance has always involved collecting data on temperature and noise levels, all of which was done with sensors interpreted by human factors. Digitisation has shown its benefits one by one as sensor data and signals could be monitored recorded and compared automatically with reference/catalogue data, the novelty of predictive maintenance being achieved by the predictive capability through Big Data analysis, using elements of artificial intelligence, able to provide decision support to decision makers.

Predictive maintenance insights are an extremely valuable asset in improving the overall maintainability and reliability of an operation. Benefits include:

- minimising the number of unexpected breakdowns;
- maximising asset uptime and improving asset reliability;
- reduce operational costs by performing maintenance only when necessary;
- maximising production hours;
- improving safety;

- Streamline maintenance costs by reducing equipment, inventory costs and labour.

Identifying barriers to AI implementation

Following the analysis, we identified a number of shortcomings, most of which are related to the human factor at both the executive and decision-making levels. We have thus sought to identify the obstacles to the implementation of artificial intelligence as a way of supplementing the shortcomings noted above. On the basis of surveys conducted by the IPSOS company[wSUR, 22] we have identified four such obstacles highlighted in Figure 5.6as follows:

- it is difficult to hire new staff with the right skills - 57%;
- cost of adoption - 52%;
- cost of adapting operational processes - 49%;
- lack of skills among existing staff - 45%.

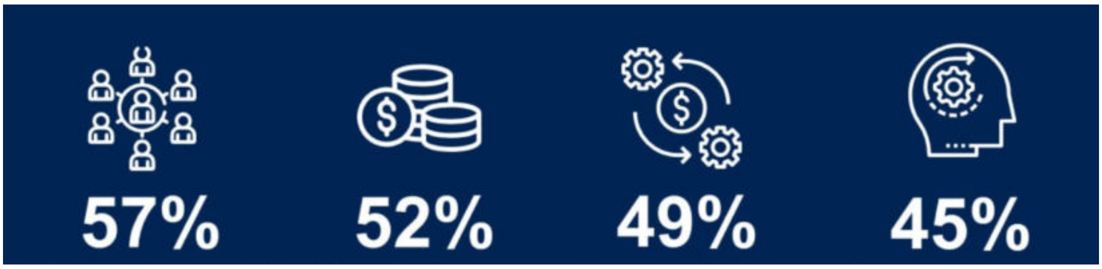


Figure 5.6: Barriers identified in AI implementation; source: Ipsos survey

In order to get a more eloquent picture of the implementation of AI technology, we have taken the results of the Ipsos company that conducted a survey[IPS, 20] among firms in the EU27 (excluding the UK, Iceland and Norway) in which respondents (8861) were asked "What is the state of implementation of AI technology in your firm?" The results (Figure 5.7) were categorised into two sectors by business area (the first part with technical profile companies in agriculture, construction, transport, waste management, sales and food, and the second part with social-human profile companies in hospitality, IT, real estate investment, education, health, research sector).

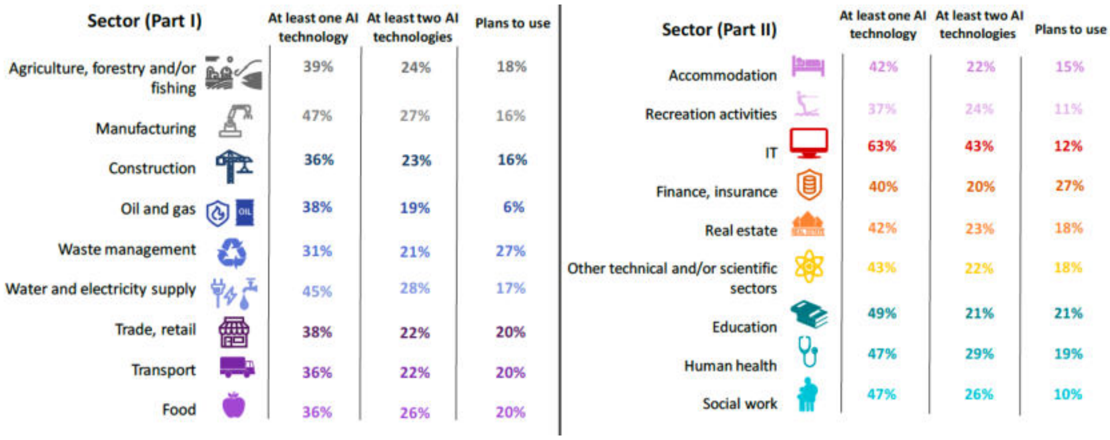


Figure 5.7Status of AI implementation in EU27 firms

We conclude that Artificial Intelligence, although it is so much in the news, is to a small extent embedded in companies and society. Its potential, together with the benefits of Big Data collection and analysis, the use of cloud servers, the interconnection of devices at the IoT level, which brings us closer to Industry 4.0, integrated and exploited to their true value, give a clear direction where we are heading.

SWOT analysis of the socio-technical relationship on digitisation in the maintenance of aerial surveillance systems

The man-machine relationship has always been a challenge because man is prone to a reluctance to new things, a reluctance to leave his comfort zone. SWOT analysis (Table 5.7) aims to identify the strengths and weaknesses of this relationship, and the opportunities and weaknesses, so that we can chart a bright digitalisation horizon.

Table 5.7 SWOT analysis of the socio-technical relationship on the digitisation of maintenance processes

STRENGHTS	WEAKNESSES
- Digitising maintenance increases the accuracy of identifying components at risk of failure; - Reduces maintenance times; - reduce the time it takes to bring the technique out of service; - Increasing the processing power of collected data using elements of artificial intelligence and self-learning;	- Staff training is slow due to a reluctance to learn; - The lack of simulators makes it difficult to train operators; - Staff shortages at instructor level for operator training; - Staff shortages at operator level;
OPPORTUNITIES	THREATS
- Using augmented reality to train operators;	- securing the digital infrastructure against cyber attacks;

- Stimulating staff to fit specific maintenance structures to the air surveillance system; - Covering the full spectrum of faults requiring maintenance, using simulators and augmented reality techniques; - absorption of funds for equipping repair workshops and improving operator training laboratories; - Using blockchain for maintenance processes;	- Possibility of remote penetration of computer systems and disruption of power chains required for maintenance; - malicious delays in maintenance processes by affecting logistics steps;

Analysing the strengths and weaknesses we see once again that the problematic element, without which maintenance cannot be achieved, is the human factor. Firstly, we are faced with a shortage of staff due to the unattractive environment and secondly due to their poor level of training.

Partial conclusions

The current energy crisis, catalysed by the conflict in Ukraine, is urging and forcing us to rethink our systems and identify and exploit conventional and renewable energy sources. Air surveillance systems, with their obligation to be able to provide 24/7 airspace information, require maintenance under any conditions and at any cost. Predictive maintenance is preferable, where sensor data is integrated into digitised systems, in order to make the necessary valuable predictions and provide the decision-maker with viable options. At the same time we note the difficulties in recruiting appropriately trained personnel and the difficulty with which digitisation solutions are accepted and implemented in aerial surveillance systems.

We propose the following directions:

- Develop the selection base of young people by stimulating education, technical training hubs;
- Stimulating the training of young people with potential for personal and professional development;
- Increase the attractiveness of maintenance jobs by clearly demarcating administrative and bureaucratic tasks;
- Filtering staff through regular testing and re-staffing on a grading scheme that clearly demarcates staff by competence levels;
- Material and financial incentives for maintenance staff who perform to the highest standards;
- Provide training opportunities with external partners;

- Implement new technologies as quickly as possible, like our partners in more developed countries, while maintaining stability, physical and cyber security, and air surveillance systems.

Rigorous planning that will take into account the relevant wishes of the executive staff in the maintenance of aerial surveillance systems, allocation/access to investment funds, organic implementation of new technological solutions, will ensure that in the future the depreciation of equipment will be rapid and the resilience of aerial surveillance systems will be at its maximum.

6 CASE STUDIES, PRACTICAL APPLICATIONS AND REAL OPTIONS GAMES WITH IMPACT ON RISK MANAGEMENT IN RADIOLOCATION SYSTEMS MAINTENANCE

The chapter is a defining element of the thesis, in which a series of studies with an impact on the field under investigation are carried out. An essential objective of the thesis, dealt with in this chapter, is focused on case studies on the identification of the events that occurred, the causes and factors that led to their occurrence and the necessary intervention measures (failure of the rolling bearing, pedestal breakage under the influence of strong or gusty winds, radom destroyed by lightning).

Two practical applications were carried out on vibration monitoring as a predictive method for optimised management of inherent risks (a 2D study under laboratory conditions on the experimental bench with the SkyRadar teaching radar, the complete set produced by IFM Germany consisting of VSA004 acceleration sensor, VSE002 data acquisition and processing unit, signal lamp, and a laptop unit where the software for data interpretation and establishment of damage and major fault limits was installed; the second 3D study under real flight conditions using an Arduino UNO assembly for vibration monitoring, powered from a 12V power supply, with a series of sensors attached: GPS with antenna, 6DOF sensor, barometer, RTC Real Time Clock) and a logger (recorder) equipped with a memory (SD card). A proposal for using AR in remote maintenance is included in the chapter.

The results from the analysis of the use of flexibility as a tool to increase the implementation capability of projects associated with technological change impacting on the maintenance (technical and human component) of radiolocation systems are spectacular. They highlight that today's decision makers can leverage more advanced analytical procedures to make strategic investment decisions in radiolocation system architectures. By integrating the real options paradigm, a novel way of evaluating and understanding how to formulate strategic decisions is highlighted. The application of the real options approach has revealed strategic solutions to increase the value of a project while managing risks; expansion and abandonment options have been considered in the study.

Human factor risk modelling for anticipating and predicting the evolution of risk factors involved in radiolocation maintenance is proposed to be achieved by integrating BodyCam or Augmented Reality (AR) glasses in the process of maintenance work execution. This can be used to provide assisted training for less qualified personnel, as well as to record the maintenance work performed in order to create a database (BigData) that can be uploaded to a government cloud where it can be technically audited by teams of specialists in a first phase and, in the future, can be used as input for an Artificial Intelligence (AI) model. This last proposed solution is at this point idealistic and represents **a bet with the future** At this point AI is only able to relate to text and incipient voice databases. But its evolution is spectacular. It is expected that in the not too distant future, based on an analogy with the STEM cell sampling model, the video recordings of radiolocation operations will represent the already collected database necessary for the development of an Artificial Intelligence engine dedicated to the maintenance of radiolocation systems and thus to their risk management. The creation of a digital register in which each element involved in maintenance is categorised for the purpose of human reliability analysis. By tracking the execution of maintenance operations and by periodical evaluations of the level of training, the categories of personnel are classified by degree of training (of expertise/competence, evaluated by tests of various complexities such as STANAG 6001 linguistic), equipment by degree of complexity and risks by probability of occurrence and potential impact. All these lead to increased accountability of personnel involved in the execution of radiolocation maintenance by decreasing errors of commission and omission.

SC1 - Rolling bearing failure situation in a long-range radar

Description of the situation

A long-range aerial surveillance radar was found to be excessively worn and vibrating on the electronic platform. Although according to the intervention sheet on the rolling element maintenance work was carried out in full volume with the use of appropriate oils and devices, the wear appeared and following the report of the fault to the dedicated echelon, it took the decision to stop the rotation of the radar in question and consequently to take it out of operation for detailed analysis and subsequent correction of the faults. In order to ascertain the causes of the malfunction, a committee was set up to investigate the situation and find the best solution for restoring the decommissioned aerial surveillance system to operational status as soon as possible.

Figure 6.1Technical area of the rotating system visually inspected by the technician

Investigating the fault

The 3-member commission, made up of engineers and vibration specialists, went to the site to analyse the circumstances of the fault and requested technical documentation, maintenance sheets, maintenance schedule and samples of the lubricant solutions used. Lubricant samples were also taken from the radar's rotating bearing pump unit and sent to the laboratory to ascertain the state of lubrication and the level of residual metal particles. At the same time, using dedicated instruments, wear on the raceways and the rollers of the special bearing were measured. Another measurement carried out was the horizontality of the electronic platforms.

Measurement results

The laboratory analysis of the lubricant showed that although it was in the required state of lubrication, it had excess metal particles resulting from excessive wear of the raceways and the rollers in the special bearing. Measurements showed that the flatness of the electronic platform was not within the permissible tolerance, which caused excessive stress on the bearing. On the basis of the data obtained, the committee was able to ascertain the causes of the fault but could not determine why the electronic platform was not within the permitted flatness tolerances. At the same time, the committee's report drew attention to the fact that stopping the radar's rotation in time and using it with a worn bearing could have caused other problems with the antenna, resulting in substantial material damage as well as a risk to the staff operating the equipment. The material damage was not imposed on the staff on duty because the situation was due to the installation of the rotation system at an angle outside the tolerances allowed by the installation's technical manual.

The proposed solution

The execution was completed with a proposed solution consisting in correcting the flatness of the electronic platform replacing the rotating bearing replacing the lubricating fluid in the rotating group and monitoring the rotating group for a minimum period of 6 months. As there are no special vibration measuring devices on the radar, i.e. a lubricating fluid analyser, the monitoring was only carried out visually.

Conclusions and personal contribution/proposal

Noting the problem of this failure and analyzing how to deal with these situations at the level of companies in the automotive industry, I propose a solution to reduce the risk of occurrence of this failure that involves the purchase and installation of dedicated vibration monitoring instruments (type SKF, IFM or BoB assistant) respectively the purchase of dedicated probes for the parameters of the lubricating fluid, training of staff to interpret alerts and messages, and their connection to transmit information to the central level for taking appropriate measures for planning and execution of maintenance.

SC2: Antenna ripped off electronic platform

Description of the situation

Long range radar with full paraboloid antenna and waveguide energy transmission. The position of the radar antenna in relation to the arrangement of the consoles from where the staff carried out the operational service, 30 m difference in level, the antenna being arranged on a natural hill at a distance of about 1000 m from the administrative premises from where the radar was remotely operated. Without any warning at the radar consoles, the signal on the sighting indicators disappeared. The staff on duty noted that the weather was unfavourable but the wind speed did not exceed the limits imposed by the manufacturer. When the radiolocation signal was lost, the staff on duty, who also carry out the primary maintenance of the radar, went to the place where the radar had been placed, i.e. the shelter and the antenna on the hill formation next to the technical building, and found that the antenna was no longer in its normal place on the electronic platform and had been thrown 30-50 m away from its natural place.

Investigation of the fault

In the given situation the operators reported the incident to the higher echelon and the radar at this time was taken out of operational capability. The area of responsibility for airspace surveillance of the radar was designated to neighbouring radiolocation entities so that there were no vulnerabilities in the area of responsibility. In order to analyse the incident, a committee of engineers and radiolocation specialists was appointed to go to the site and take measurements and study the technical documentation, maintenance sheets, operating schedule and weather conditions at the time of the incident. The protocols in force at the time of the incident required that when the wind speed exceeded 105 km/h or there was a gusty wind, the radar should be reported to the upper echelon and only with its approval the radar should be switched off and the antenna should be switched freely disconnected from the driver motor. it should be noted that the radiolocation station was not equipped with a weather station equipped with an anemometer to determine the wind speed and intensity, as this equipment was purchased from its own resources by the staff operating the radiolocation system. The committee also found that the anchoring systems made of textile webbing did not yield to the material yielding to the metal legs supporting the electronic platform.

Results of the survey

The field findings were quite eloquent, highlighting the fact that the very high wind speed and gusty winds overloaded the support structure of the electronic platform composed of round pipe legs in section.The overloading of the support legs led to the bending and breaking of some of them, which caused the platform to tilt and lose its flatness. with the loss of flatness of the platform, the moving antenna was repeatedly subjected to forces that were not calculated for it and under the repeated action of the gusty wind on the large surface that makes the antenna behave like a sail, the antenna came loose with the rotating bearing from the electronic platform. The Commission found that the crew had acted in accordance with the procedures in force at the time of the incident and the damage was blamed on the manufacturer.

The proposed solution

Since we are dealing with a material failure, the event committee proposed as a solution the replacement of the destroyed antenna with the mention that the support system of the electronic platform should be made by the manufacturer in a formula that ensures increased resistance to wind gusts or wind with higher speeds. Also as an organizational and administrative measure, the decision was taken to change the protocol so that when the wind speed is detected, the radar is automatically stopped by the staff on duty and only afterwards is reported its stop and the causes that led to its stop. this protocol protects the equipment and reduces the risk of injury or damage to the radar.

Conclusions personal contribution/proposal

Analysing the causes and effects of the event, I come with the proposal that each radiolocation station likely to have problems caused by the increased wind speed, i.e. first in gusts, should be equipped with appropriate wind speed measuring instruments which, directly connected to the radar rotation system, can give the command to stop the radar rotation and move the antenna to a free position in the wind, with appropriate signalling and reporting to the beneficiary echelons. The proposed solution comes as a measure to limit the risk to the staff of the radiolocation station, i.e. to reduce the risk of accidents and material damage to the radar equipment. Once the radar has stopped rotating, the acoustic and light signaling of this fact allows the staff to take appropriate measures and the higher echelons to order the neighboring structures to cover the area of responsibility of the radar taken out of operation.

SC3: Weather radars, challenges in extreme conditions

Weather radars continuously scan the atmosphere, providing data and colour images of storms and their evolution. Radar images help meteorologists to warn of hazardous phenomena and support end-user decision making in all aspects of rain and snowfall sensitive areas. But from time to time, the screen is black and no data is available. To keep downtime as short as possible, radar owners carry out preventive maintenance, constantly monitor data quality and, when something happens, they make corrections and repairs as quickly as possible.

Radar networks of European meteorological services

Main findings of the survey

Maintenance and monitoring of radar equipment

Preventive maintenance. Where it is essential for a device to function all the time (as is the case with aircraft and, to some extent, radar), maintenance should be carried out not only when parts break down, but also on a regular basis (i.e. preventive maintenance). An additional advantage of preventive maintenance is that it can be planned, generally taking into account weather conditions, to minimise the risk of downtime during major weather events.

It takes more than radar to produce radar data

Norwegian radar struck by lightning

Partial discussions and conclusions

Vibration monitoring application on 2D experimental stand - integration of predictive method at rotating element level for optimal management of inherent risks

Application for monitoring the effects of flight manoeuvres on radiolocation equipment placed on 3D aerial vectors

In the previous section in the 2D Experimental Stand Vibration Monitoring Application we performed data collection and interpretation in laboratory conditions (2D) where there is no action of external factors (wind, accelerations, severe temperature differences) the system being statically located. The only inputs are given by friction of internal components that can produce heat, as well as artificial shocks that simulate external phenomena.

Rationale for the choice of vibration analysis on board an airborne vector

In order to get as realistic a picture as possible of the conditions affecting the radiolocation systems deployed on the ground, in more and more unfavourable environments, I have proposed and developed a data collection model under real (3D) conditions, taking into account that a large number of radiolocation installations are deployed on board aircraft, and here we list:

- weather radars on all military aircraft and some civilian aircraft, particularly passenger aircraft;
- target finding radars;
- interception radars;
- fire guidance radars.

The airborne vector chosen for the study and the application for monitoring the effects of flight manoeuvres on radiolocation equipment was the IS28-B2 glider of the Aeroclub of Romania, Aerodromul Teritorial Sânpetru, registered YR-3600 (Figure 6.2We started from the hypothesis that the highest stresses in the case of radiolocation equipment occur in those installed on board aircraft because forces and pressures are exerted on them by:

- shocks caused during take-off/landing;
- accelerations (positive and negative) from the evolution of the air vector;
- pressure and temperature differences due to the altitude evolution of the air vector.

Figure 6.2 Glider IS28B2, YR-3600

Data acquisition scheme under 3D conditions

In order to monitor vibrations we have developed a system capable of acquiring real-time data on a 3D vector moving at flight speeds of 25-40 m/s. In Figure 6.3 we have represented the block diagram of the interconnection of the components of the data acquisition, processing and storage system. The basic element is an Arduino UNO, powered from a 12V power supply, to which we have attached a series of sensors: GPS with antenna, 6DOF sensor, barometer, RTC Real Time Clock) and a logger (recorder) equipped with a memory (SD card).

The Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (6 of which can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, and a reset button. It contains everything needed to support the microcontroller; to get started, simply connect it to a computer with a USB cable or power it with an AC/DC adapter or battery. The cost is minimal, and the device can be purchased from online platforms

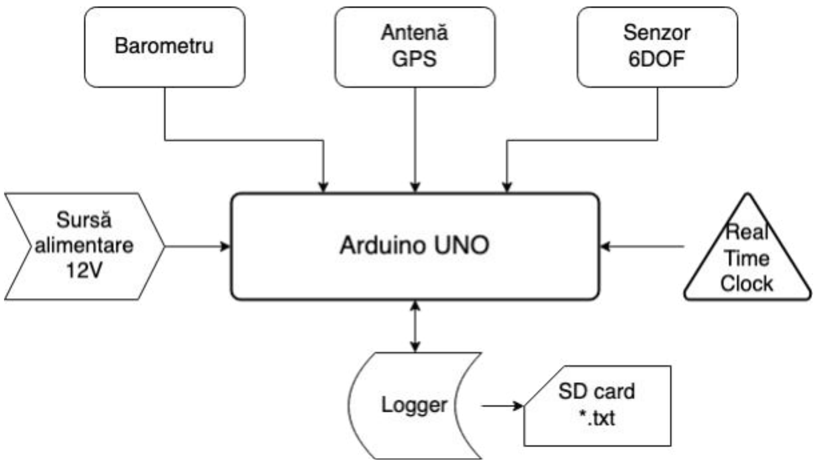


Figure 6.3 Data acquisition scheme under 3D conditions

Technical characteristics of the GY-521 module with gyro sensor and 3-axis accelerometer with MPU-6050 chip, ADXL345 (Figure 6.4 - Photo source: https://www.sigmanortec.ro/Modul-giroscopic-si-accelerometru-3-axe-GY-521-p126016326)

Supply voltage: 3-5 VDC (internal voltage stabilizer)
Communication: IIC standard
Gyro range: + 250, 500, 1000, 2000° /s
Accelerometer domain:± 2,± 4,± 8,± 16 g
Dimensions (mm): 21*15

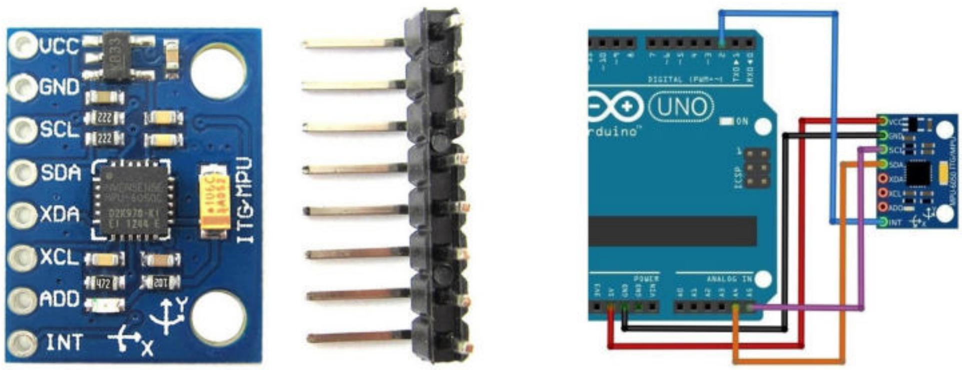


Figure 6.4 GY-521 module with gyro sensor and 3-axis accelerometer with MPU-6050 chip, ADXL345 (a) mounting kit, (b) wiring diagram

NEO-6M GPS module

GPS module GY-NEO6MV2 (Figure 6.5) is easy to use, communicates via serial transmission, and is powered by 5V. It can be used with a baud rate of 4800, 9600 or 115200 kbps. Technical specifications of the module:

- Supply voltage: DC 5V;
- Model: GY-GPS6MV2;

- Antenna: made of ceramic;
- EEPROM for saving information when power is interrupted;
- Battery backup;
- Antenna size: 25 x 25 mm;
- Module size: 26 x 36 mm;
- Mounting hole diameter: 3 mm;

Figure 6.5 NEO-6M GPS module

SD memory card adapter (Figure 6.6) is used to store the data collected and interpreted by the Arduino kit for later analysis on the ground

The features of the module are as follows:

- Supports Micro SD card (<=2G), Micro SDHC card (<=32G) (high speed card)
- Level conversion circuit board that can interface the level is 5V or 3.3V
- Power supply is 4.5V~5.5V, circuit board voltage regulation 3.3V
- The communication interface is a standard SPI interface
- 4 M2 screw positioning holes for easy installation
- Size: 4.1 x 2.4 cm

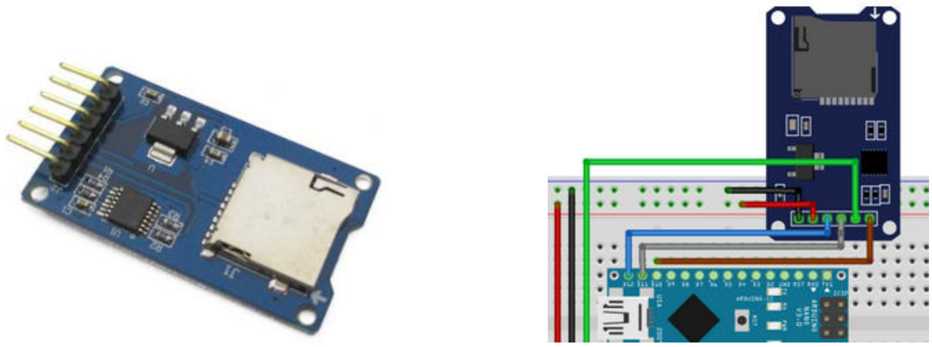


Figure 6.6 SD memory card adapter (a) mounting kit, (b) connection diagram

Data acquisition management

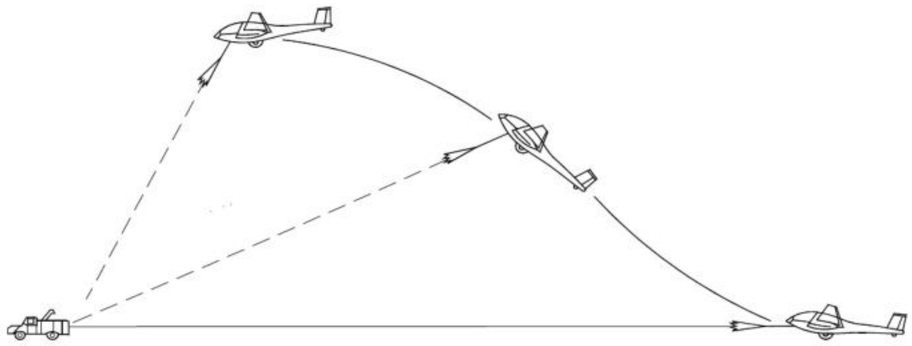
In order to carry out the data acquisition to achieve the proposed objectives, we established and executed the following steps:

- installation of the acquisition system on board the air vector;
- Establishing the flight scenario;
- We set up a scenario with a classic lap where we simulated the phases:

- Runway (aircraft fuselage shocks due to grass runway);
- Take-off/take-off;
- Steep take-off slope (positive acceleration);
- Horizontal flight with turns (roll and pitch);
- Putting on slope (negative acceleration);
- Landing (ground contact shocks);
- deceleration to zero speed.

▪ Extracting data from the recorder

- Data interpretation using online applications Google Earth for precise location and DroneePlotter for highlighting the collected data.



- Figure 6.7 Glider take-off on auto-seat

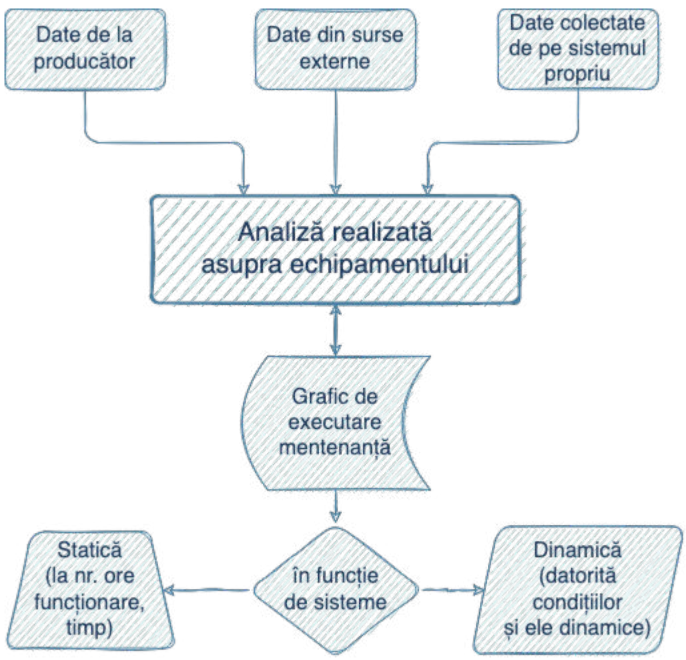


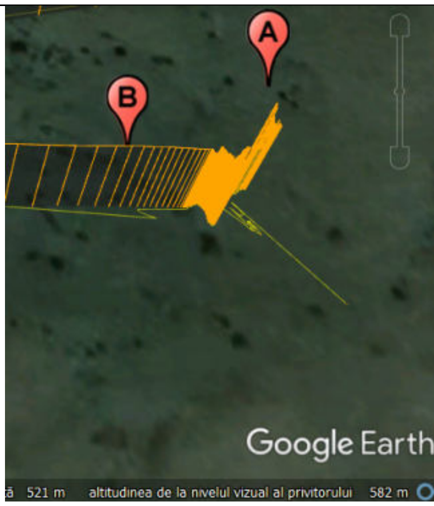
Figure 6.8: Equipment analysis chart for maintenance scheduling

Figure 6.9shows the trajectory performed by the aircraft, This was achieved by correlating the acceleration and gyration data against the aircraft's GPS position, altitude and roll and pitch motions. Points A, B, C, E, D represent the essential flight stages.

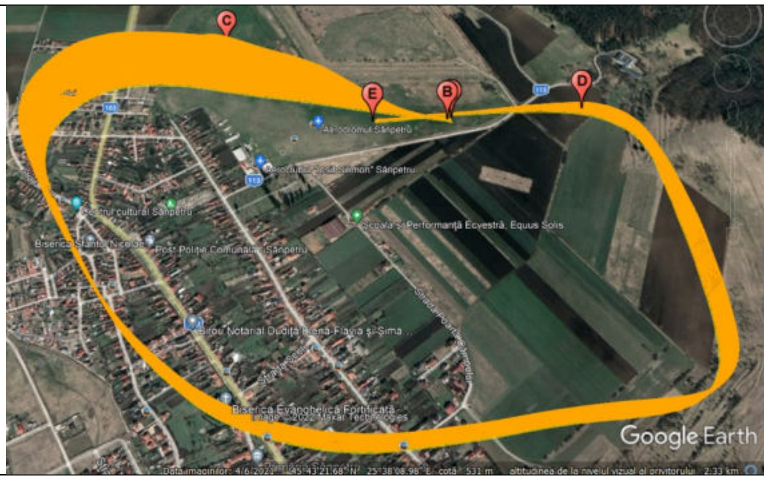
Figure 6.9 Aircraft path for sensor testing in 3D conditions

Data interpretation

In order to analyse the data collected by the sensors during the flight path performed, we have noted the essential flight stages as follows:

Take-off stage (area marked on the chart between points A-B): risk factors influencing the radiolocation equipment on board the aircraft have been assessed for the following stages identified as critical ○ Ground rolling ○ Uncoupling ○	

Acceleration phase and reaching flight altitude: (area marked on the graph between points B-C) In this phase of the flight we looked at how the following steps influence the rdlc teams - Accelerating on a slope - The moment of detachment of the mosor towing cable	

- Horizontal flight stage (the area marked on the graph between points C-D):
    o Accelerations with very low values
    o Turning (Rolling and pitching)
	

- Landing stage (area marked on the chart between points D-E)::	

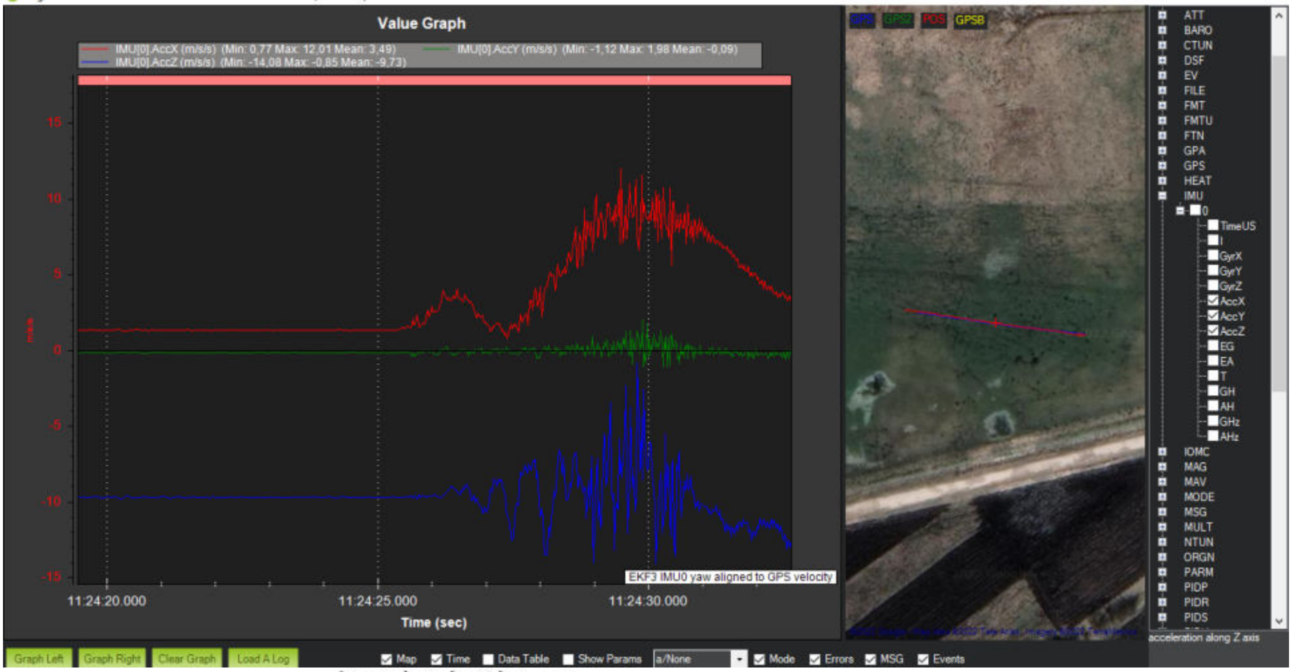
- :
-
-
    - Slope setting (negative acceleration)
    - Landing (ground contact shocks)
    - deceleration to zero speed.

This was achieved by correlating acceleration and gyration data against the aircraft's GPS position, altitude and roll and pitch motions.

Take-offs and landings

Socuri

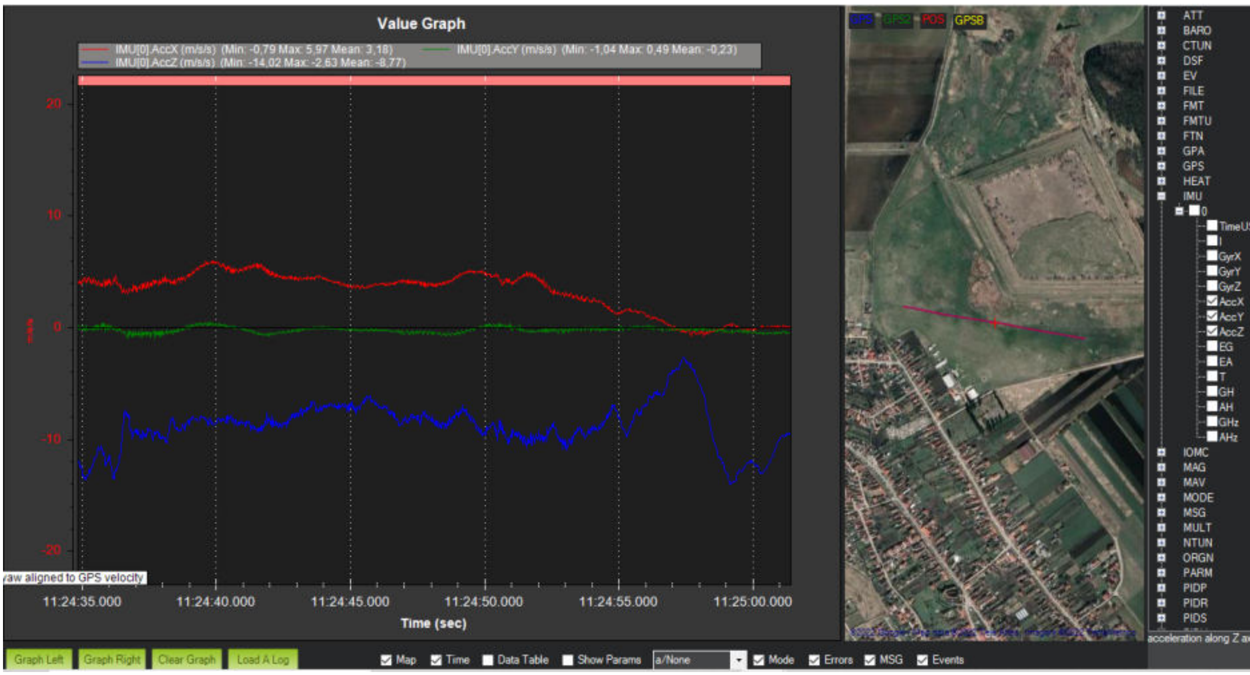
In the chart .... It is evaluated the taxiing and take-off phase on the grassy runway, between points A-B, where we have identified on the data collected with the logger from the experimental set-up, the vibration variation on the 3 axes marked with distinct colors (plane with axes z vert gyration blue x longitudinal roll red and y st

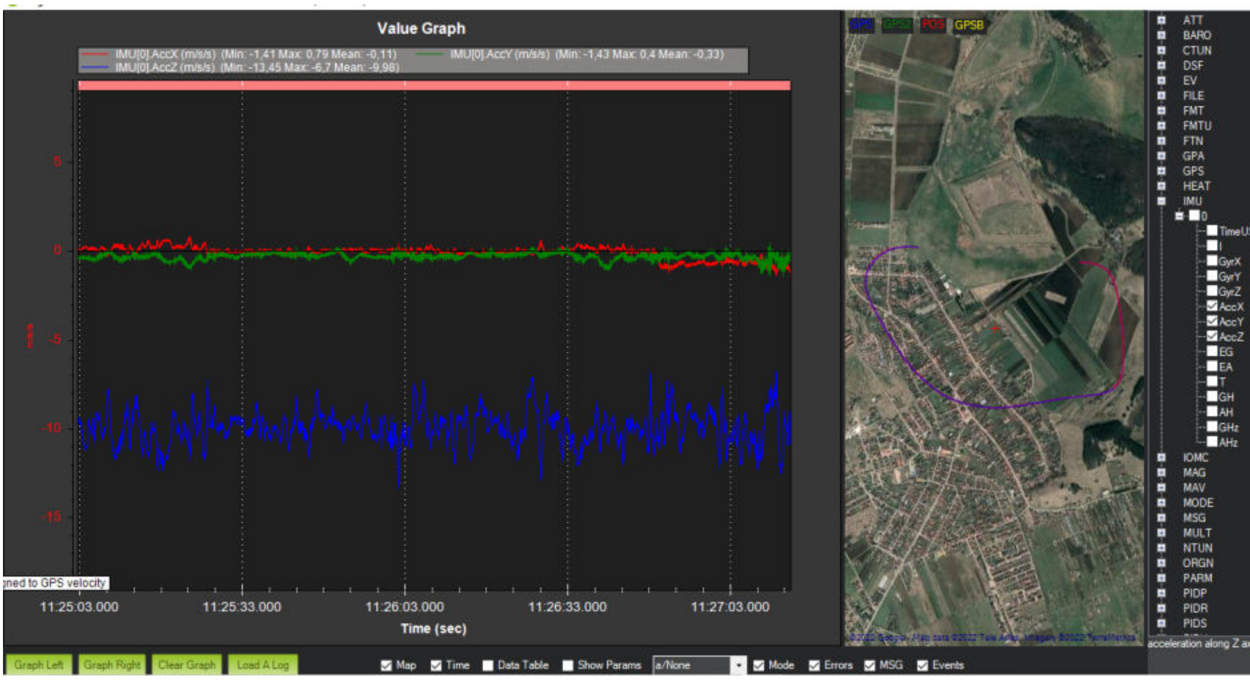


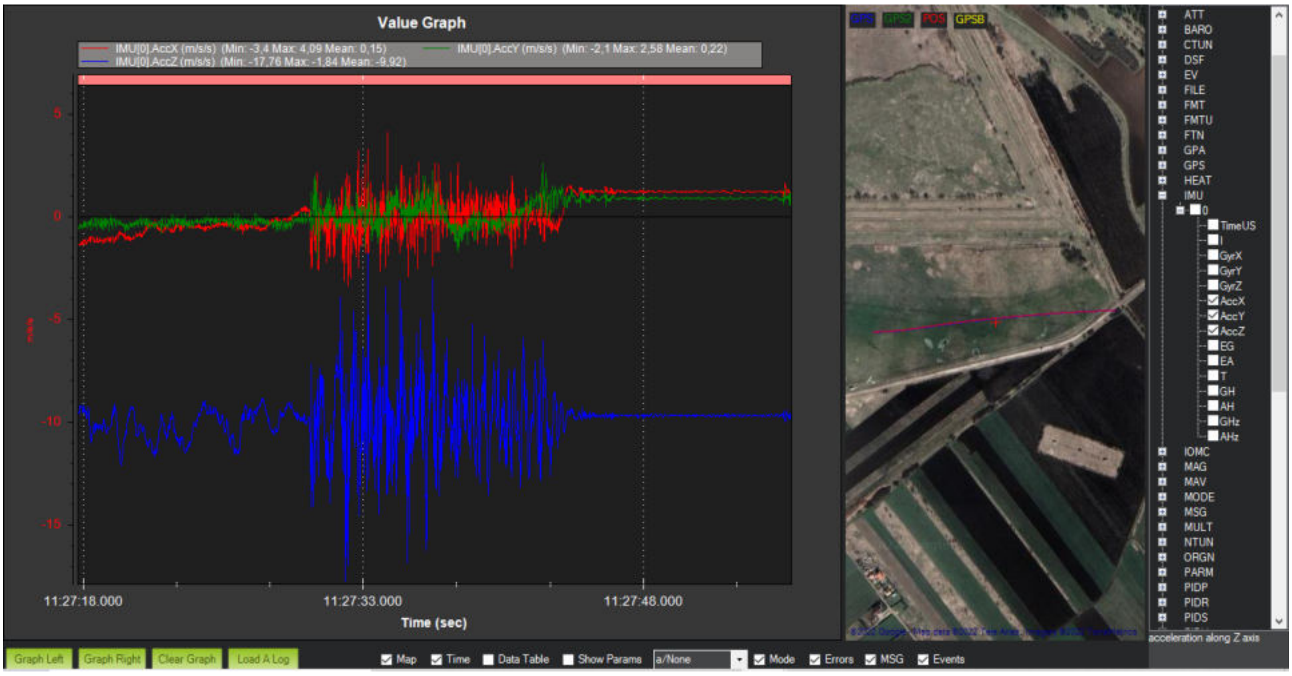
g dr pitch green)

- on the x-axis you can see the acceleration increase with the pilot's horizontal wing trim and the aircraft rolling on the ground. The value of the vibrations increases relatively steadily until the aircraft has reached ground speed, where their value has stabilised. At this stage the maximum value on the x-axis was $10mm/s^2$
- on the y-axis the value of accelerations is negligible reaching a maximum of $1mm/s^2$

- on the z-axis the greatest variations in accelerations were recorded, compared to the x-axis, on this axis the variations were with high amplitude and frequency f reaching maximums of 13mm/s^2







Conclusions

We found the following conclusive for the study:

- the highest vibrations with major impact on the radiolocation equipment are evident in the take-off and landing phases;
- From measurements we have found that vibration variation on the Z-axis is the most damaging due to the frequency and amplitude with which it occurs;
- The X-axis has low relative values during the take-off and landing phases and negligible values during the other phases of flight (glide);
- The Y-axis has negligible values at all stages of flight.

Personal contribution

The results obtained indicate that the design and maintenance of radiolocation systems must take into account these essential aspects by introducing corrective technical solutions (dampers) or designing equipment with parts that do not involve mechanical movement - the development of electronically swept antennas of the radiated beam.

Another aspect of maintenance is required to take into account the type of operations/maneuvers that the aircraft performs, thus resulting in two categories:

- Aircraft that have long flight cycles and therefore few landings or take-offs (e.g. AWAKS) with in-flight refuelling;
- Aircraft with short flight cycles by default with frequent dec and at (e.g. fighter aircraft, no in-flight refuelling possible).

Drawing

Through the scalable and modular system we demonstrate that we can collect data in extreme 3D conditions from different types of equipment, the data collected from them can provide essential elements for the design of specific radiolocation equipment and systems as well as the identification of vulnerable points that require increased attention in the framework of maintenance execution.

This equipment has the capability to identify and report problems that occur with radiolocation equipment that have not been identified and addressed by the manufacturer (especially equipment with no operational history).

Proposals on the use of innovative technology - AR glasses - in remote maintenance of radiolocation systems

Augmented Reality (AR) is known as the medium in which we superimpose digital information on a background of surrounding reality. AR is clearly distinguished from VR (Virtual Reality) in that the entire environment (represented information and background) is constructed virtually and can be represented by dedicated devices in which the actor is completely isolated from the physical environment in which they are located.

In order to be able to perform AR functions, specialised tools for processing, rendering and visualising information with powerful computing and processing capabilities are needed.I will not dwell on the hardware and software components of AR, as I want to focus this section on the use of innovative AR technology in the remote maintenance of radiolocation systems. I have been introduced to this technology in the framework of the DDHE (Digitalisation of Defence Higher Education) project under the Erasmus +

analysis of the use of flexibility as a tool to increase the implementation capability of projects associated with technological change impacting on the maintenance (technical and human component) of radiolocation systems

In the current geo-strategic environment where paradigm shifts (paradigm of changing equipment and technology in the context of moral attrition) are increasingly present, and the prices of resources and implicitly of services are constantly evolving, an analysis using the paradigm of real options is proposed. Given that state systems are known to be conservative, the proposed approach provides decision-makers with a useful tool to make the management of available financial resources easier and more transparent.

A traditional approach used to deal with risk and uncertainty is to apply *scenario* analysis. *For* example, scenario analysis is a central part of the capability-based planning approach widely used to develop strategies by the Department of Defense, USA[MUN,10] . In the case of military planning, the problems are exacerbated by the lack of objective ways of estimating benefits in monetary units. Without a monetary benefit analysis, it becomes difficult (if not impossible) to compare the net benefits of different scenarios. In addition, interdependencies have to be interpreted in a largely subjective manner. This makes it impossible to apply powerful mathematical statistical tools that allow a more objective analysis of the system architecture of radiolocation systems.

Objective of the analysis

In the current context where multiple crises, and here we list generically the energy resources crisis, the supply chain crisis, the generation change crisis, the semiconductor crisis, are having a negative impact on regional and international security, the aim is to analyze some aspects that can improve the risk management of radiolocation systems and ensure the operational availability of the air surveillance system. The starting solutions consider efficient selection of products and services from the markets, effective and dynamic implementation (retrofitting, upgrading or replacement of obsolete systems) and efficient maintenance of radiolocation equipment and systems. The aim of the analysis is to support decision-makers in ensuring managerial flexibility in the implementation and maintenance processes of radiolocation systems. These optimisation options start from the evaluation of flexible alternatives formulated on the basis of the real options paradigm.

Working assumptions

In high-risk military situations, such as upgrading the radiolocation system architecture, real options can help identify risk mitigation strategies. In fact, both business and the military have applied real options approaches for hundreds of years - the military calls this approach courses of action. With real options analysis, we can quantify and evaluate each strategic path and develop strategies to hedge, mitigate or sometimes profit from risk.

The stages of this research are:

A. Formulating the problem of investment in the maintenance of radiolocation systems.
B. Assessment of costs, risks and selection of management alternatives
C. Determination of leading indicators, volatility and risk-free rate
D. Analysis based on real options
    a. formulation of flexible alternatives,
    b. assessing the value of built-in flexibility through the use of options
E. Formulation of optimisations based on the evaluation of flexible alternatives
    a. sensitivity analyses
    b. comparison of flexible alternatives
F. Finalising the decision-making process

Based on the questionnaire to the maintenance staff operating the radiolocation systems, and looking at the life expectancy of the analogue equipment, the need for replacement and/or refurbishment/modernisation arises. Although in the literature this process involves going through an algorithm for conducting the opportunity analysis, we find that the process is static; manufacturers' bids that meet the requirements in the specifications end up being statically analysed by a committee appointed for this purpose, as follows:

- Checks and systematizes the documentation provided,
- They carry out an analysis of each piece of equipment and determine if it is eligible,
- Prioritise the equipment being purchased,
- Estimate benefits and costs
- I propose for approval and implementation.

There is a lack of any flexibility to adapt along the way in this approach, which is why it is proposed to change the paradigm of investment processes in new programmes to improve the capabilities of air surveillance systems. The dynamic approach to investment in upgrading, modernising or replacing obsolete systems and maintaining radiolocation equipment and systems is based on the assumption of irreversibility of investment and changing courses of action over time, e.g. response to interest rate movements. After this step, costs and benefits are assessed and the selection of management alternatives is formulated. The timing of the purchase (now, later, never) depends on two other variables that need to be taken into account, namely the risk-free rate and volatility, the latter being in fact the expression of the composite risk or opportunity conferred. The next step is the use of real options starting from the formulation of flexible alternatives and assessing the value of the embedded flexibility resulting from the use of options. The final goal requires the formulation of optimisations based on the evaluation of flexible alternatives, based on sensitivity analysis and comparison of flexible alternatives. The final step is the completion of the decision-making process. Once these desiderata have been achieved through repeated simulations, the negotiation and establishment of the terms of contracts with equipment manufacturers and maintenance service providers is carried out under conditions adapted to market movements.

Methodology and tools used.

Flexibility in the implementation and maintenance of radiolocation systems aims to improve the overall value of the project. It can be shown that flexibility can deliver truly significant increases in Total Expected Value (TEV), by 30-35% or more in some cases, compared to traditional, static models that do not incorporate flexibility. The project value refers to the Net Present Value (NPV) which during the simulations will be normalised to the reference value of 100. From the perspective of the airborne surveillance system by means of the radiolocation systems in the composition, the benefits can be represented by the improvement of the level of operational availability and implicitly the reduction of the vulnerability of unauthorised penetration of airborne vectors into the area of responsibility.

Flexible designs can provide protection against risks of any kind , in the context that flexibility in the early phase of projects changes the distribution of outcomes and exploits favorable opportunities for action [HAS, 06], [WEK,04] From the classical options literature, flexibility confers value when uncertainty is greatest. Flexibility is most valuable for long-term projects. The future is more uncertain for long-term commitments as movements and fluctuations in the variables of interest cannot be predicted. Hence the tendency to wait longer and longer, to postpone decisions in order to gather as much relevant information as possible. However, in game theory, this tendency cancels out the advantage of the first move.

To make instrumentation as easy as possible, the input value is normalised to 100, after which the system can be scaled to the level required by the actual situation. In the analysis the ad-on MS Excel Real Option Games (JOR - ROG Real Option Game) version 2022 and the elements of Trigeorgis theory, real option theory [HUL, 06], DerivaGem simulator and Real Options Valuation Software simulator, created by Dr. Johnathan Mun in California, USA, from which the Super Lattice Solver (SLS) module is used, necessary to create the graphs.

Further consideration is being given to the possibility of increasing the value of radiolocation systems maintenance improvement projects by integrating Expansion and Abandonment options respectively.

Factors affecting option prices

There are five factors that affect the price of a stock option:

1. The current price of the underlying asset, S
2. Strike price, K
3. Expiry time, maturity, T
4. Volatility, σ
5. Risk-free interest rate, r_f

The following shows the impact of option values when changing key parameters:

Underlying asset price and strike price

Call options become more valuable as the price of the underlying asset rises and less valuable as the strike price rises. For put options, the behaviour is exactly the opposite, with put options becoming less valuable as the price of the underlying asset rises and more valuable as the strike price rises.

Volatility

The volatility of the underlying asset is a measure of the uncertainty of future developments. The holder of the call option benefits from the increase in the price of the underlying asset but also has a limited risk in the event of a fall in price, the maximum loss being given by the option price. Similarly, the holder of the put option benefits from price declines, but with protection from loss in case of mispricing on the increase in the value of the underlying asset.

Risk-free interest rate

The risk-free interest rate affects the price of an option in a way that is correlated with the impact on the return on the underlying asset.

Scenario analysis using real options

Real options analysis is useful not only for evaluating a firm through the lens of its strategic business options: it can also be used as a strategic business tool in capital investment and acquisition decisions. The investment decision in a new radiolocation architecture project involves understanding the value of different strategies associated with alternative strategies.

A. Formulating the problem of investment in the maintenance of radiolocation systems.

The scenarios for the realization of an investment in radiolocation architecture can be normalized and the investment (I) is considered to be 100 over a typical period of these projects, 5 years. The parameters of the problem are Rf - risk-free rate, T- time and net benefit flows Fi (i=1-5), $F_i = B_i + C_i$

$$I < \frac{\sum F_i}{(1+a)^i}$$

$$F_i = 10 * (1+a)^i$$

Where:

a - represents the discount factor and can take values between 0.05-0.20, in the current context perhaps even more. This discount factor is influenced by inflation, interest rates and adverse financial elements

B_i - benefits - increased national security by ensuring operational availability of Radiolocation systems

C_i - costs involved (with implementation, maintenance and physical and moral depreciation of the facilities

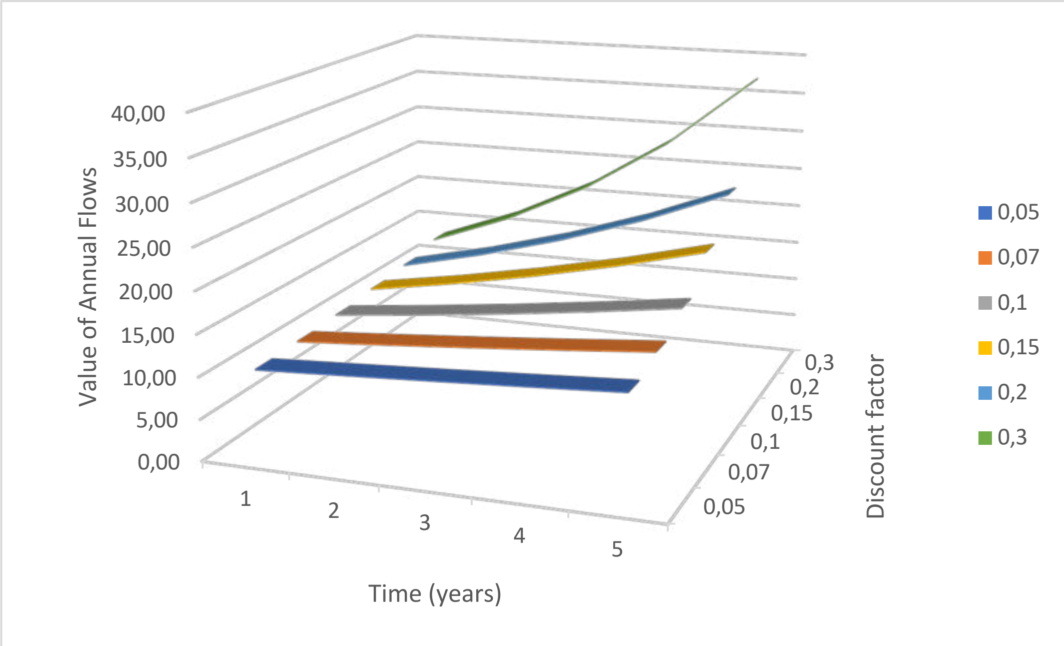


Figure 6.10Variation in the value of annual flows expressed in relation to different discount indices

B. Assessment of costs, risks and selection of management alternatives
C. The determination of volatility (as an expression of the uncertainty of the external environment) and the risk-free rate are the main parameters in the proposed analysis.
D. Analysis based on real options
    a. formulation of flexible alternatives,
    b. assessing the value of built-in flexibility through the use of options
E. Formulation of optimisations based on the evaluation of flexible alternatives
    a. sensitivity analyses
    b. comparison of flexible alternatives
F. Finalising the decision-making process

It should be noted that uncertainty increases over time (the so-called cone of uncertainty) but risk may or may not increase over time. Forecasting the future net benefit streams of flexible projects involves understanding probability distributions. Modelling based on geometric Brownian motion (generalised Wiener process) can be used:

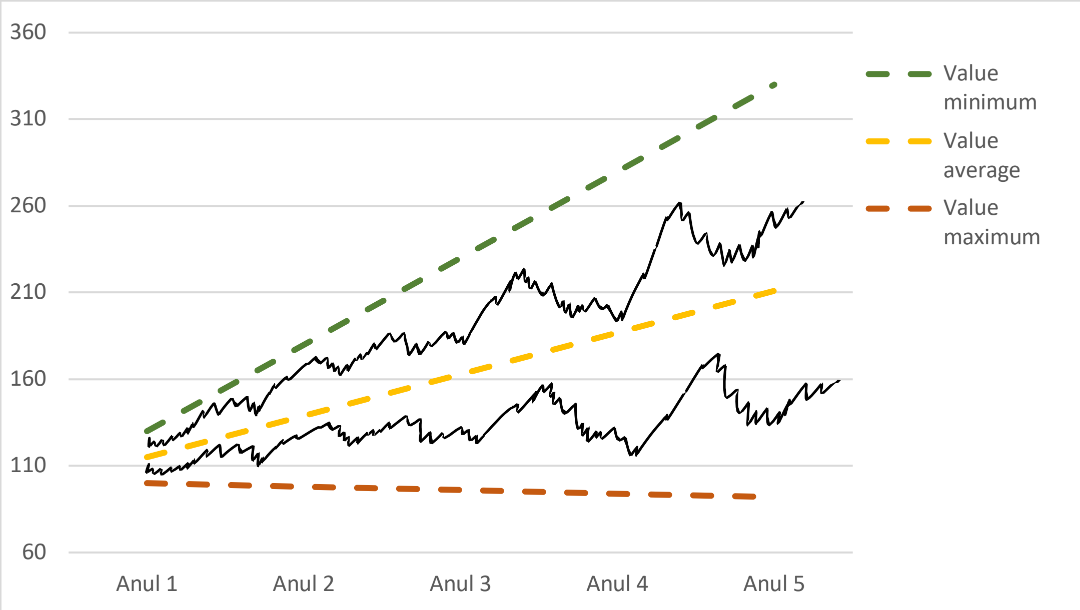


Figure 6.11 Uncertainty cone and volatility effect visualization.

Modelling based on geometric Brownian motion (generalised Wiener process) is used to estimate stock prices under constant volatility. The model can be adapted to the valuation of real options with the exception that in this case the technique based on binomial lattices (and discrete uncertainty cone simulation) is introduced.

Flexibility analysis for the Expansion option

Consider the normalised static value (S) of the open architecture radiolocation systems investment project (as the sum of the net discounted flows) and an implementation duration (T) of 5 years. The idea of deepening the expansion decision is to implement an additional investment (S_P) of 62.5% of the static value of the project, which according to expert analysis would double the benefits obtained. For this analysis, volatility (σ) 35%, risk-free rate (r_f) 15%, without dividend payments are taken into account.

In step 1 (the evolution within the latex is in this case from left to right) the dynamics of the underlying asset represented by the value (S) of the static project is evaluated considering as parameters: growth rate (u), decline rate (d), neutral probability (p). These parameters are calculated according to the following formulae:

$$u = e^{\sigma\sqrt{\delta t}} = e^{0,35\sqrt{1}} = 1,4191 \tag{6.1}$$

$$d = {}^{1}\!/_{u} = e^{-\sigma\sqrt{\delta t}} = e^{-0,35\sqrt{1}} = 0,7074 \tag{6.2}$$

$$p = \frac{e^{r_f(\delta t)} - d}{u - d} = \frac{e^{0,07(1)} - 0,7074}{u - d} = \frac{1,0725 - 0,7074}{1,4191 - 0,7074} = \frac{0,3651}{0,7117} = 0,5149 \tag{6.3}$$

To confirm, we entered the input data into the DerivaGem_400 software (an add-in for the Microsoft Excel spreadsheet). Enter the desired input data, choose the "call" option corresponding to the desired "request" expression and press the "Calculate" key.

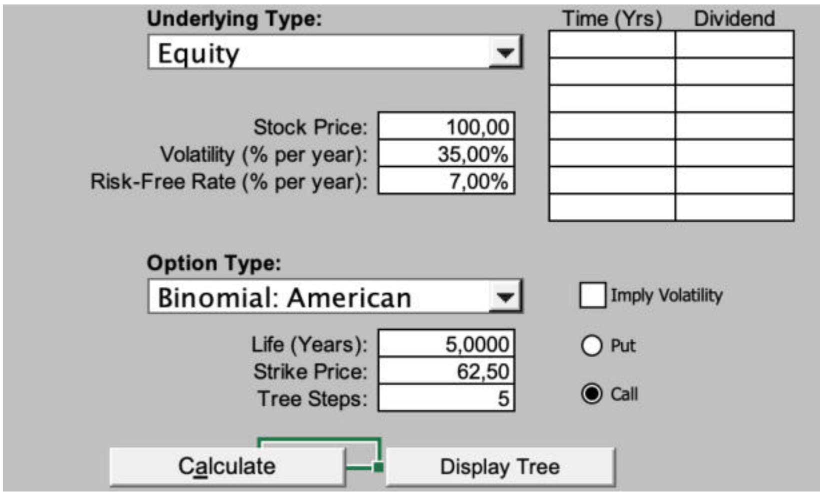


Figure 6.12DerivaGem software dialog box for entering input data

The software performs the calculations based on the input data and displays a button that displays the created binomial tree (Figure 6.12).

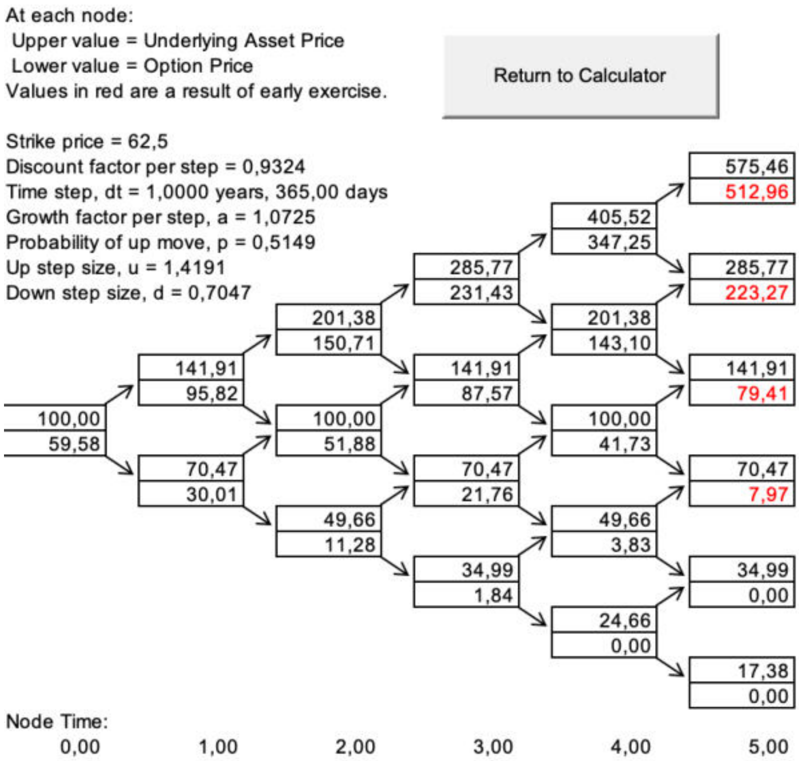


Figure 6.13Binomial tree for the expansion option

2A

100,00	141,91	201,38	285,77	405,52	575,46
	70,47	100,00	141,91	201,38	285,77
		49,66	70,47	100,00	141,91

34,99	49,66	70,47
	24,66	34,99
		17,38

Figure: 1.5 Evaluation of the 5-step expansion option (with Gem Derivative)

In the second step (the latex evolves this time from right to left) the expansion option is evaluated. It starts from the extreme right node 5A having the associated value of 1088.42 calculated from the expansion maximization condition and considering the cost of the additional acquisition:

1088,42=2*575,46-62,5 (6.4)

NPVE		2A	3A		5A
159,58	237,73	352,09	517,20	752,77	1088,42
Continue	Continue	Continue	Continue	Continue	Expand
	100,48	151,88	229,48	344,48	509,03
	Continue	Continue	Continue	Continue	Expand
		60,94	92,23	141,73	221,31
		Continue	Continue	Continue	Expand
			36,83	53,48	78,44
			Continue	Continue	Expand
				24,66	34,99
				Continue	End
					17,38
					End

At the intermediate decision node 2A the allocated value is:

201,38*2-62,5=352,09 (6.5)

This value is reflected in the calculation based on the weighted average option value resulting from the risk-neutral probability analysis and the open-endedness of the expansion option:

517,20(3A)*p+229,48*(1-p)=352,09 (6.6)

In the final node it results that for rf=7% the expansion project value with flexibility included NPVE = 159.58. From here the value of the option, interpreted as the flexibility value of the expansion strategy, is highlighted:

159,6-137,5=22,1 (6.7)

These calculations were performed for various values of volatility and risk-free rate resulting in the graphical representation of the project value with built-in flexibility in Fig...

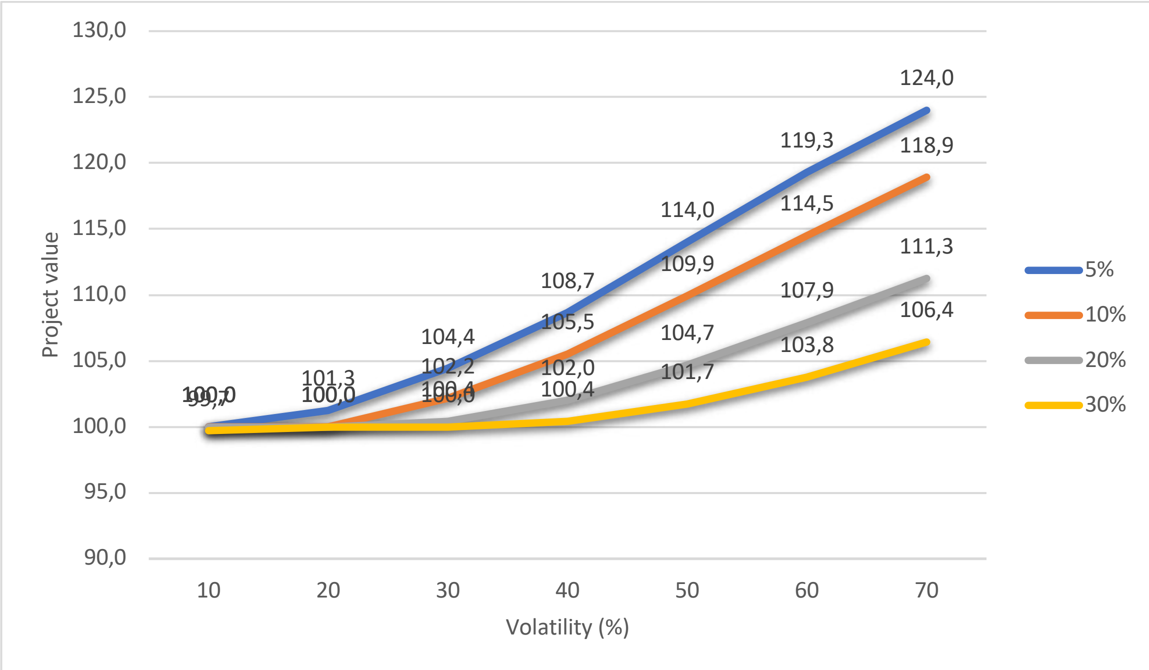


Figure 6.14: Isovolatility lines for the expansion option expressed as a function of various values of risk-free rates

Flexibility analysis in the case of the Abandonment option

Consider the normalised static value of the open architecture radiolocation systems investment project (as the sum of net discounted flows) and a duration of 5 years. The idea of deepening the abandonment decision is to implement an abandonment barrier of 2/3 of the normalised static value of the project.

In the first step (the evolution within the latex is in this case from left to right) the dynamics of the underlying asset represented by the S-value of the static project is evaluated considering as parameters: growth rate (u), decline rate (d), neutral probability (p).

$$U=1.35,\ d=1/u=0.7408 \text{ and } p=0.51 \qquad (6.8)$$

100,00	134,99	182,21	245,96	332,01	448,17
	74,08	100,00	134,99	182,21	245,96
		54,88	74,08	100,00	134,99
			40,66	54,88	74,08
				30,12	40,66
					22,31

In the second phase (the latex evolves this time from right to left), the abandonment option is evaluated considering profit maximization in the abandonment versus continuation variants.

		2A				
104,42	136,21	182,21	245,96	332,01	448,17	
Continue	Continue	Continue	Continue	Continue	End	
	82,28	102,63	134,99	182,21	245,96	
	Continue	Continue	Continue	Continue	End	
		69,72	79,72	100,00	134,99	
		Continue	Continue	Continue	End	
			66,60	66,98	74,08	
			Abandonment	Continue	End	5E
			3D	66,60	66,60	
				Abandonment	Abandonment	5F
				4E	66,60	
					Abandonment	

The value of the option providing protection against risk is also incorporated in the second latex. For the abandonment barrier of 2/3 of the static project value, in node 2A the associated value is 182.21, the project remains open and the investment is not abandoned.

It thus follows that by increasing flexibility, achieved by incorporating an option worth only 4.42, we have ensured that the risk of losses in lower nodes 5E, 5F, 4E, 3D has been eliminated. This highlights a simple and effective way of insuring risk at a very low additional cost.

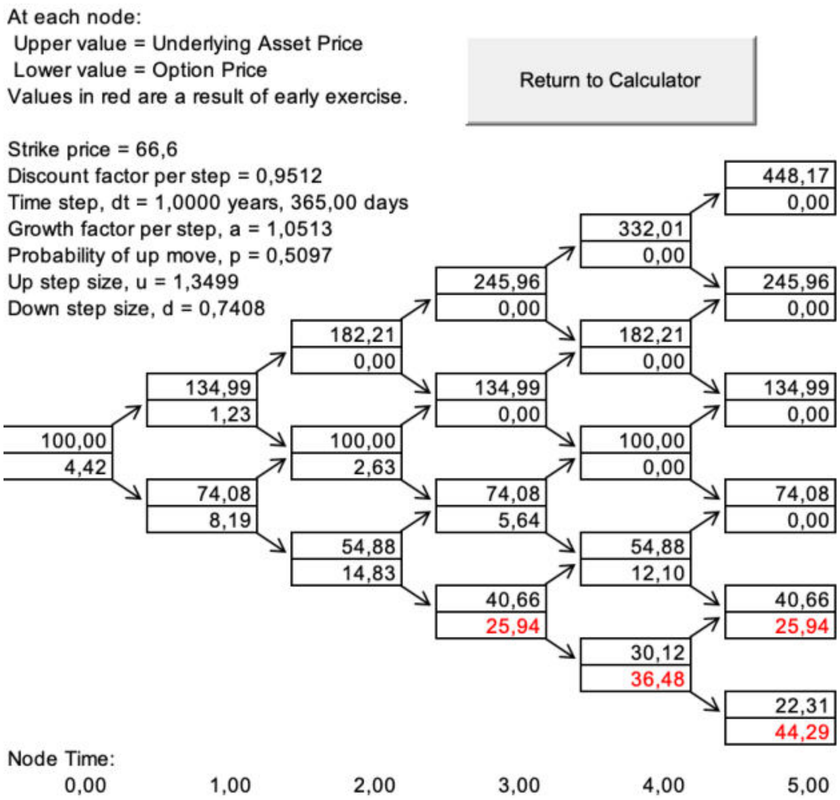


Figure:

These calculations were performed for various values of volatility and risk-free rate resulting in the graphical representation of the project value with built-in flexibility in Fig...

Results and Conclusions

Today's decision makers can leverage more advanced analytical procedures to make strategic investment decisions in radiolocation system architectures.

By integrating the real options paradigm, a novel way of assessing and understanding how strategic decisions are formulated has emerged. The application of the real options approach has revealed strategic solutions to increase the value of a project while managing risks. Expansion and abandonment options were considered, respectively, and calculations were performed for several sets of variables (volatility and risk-free rate). It has been shown that the application of real options also provides a new view on the dynamics of risk portfolios which is essential to improve strategic decision-making.

The contributions to this application are based on the implementation of the paradigm of real options for abandonment or expansion in the case of projects or investment programmes carried out under real conditions, in which the advanced uncertainty includes, in addition to the relevant set of technical-managerial elements, macroeconomic indicators representative of the external environment (volatility and risk-free rate). The static S-value of the projects has been normalised to provide the decision-maker with the overall picture in a quick and suggestive way; in this way it is possible to incorporate both the scalability of the results and elements of dynamics useful in case of extension of the research through composite options. Volatility expresses the dispersion of possible outcomes highlighting a multidimensional composite risk and has been tested for various values specific to the domain under consideration. The risk-free rate is a relevant macroeconomic indicator especially for the current environment characterised by high inflation and anti-inflationary measures expressed through restrictive monetary policies, with major impact on the design and implementation of major projects. The impact of volatility and the risk-free rate was analysed simultaneously for both the expansion and the real exit option. This contribution provides decision-makers with a quick but suggestive picture of how to build flexibility into projects and programmes in the areas under consideration, to ensure specific managerial adaptation in times of advanced uncertainty. This way of working with real options is particularly effective in the "VUCA" (Volatility, Uncertainty, Complexity, Ambiguity) environments specific to complex military systems.

Best practice solutions in performing maintenance: use of BodyCam, government cloud database with video acquisition of maintenance operations categorized by component equipment and Radiolocation systems

In everyday life and particularly in the professional environment, the concept of Lessons Learned and also Best Practices is increasingly used. Whereas in radiolocation systems maintenance, the working environment involves human interaction on the technical component, in what we have defined as SSTC.

Since 2017, Motorola Body Worn Camera (CVPC) audio-video devices for military use have been issued to police officers in territorial units. The aim of the project implementation of equipping police officers with CVPC was based on 3 important objectives:

- Production of evidentiary material for violations of the law found by the police officer,
- The production of evidence in the case of the offence of assault
- Achieving officer protection from false allegations of misconduct

Figure 6.15 Motorola CVPC from MAI

Technical characteristics CVPC, Motorola, VB400 series:

- 1920x1080P@30fps resolution, 1080p HD (2mp);
- Wifi 802.11 a/b/g/n (2.4GHz & 5GHz);
- 64GB storage capacity;
- Bluetooth monitoring sensor;
- audio: dual microphone;
- built-in GPS sensor;
- Li-Pol battery - up to 12 hours of operation;
- dimensions 68mm x 89mm x 26.6mm;
- weight 162g.

IMRMSRdlc project. (Improving Risk Management in the Maintenance of Radiolocation Systems)

In order to improve risk management in the maintenance of radiolocation systems, I propose the implementation of a project containing and using CVPC-type systems similar to those used by police officers within the MAI. The major goal of the proposed project is to identify factors in radiolocation maintenance that impact operational availability. In other words, the project aims to minimise the rate of occurrence of failures that may render radars in the national airspace surveillance system inoperative. This objective is based on the following important objectives:

- timely, qualitative and full-volume maintenance operations;
- ensuring data collection by the system by categories of radars and subsystems;

- the constitution of a database (like a black box - maintenance log) available for technical auditing in real time or later;
- storage of audio-video material on each individual system/equipment to keep a clear record of operations on the system/equipment;
- protecting staff involved in maintenance from technical audit staff who may have previously invoked the use of the platform, inconsistencies between the planning and execution of maintenance operations;
- identification of elements of risk by omission/commitment by personnel involved in the maintenance of radiolocation systems;
- creation of a teaching base for training technical staff in educational institutions/specialisation courses;
- producing a map highlighting critical equipment/sub-assembly/facility failures leading to operational unavailability of radiolocation systems;
- the constitution of repair packages for critical elements in radiolocation systems;
- decision-maker decision-making related to risk management.

The project involves going through the proposed phases in turn:

Pre-phase

involves collecting data from the territory, categorizing equipment by degree of interest and importance in terms of operational availability, categorizing maintenance staff by level of training, creating the IT application, system organization chart and determining the attributes of the staff involved in the project, writing the project, simulating the project run, conducting feedback loops with specialized staff, correcting identified gaps, finding project financing options, proposing and supporting the project to the beneficiary for approval and implementation.

Table 6.1 Correspondence between the complexity of the operation and the skill level of the maintenance staff

Degree of complexity of the operation	Qualification level of maintenance staff	The need for remote auditing	Restrictions
Very complex - operations provided by the manufacturer	N0 - operators designated by the manufacturer	Optional at the discretion of the field team	Operators N3 and N2
Complex -	N1 - manufacturer certified operators	Optional by the manufacturer's support team YES for lower level operators N2	N3 operators
Environment	N2 - operators trained and certified by op.N1	Optional by technical audit specialists level N1 or N0 YES for N3 operators	

Easy - current operations	N3 - operators trained and certified by op.N2	On request by senior technical audit specialists level N2	

Implementation phase

is carried out in parallel in several directions:

- **a.** Establishment of a technical committee to draw up the project implementation guidelines and to categorise operations according to the type of equipment and responsibilities of the staff;
- **b.** The implementation of the material base involves the purchase of CVPC devices, the labelling of work areas based on the categorisation of the technical committee;
- **c.** Training of personnel for the use of CVPC systems in the correct use of CVPC devices, registration in the platform and saving the record of the maintenance operation performed;
- **d.** Implementation by the designated IT team of the platform with files and folders, hosted by the Government Authority specialized in the cloud area with the possibility of access according to the access level of users and administrators,

Unwinding phase

of the project involves audio-video recording of maintenance operations. This phase requires maintenance personnel to switch on the CVPC device, i.e. to start recording on the device. From this point on all data will be recorded at the device level in the storage space (needing to be uploaded to the platform later) or if the more complex operation requires real-time technical auditing, live transmission can be achieved using the Wifi feature of the device.

The operator designated to perform the maintenance operation shall log in to the IMRMSRdlc platform. with the unique data and starts the maintenance work according to the schedule and standard sheet. On the basis of the GPS data and the authentication data, as well as the QR code of the equipment and the standard maintenance sheet, the system to be serviced is identified, the planned operation is certified and it is also recorded in the equipment maintenance logbook. The live technical audit is carried out in fortuitous cases and is intended to provide remote assistance to technical staff who have a lower level of training than the operation to be carried out.

Technical audit phase

is designed to meet requirements on several levels, two of which are essential. The way in which audited operations are chosen can be:

- The PARETO model, by identifying the 20% most common events;
- Following a pre-established schedule;
- at random (random function);
- to the referral of an operator's activity;
- by categories of systems.

We have previously defined that the data is recorded and saved in such a way that the operation can be identified at the IMRMSRdlc platform level. both as a sequential operation at an equipment level and as a subassembly-specific operation. In this way an analysis can be performed at the platform level to identify several aspects:

a. On the other hand, based on the overall system analysis, when identifying the failure of a critical sub-assembly in a radiolocation system, the technical audit committee has at its disposal the maintenance records of all systems in a designated category. This can identify the causes and nature of these (e.g. it can identify whether that sub-assembly is operating at full volume or with the appropriate tools or materials, and therefore identify errors of omission or commission). Conclusions and decisions can be drawn from this type of technical audit:

- to improve the standard maintenance file at that subassembly level;
- specific training of staff strictly on that operation;
- to categorise the operation to another level.

b. A second scenario is the critical failure of a radionavigation system, with the system being taken out of operational readiness, and the chain of maintenance operations carried out on the system is followed to identify the causes of the failure (similar to the investigation of the black box in aircraft). The conclusions of the technical audit committee report can form a package of measures for other radars of that type in service.

An extremely important aspect of this audit phase is the feedback loop, which plays a defining role in the development of the IMRMSRdlc platform. and therefore its resilience.

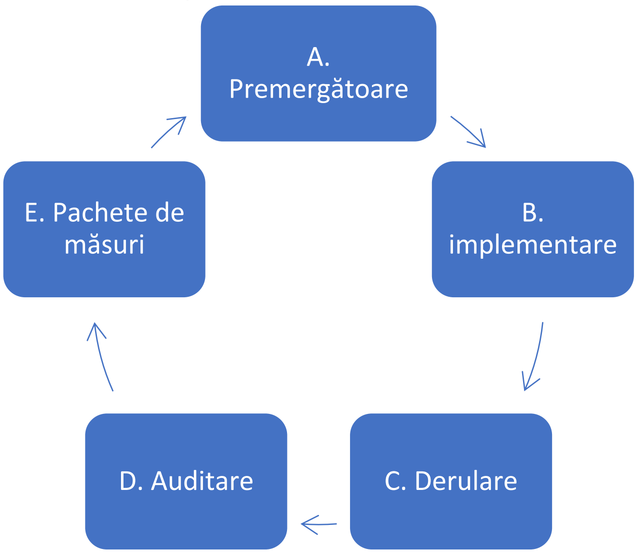


Figure 6.1 Stages of the IMRMSRdlc project.

Advantages and disadvantages of the platform:

ADVANTAGES of the platform:

- Real-time identification of risks that may arise due to human errors of omission or commission, using reduced staff in audit committees,
- protecting staff involved in maintenance from technical audit staff who may have previously invoked the use of the platform, inconsistencies between the planning and execution of maintenance operations

- achieving correct standardisation of maintenance operations with visible effects on the working climate of staff, which will reduce the likelihood of risks caused by the human factor,
- awareness by maintenance staff of the importance of following all the steps in the standard maintenance sheet,
- to get an overview of the failures that may imminently cause a system to be out of operational readiness with a negative impact on the national air surveillance system,
- to establish a solid database for identifying maintenance deficiencies in radiolocation systems, which, if properly exploited, can make recommendations to the system manufacturer.

  Disadvantages of the platform:

    - Project implementation costs
    - Resistance to new from the staff involved in the project, leading to additional operations,

Challenges and future directions: Betting on the future - Artificial Intelligence in risk management in radiolocation systems maintenance

To understand what AI can change in our lives, Professors Yolanda GIL and Bart SELMAN have mapped out the AI development directions for the next 20 years. The authors anticipate that AI will reduce health care costs, personalize education, accelerate scientific discovery, help the national defense system, and more.

In the section on digitisation and identifying barriers to AI implementation, we concluded that AI, although so much in the news, is to a small extent embedded in business and society.

Partial conclusions

7 CONCLUSIONS, CONTRIBUTIONS, FUTURE DIRECTIONS, MANAGERIAL IMPLICATIONS

Conclusions

Electronics, electrical engineering and later radiolocation, were for me areas of soul and interest. The radiolocation system is defined as a complex socio-technical system for whose proper functioning the personnel specialised in its maintenance is responsible, with the fulfilment of the tasks set out in the technical data sheets and technical documentation of the equipment. This dual interaction of the human factor with the technical system is not without potential risks whose causes cover a whole spectrum.

The PhD thesis, **Risk Management in the Maintenance of Radiolocation Systems,** was a challenge to identify, interpret and associate the inherent risks and to seek viable solutions to mitigate and limit the causes of their occurrence as well as their effects, represented by personal injury, loss of life and/or material loss. The essential purpose of radiolocation systems is the 24/7 surveillance of the airspace in the area of responsibility. These areas of responsibility overlap so that this complex architecture can be analysed as a system of systems. Operational availability is the main desideratum, the lack of which causes breaches in the area of responsibility, which is identified as a vulnerability of the air surveillance system. Therefore, having identified these possible shortcomings, I have chosen to analyse and address in the pages of this thesis, issues that cover the whole range of situations, from the basic level represented by the radiolocation system, to the higher level represented by the decision maker responsible for the system of systems architecture, design, acquisition, deployment operation and decommissioning of the systems. The personal contributions have been translated into proposals to improve risk management so that the working environment becomes safer, the stress component decreases, with the ultimate goal of maintaining the operational status of the radiolocation systems in service with minimum resources.

Operational availability must be ensured under all conditions. **The current context of** regional insecurity, multiple crises (health, geopolitical, resources, supply chains, semiconductors, personnel dynamics, technological evolution, etc.) puts additional pressure on the radiolocation system and in particular on the personnel involved in the operation and maintenance of the systems.

The proposed research topic fits into the general picture of risk management at the level of socio-technical systems that concern flight safety. In a detailed search, we identified research on the human factor and the performance of pilots and air traffic controllers, but we did not find any relevant analysis of the risk management of the maintenance of radiolocation systems and the personnel who perform it. From the research carried out we identified that risk management is treated and analysed at the level of corporations and multinational companies at a rather high level. However, the analysis from this perspective of risk management in specialised, niche areas such as the maintenance of radiolocation systems is not sufficiently addressed, and this has aroused my intense interest.

The topic of the thesis is **of particular topicality and importance** due to the need to ensure permanent operational availability of radiolocation systems in the perspective of the regional conflict Ukraine - Russian Federation, Romania being on the NATO border. The thesis deals with current issues of risk management in the context of multiple crises (resource crisis, supply chain crisis, generation change crisis, semiconductor crisis) by addressing the use of flexibility as a tool for real options in the process of deployment and maintenance of radiolocation systems. Throughout, the thesis arouses interest, with the way the case studies are treated reinforcing this belief. The approach is progressive, from integrated implementation of preventive maintenance in radiolocation systems, to database implementation and enrichment solutions, to sampled technical auditing of the actions of maintenance staff, culminating in the use of innovative AR (Augmented Reality) and IoT (Internet of Things) tools. To clarify the concepts we have concisely formulated the identified problems and proposed solutions. The multidisciplinary and interdisciplinary nature of the thesis makes it stand out in the literature as a good tool for personnel performing maintenance as well as those implementing solutions to reduce risks in radiolocation systems.

Whichever way we look at a given field, it comprises the academic/academic area, the fundamental research, development and innovation area and obviously the practical/applied area, which is close to industry. These areas do not have clear demarcations, but coexist in an ecosystem that aims at stability and continuous operational availability on the one hand, and **scientific progress** and continuous development of the field on the other. The academic area, that of training future radiolocation specialists, has a clearly determined role in motivating and training young people, putting all material and knowledge resources at the service of those who are the future pioneers of radiolocation. The research, development and innovation area uses specific methods, techniques and tools to respond to contemporary and future challenges. The practical/application area provides the material and technological resources to implement the products of research and innovation.

Today's scientific context, as in any field, is in constant flux. A clear picture, by conducting the literature review in the second chapter of the thesis, highlighted authors with interest in the field of risk management, methods and tools used in risk management in industrial processes and in the maintenance of equipment, systems, as well as the fields in which they are applied (aviation, marine, nuclear, etc.). In the light of the results obtained, we have shown that it is appropriate to abandon reactive or corrective methods in carrying out risk management and to adopt instead the methods most suited to the current context, namely predictive and interactive methods.

Also, in order to achieve a picture as close as possible to reality, to narrow the gap between the theoretical component of the literature and the practical one in the operational working environment, I have developed, applied and analysed a questionnaire whose products have directed my research to identify and propose solutions that can improve the maintenance of radiolocation systems and thus optimise risk management in the field of interest. Again, the identification from open sources of the maintenance needs of equipment in radiolocation systems is without doubt the most truthful and current resource and impetus for research. We have identified that there are launched public tenders seeking partners for the supply of spare parts and sub-assemblies of the composition of the TPS-79(R) - Gap Filler radars in the amount of $ 82,060.00 (January 2016), for the provision of repair service type Repair and return of defective equipment specific to the TPS-79(R) - Gap Filler radars (January 21, 2019) with an estimated price of 201,898,153.94 lei, equivalent at that time to $ 48,000 (**Error! Reference source not found.**.

Contributions

In order to adequately cover the chosen topic, we have broken down the above-mentioned general objective into operational objectives for a step-by-step treatment of the research topic.

First contribution. We have identified/mapped, through the products of a dedicated questionnaire, the situations and needs of colleagues specialising in the operational environment and the systems they support. Also at the same time we checked the visibility of radiolocation systems, we identified from open sources, the specific radiolocation maintenance issues reported by dedicated institutions. We found the most important risks reported: ionising radiation, electrocution and logistical problems of rapid supply with spare components and accessories.

The **second** very important **contribution** is the analysis of the literature and implicitly the identification of works with specific applicability to the chosen research topic. In the analysis we used the Web of Science and Scopus tools to filter and select the documents relevant to the thesis topic. The results of these analyses materialized in the categorization of techniques and models used in maintenance and authors dedicated to this field. Another important result of this literature review is the common areas treated in the literature:

- Methods to identify latent errors or latent factors
- Human-machine interface interaction
- New taxonomy or revision of an old taxonomy
- Impact of lack of knowledge or awareness

An important remark is that nowhere is the risk of **sabotage** identified and treated. That is why I have chosen to refer to this element in the chapter on monitoring the maintenance operator's activity via the CVPC.

A **third major contribution** was the identification of the events recorded and the causes that led to their occurrence and the measures/actions that were taken. Following the model of the analysis of aviation events, to identify these events we have resorted to travelling in the territory and collecting information of interest. We have thus identified a particular problem of the structure of the platform on which the antenna is positioned at a type of radiolocation station, as well as an adjacent problem related to the intervention procedure in gusty or very high wind speeds. We also found that the measures outlined as tasks did not fully cover the problem. As a solution, we proposed to reinforce all the pedestals or to cover them with specific RADOM-type protections, or to equip them with vibration sensors for predictive identification of shocks caused by wind gusts or bearing wear. Another solution in this respect was to equip with dedicated weather stations, or to couple to a pre-existing dedicated system with the possibility of emergency shutdown of the radiolocation station and moving the antenna to a free position for minimum wind resistance.

The **fourth contribution** is that we have identified the gap between what is regulated by the technology sheets and technical documentation of radiolocation systems and the reality in the operational environment, where the rules are not always followed and the pressure of the situation and logistical shortcomings create the conditions for accidents. The proposed solution was to equip and implement a system for recording the interventions carried out on the system, with the possibility of remote expert technical auditing. Strategic benefits can be achieved through this system. I name some of them: identification of latent problems, evaluation of inappropriate decisions, prioritisation of actions, improvement of execution timing, implementation of change processes.

The fifth personal **contribution** is a concept for integrating predictive maintenance at the level of rotating elements. For this project I have designed, implemented and tested a 2D experimental test stand (in the Laboratory), suitable for ground based radiolocation systems, integrating industry components (motion transducers, PLC, software component) to identify vibrations in moving elements. To perform the rotational motion I used a teaching radar from the radiolocation laboratory of the institution where I work as a senior instructor - the Air Force Academy "Henri Coandă". During the study I carried out simulations and treated 2 problems:

- Identification of bearings in ECU systems that will require maintenance in the immediate future; the method consists of measuring and monitoring the variation in vibration levels due mainly to mechanical wear,
- Identification of shocks in the radiolocation system antenna, caused by wear of the rotation bearing or unfavourable weather conditions with strong or gusty winds; the proposed solution, once integrated, is able to warn the service personnel that there are problems in the antenna, and if necessary, in case of emergency, it can perform automatic stop of rotation and leave the antenna free for minimum resistance. We have achieved this by setting threshold levels: Warning (Yellow), Major fault (Red) translated into an antenna rotation stop command.

The sixth contribution is that we have designed and implemented a vibration measurement concept in 3D conditions (real conditions) for simulating flight effects on radiolocation equipment on board airborne vectors. The recorder consists of an Arduino UNO board, GPS sensor with antenna, Time Base (RTC), 3-axis acceleration detection and measurement sensor, SD memory card interface. The results obtained and interpreted provide the necessary elements for implementation/transfer to the beneficiary through a pilot programme.

The seventh contribution with the aim of modelling human factor risks is to propose a concept in which maintenance work is recorded using BodyCam/AR Glasses. These recordings allow the constitution and development of a database of maintenance operations footage, classified by systems, saved in the government cloud with privileged access to technical audit teams. Based on this and other indicators I believe that the human reliability analysis component can be scalably and modularly integrated.

The eight contribution I made was in scenarios using the specialized DerivaGem and CrystalBall software. With their help we have demonstrated Flexibility Integration as a tool to increase the implementation capability of projects associated with technological change impacting the maintenance (technical and human component) of radiolocation systems. Current decision makers can leverage more advanced analytical procedures to make strategic investment decisions in radiolocation system architectures. By integrating the real options paradigm we have highlighted a novel way of evaluating and understanding how to formulate strategic decisions. By applying the real options approach we have highlighted strategic solutions to increase the value of a project while managing risks. Expansion and abandonment options were considered, respectively, and calculations were performed for several sets of variables (volatility and risk-free rate). We have shown that the application of real options also provides a new view on the dynamics of risk portfolios, which is essential to improve strategic decision-making.

The new contribution is the development of an integrated set of decision-making tools based on guidelines/steps to achieve best practice in the maintenance of radiolocation systems. We highlighted the need to move from static (cause-effect) models to dynamic (adaptive, resilient, cyclic) IT-assisted models. This contribution is also a future research direction. The proposal I am making is at this point ideational and represents **a bet with the future**. I strongly believe that in the not too distant future, based on an analogy with the STEM cell sampling model, the records proposed in the previous contribution will represent the data base, already collected, necessary to develop an Artificial Intelligence dedicated to the maintenance of radiolocation systems and implicitly to their risk management.

Research methodology and development of the thesis architecture

In writing this thesis I have used a panoramic, overview approach characteristic of leadership, but where I felt that the situation required it I have made it concise. I have integrated conventional techniques and methods specific to the field under consideration, but also innovative models to make up for missing data or elements at the confluence of the technological and human factors. The studies carried out are scientifically relevant because of their bold approach to concepts specific to change management, maintenance management and project management under uncertainty. Proposals for upgrading mechanical components, vibration analysis on two platforms, flexibility analysis as a tool for real options and implementation of innovative technologies, give value to this thesis.

The results obtained through the analysis of flexibility as a tool to increase the implementation capability of projects associated with technological change have a significant impact on the efficiency of the maintenance processes of radiolocation systems. Adaptation through increased flexibility is analysed using the real options of expansion and abandonment respectively and provides insight into the decision-making process, i.e. benefits related to risk reduction under technological change and uncertain multi-crisis environments. Also the results obtained from the acquisition and processing of vibration data as well as best practice proposals make substantial contributions to the operational environment. The treatment of the objectives in the described manner gives the thesis originality and innovative character, succeeding in arousing the interest of specialists as well as researchers in the field.

We used modern tools in the study of the research topic: VOSviewer for literature filtering, specific devices used in industrial engineering and autonomous airborne vector systems, software for data analysis and interpretation, comparative analysis useful to be integrated in the field of maintenance of radiolocation systems.

The information obtained from the case studies, the applications and the analysis of the questionnaire and the literature was presented in an easy to interpret and understand manner. These results can be a starting point for future studies as the proposed methods are scalable. Both the literature, transparent information from open sources, and the basic interests and needs in the operational environment were explored in depth and formed the basis for personal studies and contributions.

Dissemination of research results (Annex) includes the publication of 5 BDI articles and 1 ISI Proceedings article at 35th IBIMA 2020 on the topic of the research area. In the thesis I used my practical experience, methods from engineering and management as well as methods from statistics. The thesis is organized in 8 chapters and related appendices with the role of completing the picture made in the chapters. The approach of the thesis is interdisciplinary but also multidisciplinary and the objectives are anchored in the specificity of the treatment of radiolocation systems in Romania.

The integration of all the applications, case studies, analyses and applications carried out and demonstrated, I believe, have brought clarifications in the field and provide effective and feasible solutions to improve risk management from the perspective of maintenance of radiolocation systems in the context of disruptive technological change and the current multiple crises, resulting in: reducing the number of events causing injury or even death of personnel, reducing the effects of risks, implementing new solutions in radiolocation systems and making the most appropriate decisions by decision makers.

Multidisciplinary involvement in projects

National projects

In the framework of the grant scheme Digitizing Universities and Preparing them for the Digital Professions of the Future, funded by the National Recovery and Resilience Plan, the Air Force Academy "Henri Coanda" Brasov, participated with the project F-PNRR-GDU-1-2022-0073, ministry code 1357725267. The project was declared eligible and appears on the 6th position in the intermediate list of eligible/non-eligible projects.

I am part of a project team coordinating, developing and deploying special purpose UAVs, FLIR sensors, GPS with the benefit of special operations forces elements.

International projects

Active participation in the Erasmus+ DDHE project

PROJECT
IMPLEMENTATION OF DIGITALIZATION IN DEFENCE HIGHER EDUCATION (DDHE)

Source of financing	European Commission / Erasmus+ / The National Agency for Community Programmes in the Fields of Education and Vocational Training
Project type	KA 226 - Partnerships for Digital Education Readiness in the Field of Higher Education
Number of contract	2020-1-RO01-KA226-HE-095411
Total funds	**137740 Euro**
Project period	01.04.2021 – 31.03.2023
Manager of the project	Assoc prof. eng. Ecaterina Liliana Miron, PhD
Involved universities	**Coordinator:**- "Henri Coandă" Air Force Academy, Brasov, Romania **Partners:** -Vasil Levski National Military University, Bulgaria -Hellenic Air Force Academy, Greece -War Studies University, Poland

- Project summary
- Project ativities
- Website

Implementation of Digitalization in Defence Higher Education (DDHE)

Through the KA2 action of the Erasmus+ programme, joint study modules have been created to standardise the curriculum on specialised programmes in the defence system, including mobility placements for students and teaching staff. Learning modules set up before the pandemic period had a complementary role to F2F teaching. On careful research it was found that the major drawback of these modules is that the teaching/learning methods are not adapted to the pandemic situation. As a result, AFAHC, together with its partners, proposes a solution to at least partially eliminate the classical format of teaching materials designed for the modules.

Why is this project proposed at transnational level? To continue the completed project

in 2018 by AFAHC and partners, but also to continue the process of standardisation of competences, for each specialty, at European level. An additional reason for designing this project is the pace of development of technical systems used in all fields of activity and their digitisation. In order to achieve the aim of the project, which is to increase the level of student training by updating teaching/learning methods to the current context, and following the needs analysis in the partner academies, the following partial objectives have been set:

- Raising the level of digital skills of teachers in partner universities
- Increasing student engagement and attraction to the research process
- Introduction of digital educational resources
- Presence and introduction of VR and AR systems in all teaching/learning processes
- partner universities
- -The establishment of a library where all project materials can be found

The results obtained make the two categories of project participants, the target group and the beneficiaries, merge to a large extent. Throughout the project, colleagues (teachers and students) from European organisations will be involved, mainly in the dissemination process, at different stages in order to achieve a high level of impact at international level, but also a high transferability rate of the project results.

A correct and successful project development contains stages of design, implementation and evaluation, dissemination. In line with the project objectives, through the categories of target groups, the following activities were considered:

- Design of educational resources in digital format for 12 technical and humanities subjects
- Design/develop VR/AR applications for the established disciplines, according to their profile and specificities. These applications are suitable for technical subjects that include practical lessons.
- The introduction of all educational resources in a digital library with free access to the project universities and their partners in the future.

Personal contributions to the projects involved

As part of the Implementation of Digitalization in Defence Higher Education (DDHE) project we developed digital content for the Radar Fundamentals subject with progress assessment and interactive, engaging elements created with eXe_learning software. The materials consisted of 10 lectures and 7 applications that will be made available to students at the institutions involved.

Under the Digitising Universities and Preparing them for the Digital Professions of the Future grant scheme, funded by the National Recovery and Resilience Plan, we designed the architecture of the radiolocation and electronic warfare lab with modern equipment, Chrome Book consoles, dedicated RF software, large interactive display.

Active participation together with Mr Sebastian POP and Mr Cătălin CIOACĂ in a program for the development of UAVs with special purpose, FLIR sensors, GPS.

ORIGINALITY

The focus of the thesis is on practical applications of a unique nature, case studies based on discussions with specialist colleagues in the field. An element of originality is the development of the questionnaire applied to radiolocation specialists, which they themselves declared. One of the questions in the questionnaire addressed this very issue. 83.3% of respondents selected that they were NOT aware of or had NOT participated in such a project dealing with the subject.

FUTURE RESEARCH DIRECTIONS (on the research boundary)

The products resulting from the measurements for the rotating elements - rolling bearing and ECU bearing vibration analysis - carried out on the test bench and the Arduino UNO-based system on board the glider, offer the possibility of knowledge transfer to the beneficiary. The implementation of these projects will be further developed in all Air Force aircraft.

A future direction of research may be the development of questionnaires and their regular application to bring decision-makers closer to the pragmatic situation in the operational area.

Using HoloLens glasses for AR visualization as well as creating AR items requires more refined and up-to-date equipment.

Another future research direction is the implementation of CVPC body devices in test teams. Software platform development in government cloud server is another future research direction.

DISSEMINATION OF RESULTS

The dissemination of the research results includes the publication of 5 BDI articles and 1 ISI Proceedings article at 35th IBIMA 2020. Starting from the honest recognition of the limitations of the research, the PhD candidate proposes as future research directions the implementation at national level in all the structures of the national air surveillance system as well as extended to the specialized structures of the alliances of which Romania is part.

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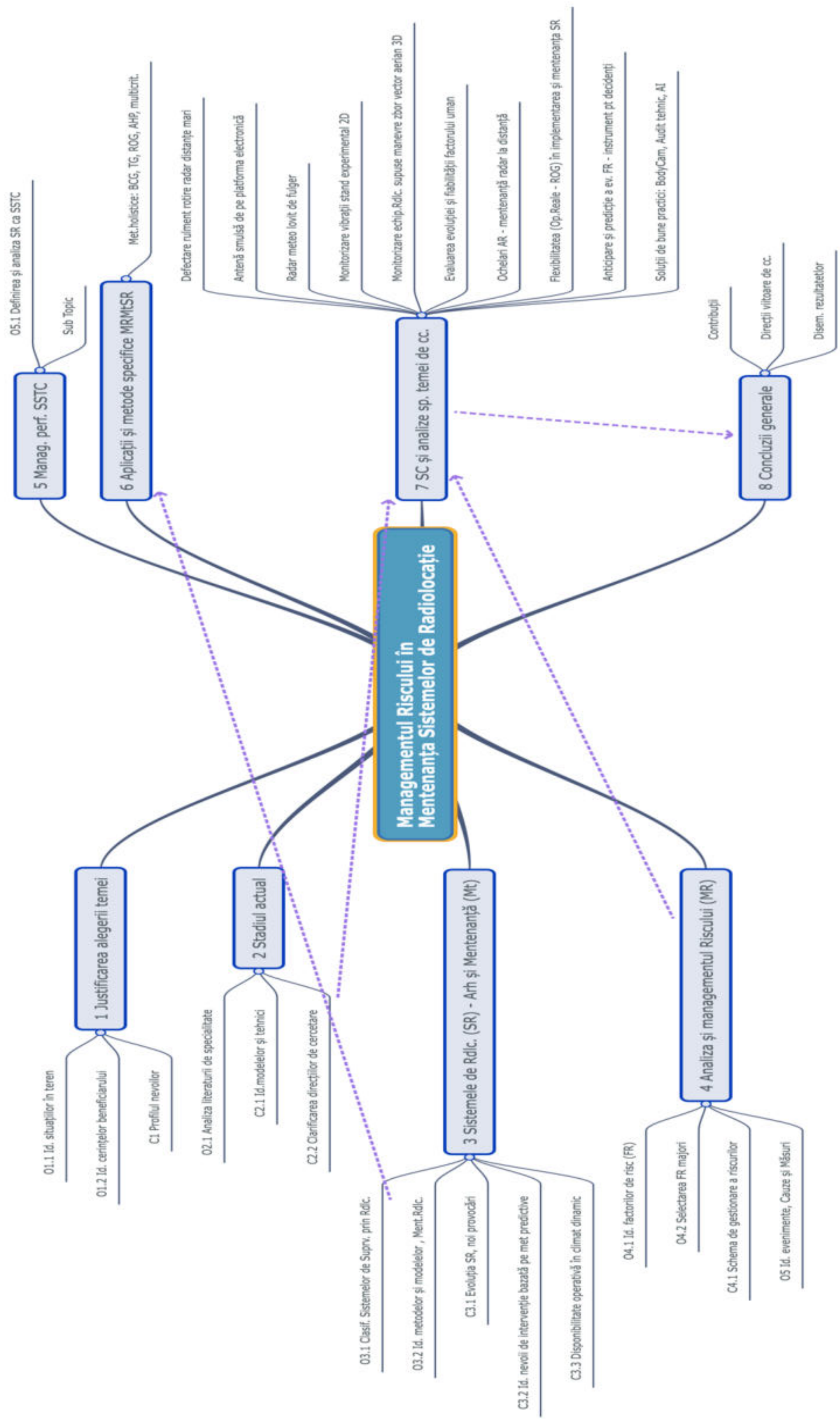
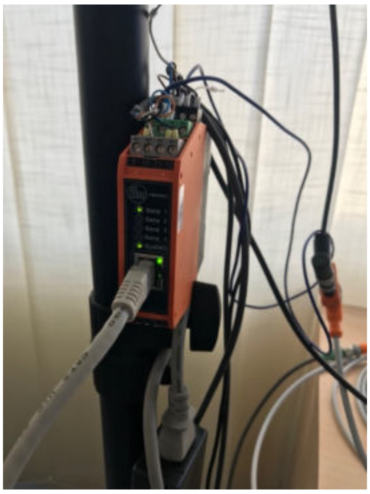
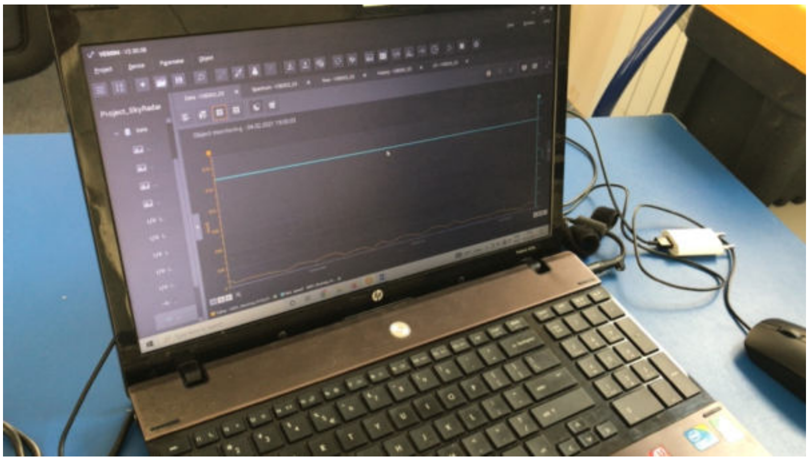
ANNEXES

Annex 1: Thesis architecture: Relationships between objectives and contributions

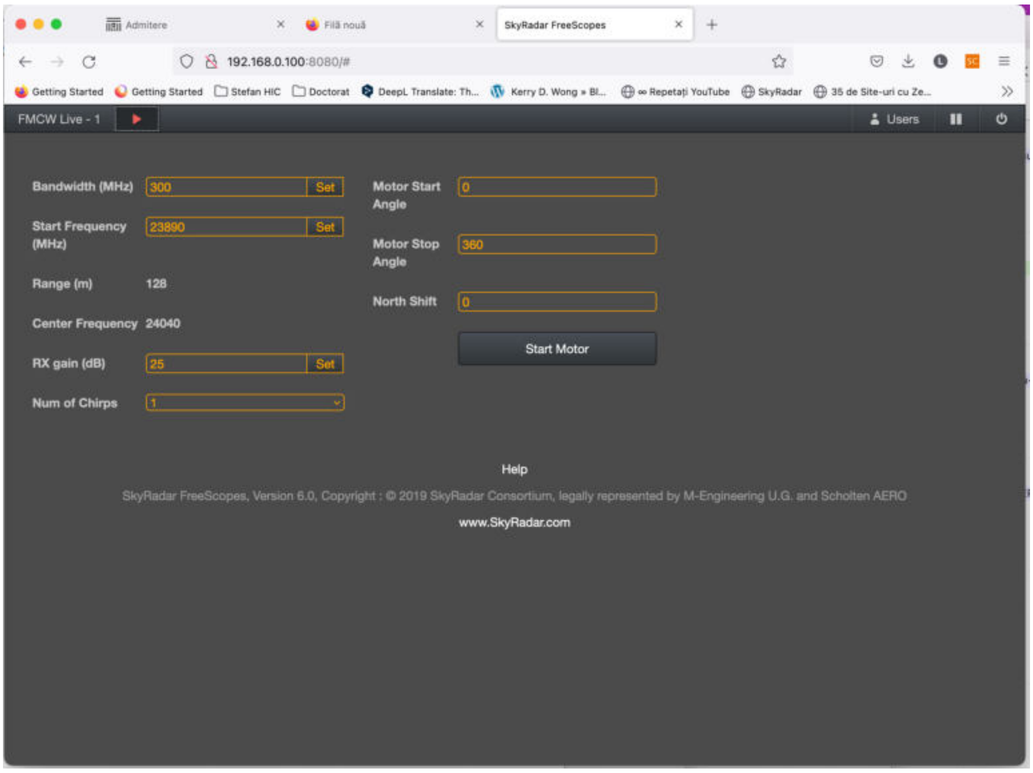


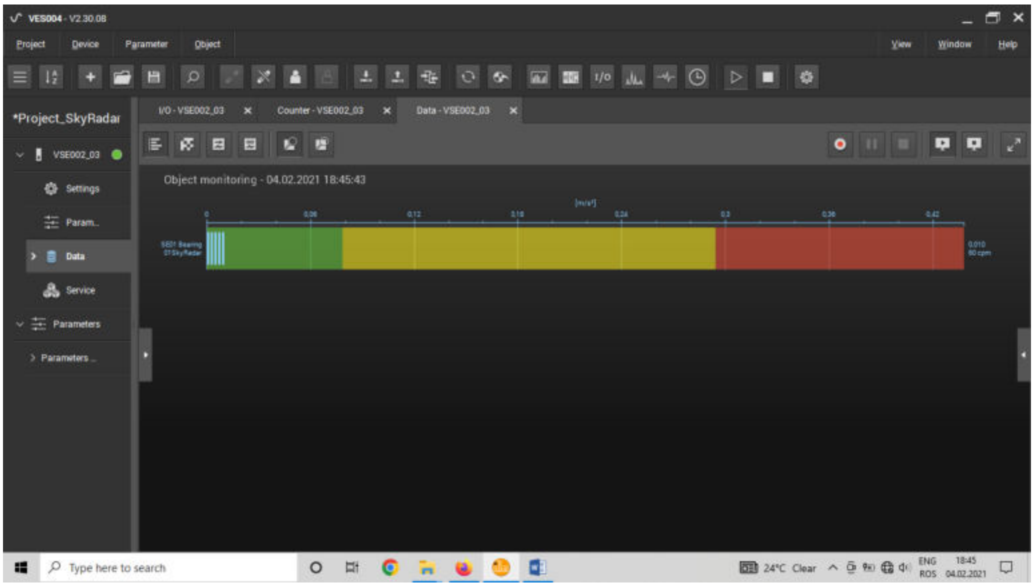
Annex 8: Experimental vibration measurement stand

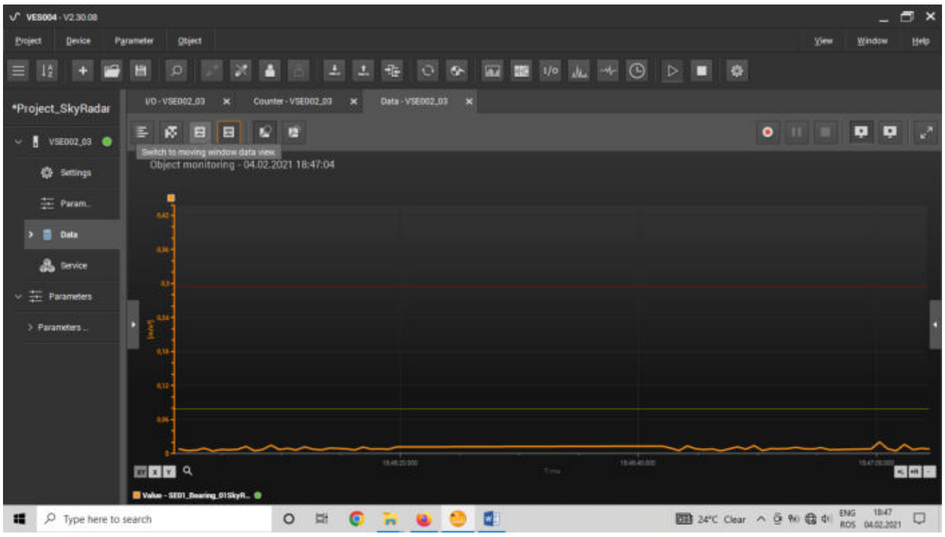


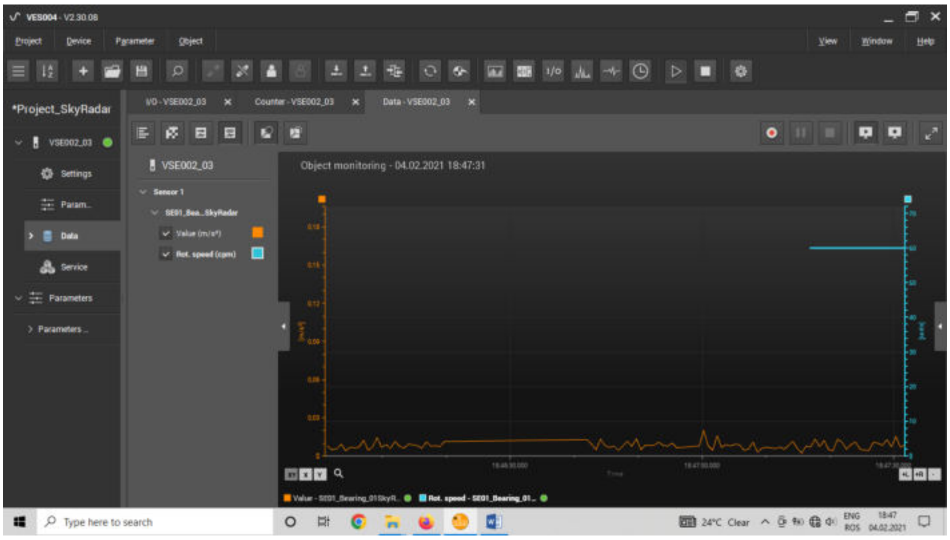


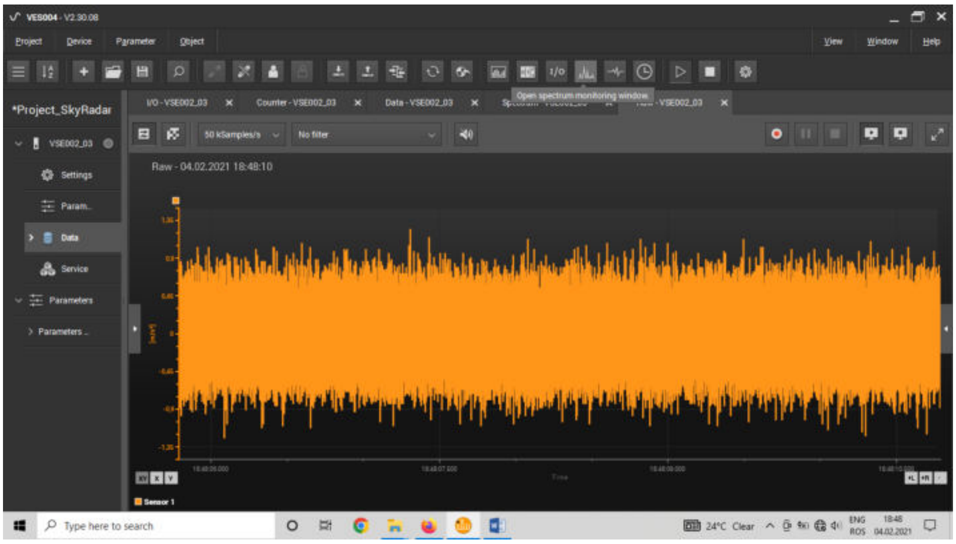
Appendix 9: Screenshots IFM Software VES004 v2.30.08 during the execution of vibration measurements on the experimental stand

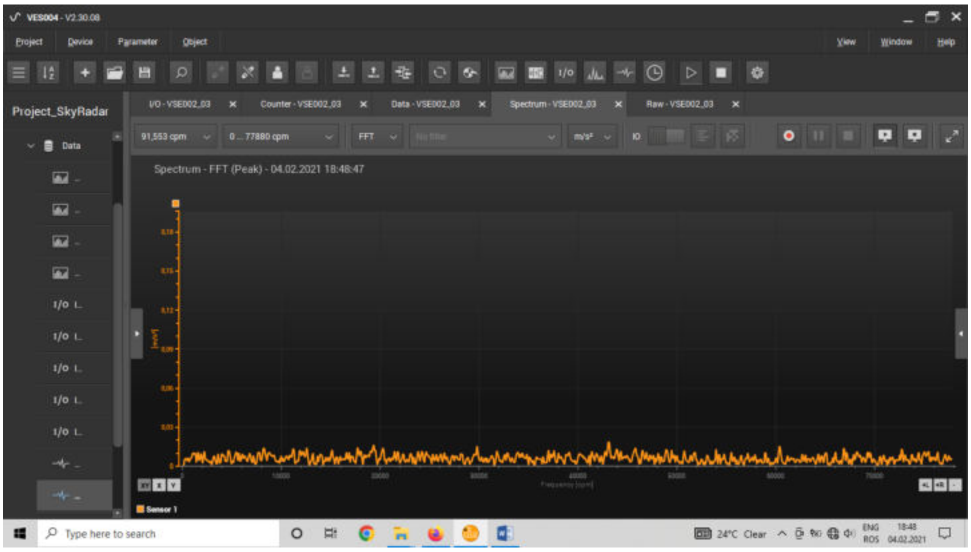


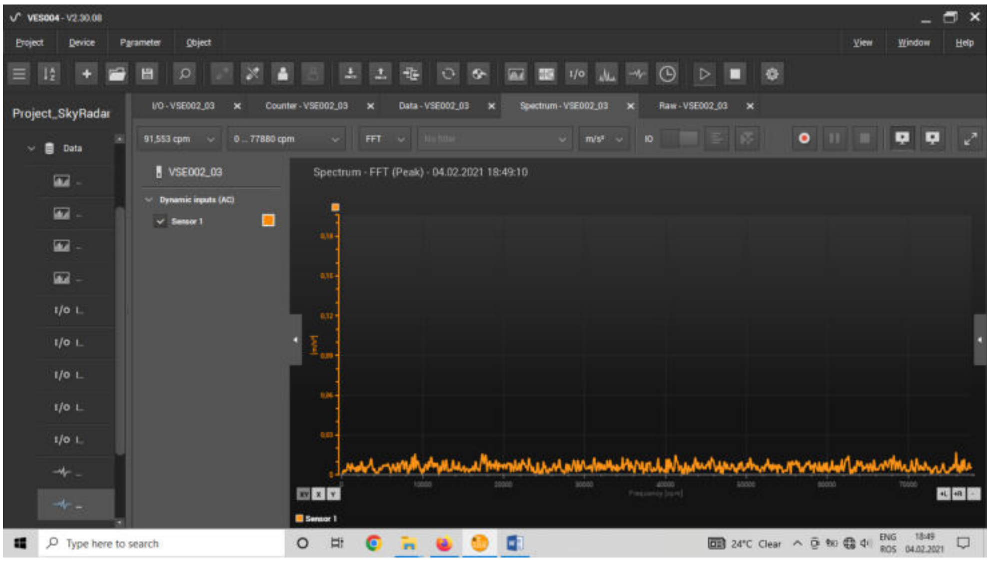


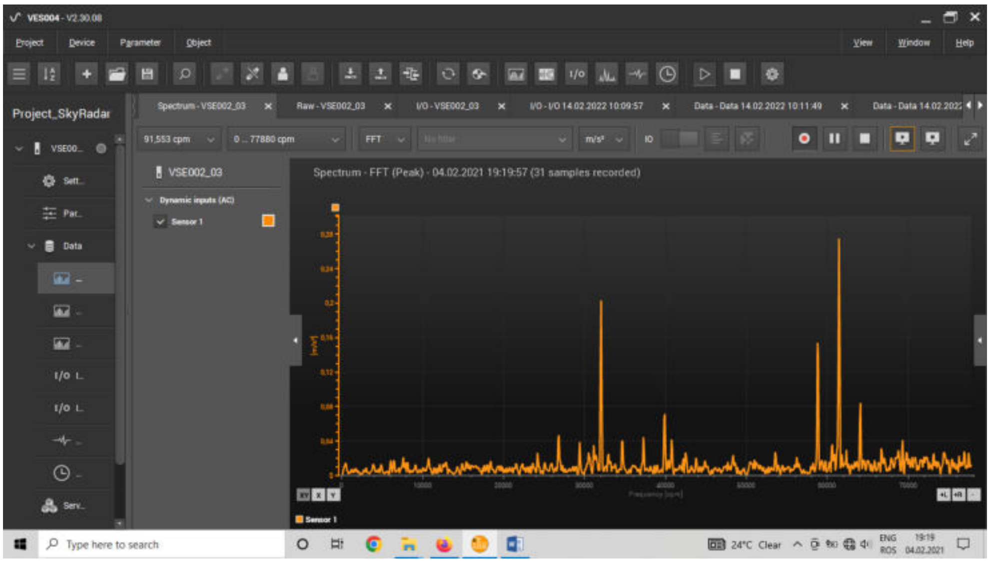

VES004 - V2.30.08
Project Device Parameter Object
View Window Help
*Project_SkyRadar
VSE002_03
Settings
Param..
Data
Service
Parameters
Parameters ..
I/O - VSE002_03
Counter - VSE002_03
Data - VSE002_03
Switch to moving window data view
Object monitoring - 04.02.2021 18:47:04
Value - SE01_Bearing_01SkyR..
Type here to search
24°C Clear
ENG
ROS
18:47
04.02.2021

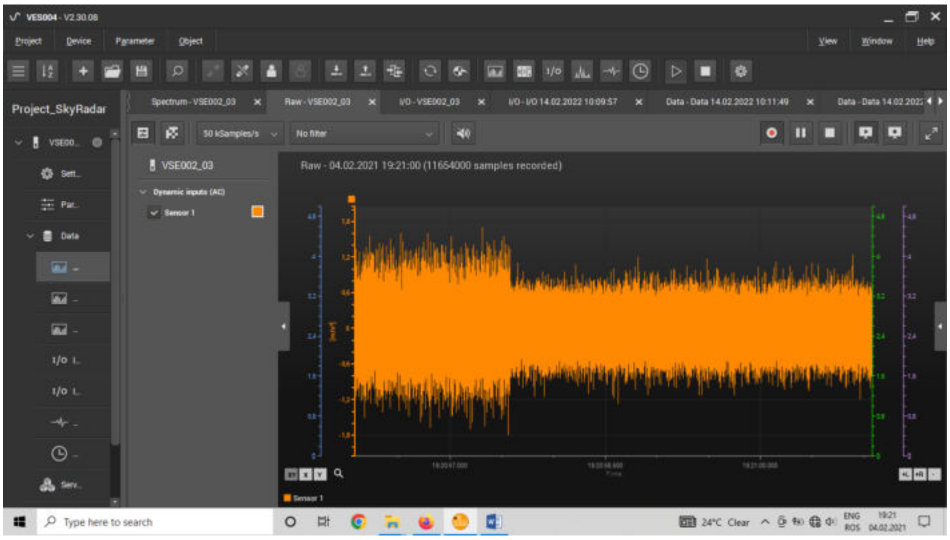

VES004 - V2.30.08
Project Device Parameter Object
View Window Help
*Project_SkyRadar
VSE002_03
Settings
Param..
Data
Service
Parameters
Parameters ..
I/O - VSE002_03
Counter - VSE002_03
Data - VSE002_03
VSE002_03
Sensor 1
SE01_Bea..SkyRadar
Value (m/s²)
Rot. speed (rpm)
Object monitoring - 04.02.2021 18:47:31
Value - SE01_Bearing_01SkyR..
Rot. speed - SE01_Bearing_01..
Type here to search
24°C Clear
ENG
ROS
18:47
04.02.2021

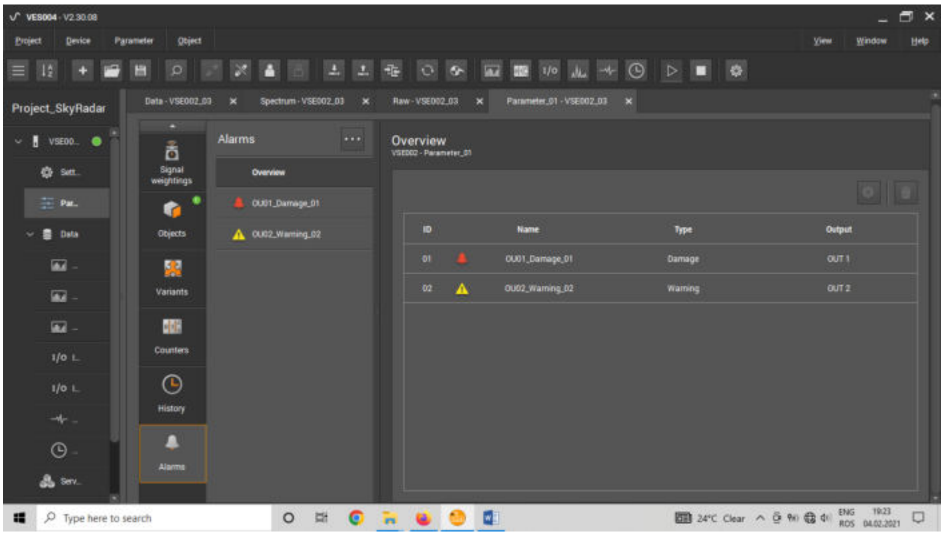

VES004 - V2.30.08
Project Device Parameter Object
View Window Help
*Project_SkyRadar
VSE002_03
Settings
Param..
Data
Service
Parameters
Parameters ..
I/O - VSE002_03
Counter - VSE002_03
Data - VSE002_03
Open spectrum monitoring window
50 kSamples/s
No filter
Raw - 04.02.2021 18:48:10
Sensor 1
Type here to search
24°C Clear
ENG
ROS
18:48
04.02.2021

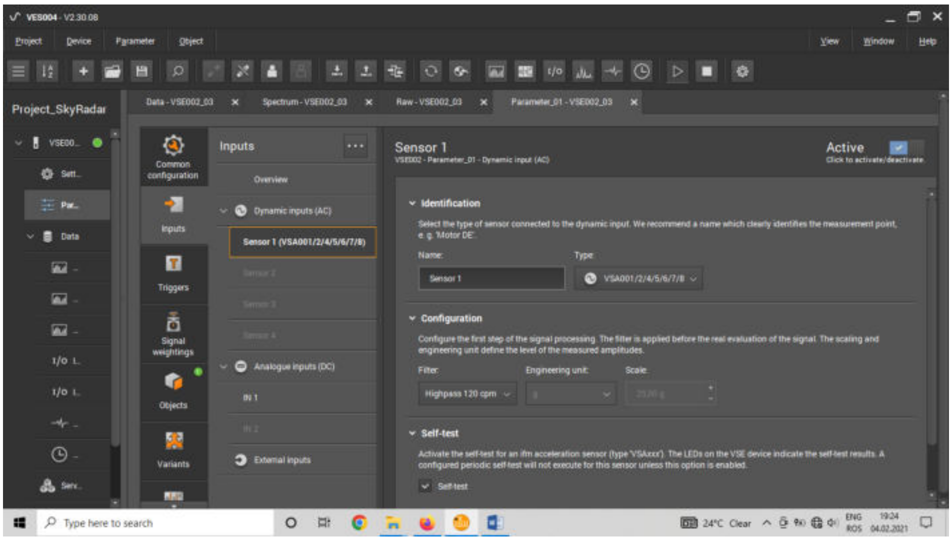

VES004 - V2.30.08
Project_SkyRadar
Spectrum - FFT (Peak) - 04.02.2021 18:48:47
Sensor 1

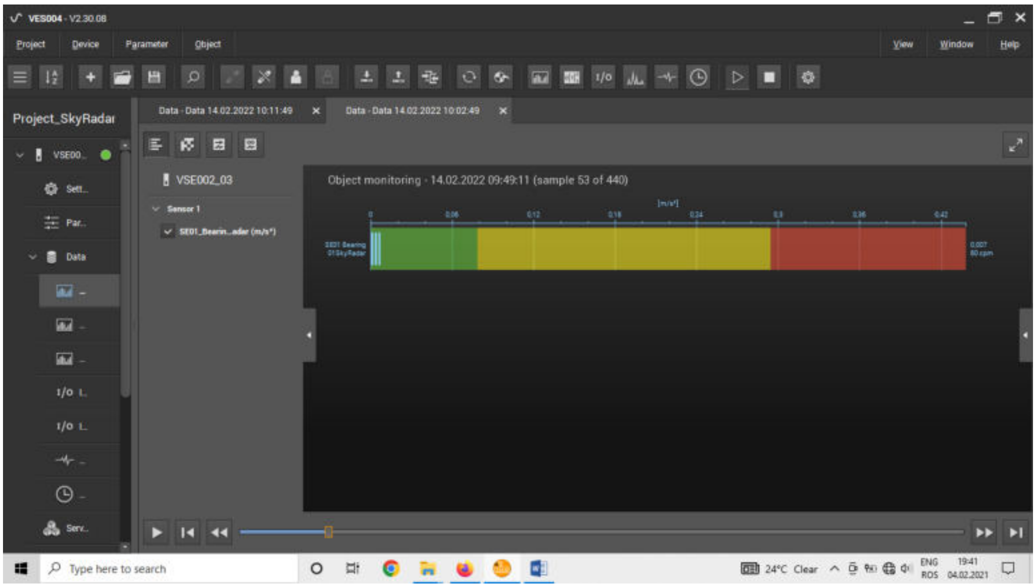

VES004 - V2.30.08
Project_SkyRadar
VSE002_03
Spectrum - FFT (Peak) - 04.02.2021 18:49:10
Sensor 1

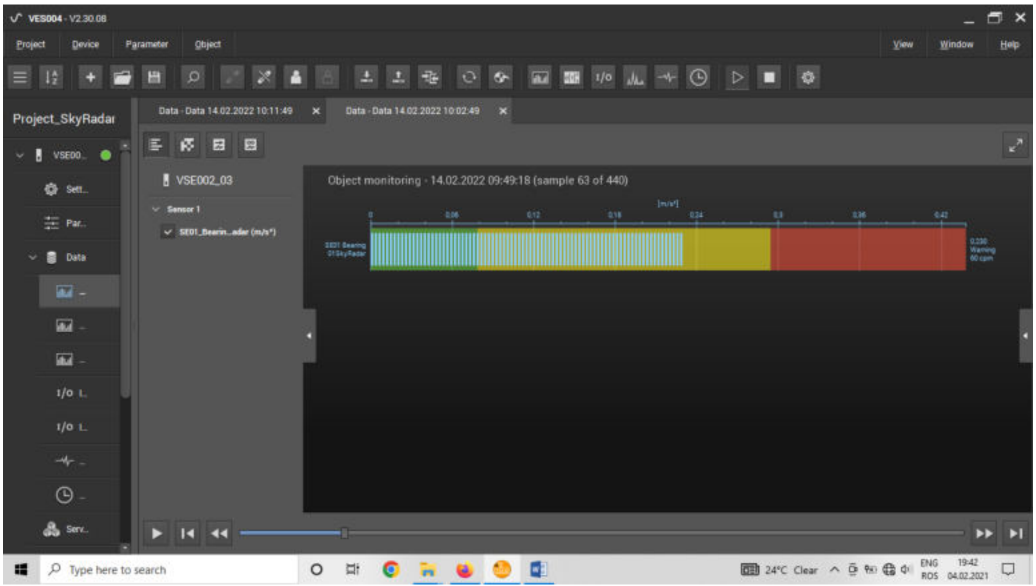

VES004 - V2.30.08
Project_SkyRadar
VSE002_03
Spectrum - FFT (Peak) - 04.02.2021 19:19:57 (31 samples recorded)
Sensor 1

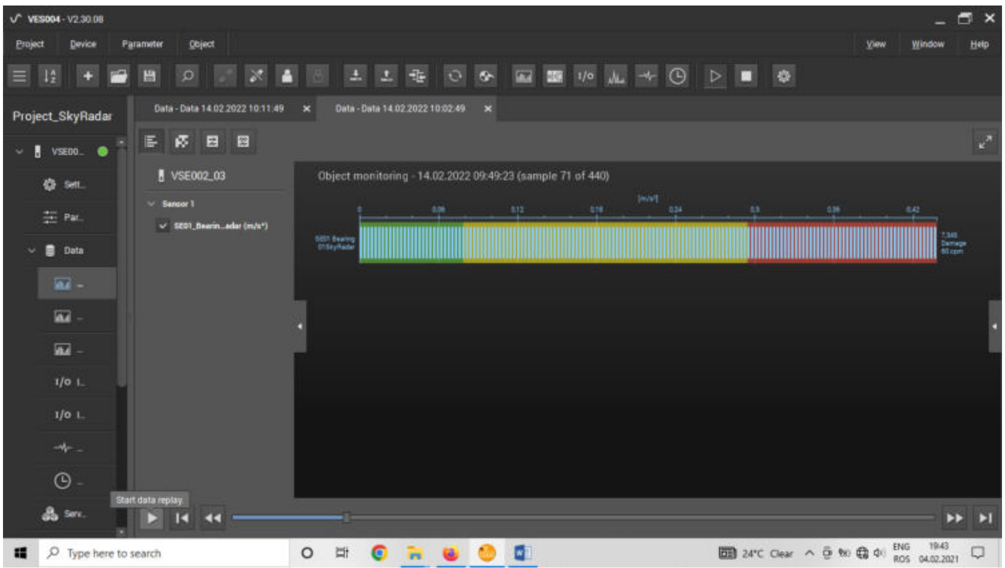

VES004 - V2.30.08
Project
Device
Parameter
Object
View
Window
Help
Project_SkyRadar
Spectrum - VSE002_03
Raw - VSE002_03
I/O - VSE002_03
VSE002_03
Raw - 04.02.2021 19:21:00 (11654000 samples recorded)
Type here to search


VES004 - V2.30.08
Project_SkyRadar
Data - VSE002_03
Spectrum - VSE002_03
Raw - VSE002_03
Parameter_01 - VSE002_03
Alarms
Overview
OU01_Damage_01
OU02_Warning_02
Signal weightings
Objects
Variants
Counters
History
Alarms
ID
Name
Type
Output
01
OU01_Damage_01
Damage
OUT 1
02
OU02_Warning_02
Warning
OUT 2
Type here to search


VES004 - V2.30.08
Project_SkyRadar
Data - VSE002_03
Spectrum - VSE002_03
Raw - VSE002_03
Parameter_01 - VSE002_03
Inputs
Overview
Dynamic inputs (AC)
Sensor 1 (VSA001/2/4/5/6/7/8)
Analogue inputs (DC)
IN 1
External inputs
Common configuration
Inputs
Triggers
Signal weightings
Objects
Variants
Sensor 1
Active
Identification
Configuration
Self-test
Type here to search

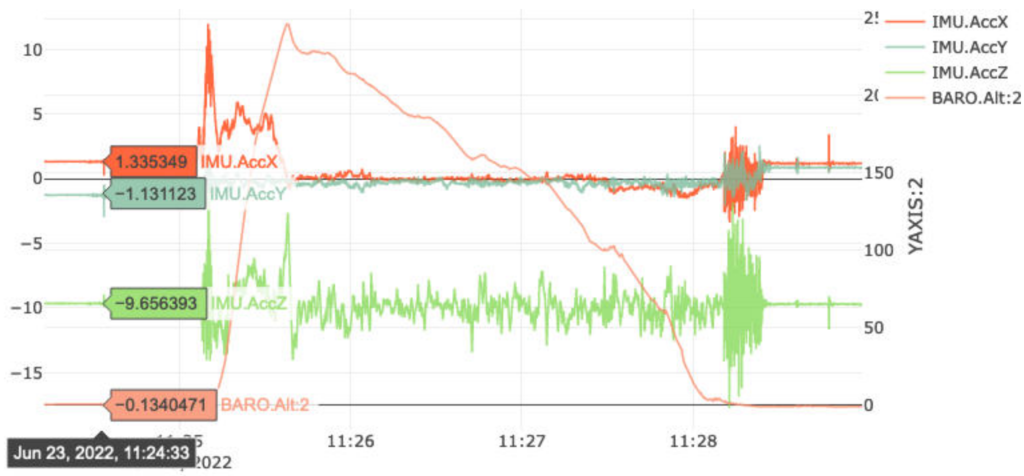

VES004 - V2.30.08
Project
Device
Parameter
Object
View
Window
Help
Project_SkyRadar
Data - Data 14.02.2022 10:11:49
Data - Data 14.02.2022 10:02:49
VSE002_03
Sensor 1
Object monitoring - 14.02.2022 09:49:11 (sample 53 of 440)
Type here to search
24°C Clear


VES004 - V2.30.08
Project
Device
Parameter
Object
View
Window
Help
Project_SkyRadar
Data - Data 14.02.2022 10:11:49
Data - Data 14.02.2022 10:02:49
VSE002_03
Sensor 1
Object monitoring - 14.02.2022 09:49:18 (sample 63 of 440)
Type here to search
24°C Clear


VES004 - V2.30.08
Project
Device
Parameter
Object
View
Window
Help
Project_SkyRadar
Data - Data 14.02.2022 10:11:49
Data - Data 14.02.2022 10:02:49
VSE002_03
Sensor 1
Object monitoring - 14.02.2022 09:49:23 (sample 71 of 440)
Start data replay
Type here to search
24°C Clear

Annex 10: Data acquisition and interpretation in Planor IS28B2 3D Air Vector

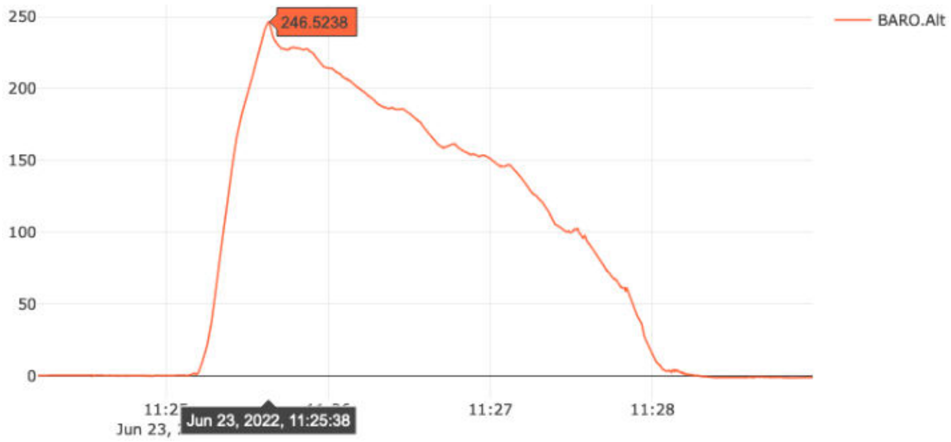
We use an online software dedicated to graphical representations of flight parameters, including those of interest (vibrations, / accelerations on the 3 axes) that does not require installation or license: https://plot.dronee.aero/



Point A - the moment of the start of the run, the first recorded accelerations, the traction shock given by the self-propelled vehicle

Point B, Time to get off the ground (11:25:07) and start climbing the slope

At take-off Maximum acceleration values on all 3 axes, especially the X-axis, value 12.01mm/s2, which give shocks to the installations mounted on the edge of the aircraft, implicitly the radiolocation equipment that would be mounted.

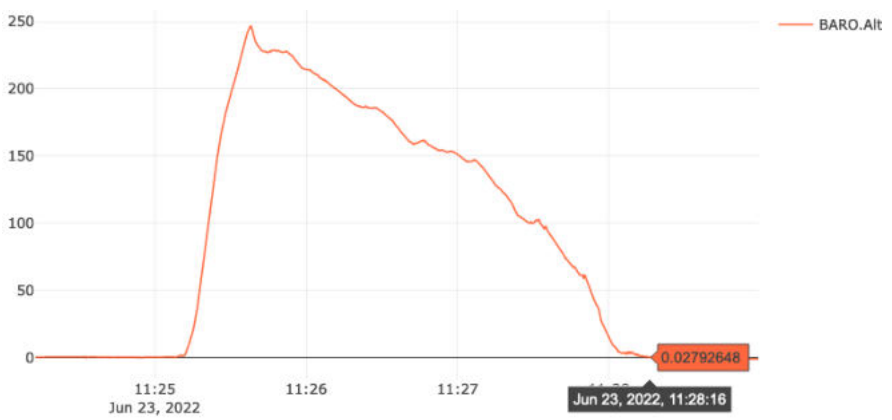


Point C, Maximum point (Altitude 246 m from take-off site)

Time of reaching maximum altitude and time of decoupling from the autopilot 11:25:38

Time on slope 21seconds

The disconnection from the autothruster is highlighted by the lack of traction that is observed from the neutral accelerations that are maintained throughout the smooth flight,



Point D+02, Landing time 11:28:16

Flight time 2 min 38 sec

The moment of runway touchdown, acceleration and therefore high shocks on all 3 axes, with effects on the fuselage and equipment on board the aircraft.

After scoring, the results of the data acquisition system show vibrations due to uneven ground and grass on the grassy runway

Complete stop of the aircraft, without variation of acceleration values