

T.C.
GAZIANTEP UNIVERSITY
INSTITUTE OF SOCIAL SCIENCES
DEPARTMENT OF AVIATION MANAGEMENT

**ASSESSMENTS OF RISKS AND ACCIDENT CAUSED
BY DANGEROUS GOODS IN AIR
TRANSPORTATION: A CASE STUDY OF THE
VALUJET FLIGHT 592 ACCIDENT**

MASTER'S THESIS

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Thesis Advisor: Assoc. Prof. Nisa SEÇİLMİŞ

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ABSTRACT

ASSESSMENTS OF RISKS AND ACCIDENT CAUSED BY DANGEROUS GOODS IN AIR TRANSPORTATION: A CASE STUDY OF THE VALUJET FLIGHT 592 ACCIDENT

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The transportation of hazardous materials poses serious risks to human life and the environment. The aim of this thesis is to examine the risks that may arise in the logistics processes of dangerous substances transported by air and the effects of accidents caused by these substances, as well as to understand how current legislative regulations shape and regulate these processes. Document analysis and case study, which are qualitative research methods, were used in the study. The findings of the document analysis, which examined previous studies and reports in order to understand the factors contributing to accidents and the necessary preventive strategies, emphasize that stricter regulations, comprehensive risk assessments and effective training programs should be implemented to prevent future tragedies. The ValuJet Flight 592 accident, which was selected as a case study, was examined using the Human Factors Analysis and Classification System (HFACS) model. The findings show how human errors and organizational deficiencies within the aviation industry can lead to catastrophic outcomes, and that such accidents are not solely the result of individual errors but are also driven by systemic failures, including poor decision-making, inadequate inspections, and insufficient safety measures at the organizational level. The study emphasizes developing a robust safety culture that transcends technical competence involving organizational practices, managerial decisions, and individual responsibilities. The study's implications extend to public policy, industry practices, and regulatory frameworks, advocating for adopting advanced technologies, enhanced training, and stringent oversight to ensure compliance with safety standards. Ultimately, this research calls for collaborative efforts to improve safety protocols, minimize risks, and protect future generations from the dangers associated with hazardous material transportation.

Key Words: Air Transportation, Dangerous Goods, Safety Management Systems, HFACS

ÖZET

HAVA TAŞIMACILIĞINDA TEHLİKELİ MADDELERİN NEDEN OLDUĞU RİSK VE KAZALARIN DEĞERLENDİRİLMESİ: VALUJET FLIGHT 592 KAZASI ÜZERİNE BİR İNCELEME

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Tehlikeli maddelerin taşınması insan hayatı ve çevre için ciddi riskler oluşturmaktadır. Bu tezin amacı, hava yoluyla taşınan tehlikeli maddelerin lojistik süreçlerinde ortaya çıkabilecek riskleri ve bu maddelerin neden olduğu kazaların etkilerini incelemek, ayrıca mevcut yasal düzenlemelerin bu süreçleri nasıl şekillendirdiğini ve düzenlediğini anlamaktır. Çalışmada nitel araştırma yöntemlerinden doküman analizi ve örnek olay incelemesi kullanılmıştır. Kazalara katkıda bulunan faktörleri ve gerekli önleyici stratejileri anlamak amacıyla önceki önceki çalışmaların ve raporların incelendiği doküman analizi bulguları, gelecekteki trajedileri önlemek için daha sıkı düzenlemeler, kapsamlı risk değerlendirmeleri ve etkili eğitim programlarının uygulanması gerektiğini vurgulamaktadır. Örnek olay olarak seçilen ValuJet Flight 592 kazası, İnsan Faktörleri Analiz ve Sınıflandırma Sistemi (HFACS) modeli kullanılarak incelenmiştir. Bulgular, havacılık sektöründeki insan hatalarının ve organizasyonel eksikliklerin nasıl felaketle sonuçlanabileceğini, bu tür kazaların sadece bireysel hatalardan kaynaklanmadığını, aynı zamanda kötü karar alma, yetersiz denetimler ve organizasyonel düzeyde yetersiz güvenlik önlemleri gibi sistemik başarısızlıkların da etkili bir neden olduğunu göstermektedir. Çalışma, teknik yeterliliğin ötesine geçen, organizasyonel uygulamalar, yönetsel kararlar ve bireysel sorumlulukları içeren güçlü bir güvenlik kültürünün geliştirilmesi gerektiğini ortaya koymaktadır. Çalışmanın sonuçları, kamu politikası, endüstri uygulamaları ve düzenleyici çerçeveler üzerinde önemli etkiler taşımakta olup, güvenlik standartlarına uyumu sağlamak için ileri teknolojilerin benimsenmesini, gelişmiş eğitim programlarının uygulanmasını ve sıkı denetimlerin yapılmasını savunmaktadır. Sonuç olarak, güvenlik protokollerinin iyileştirilmesi, risklerin en aza indirilmesi ve tehlikeli maddelerin taşınmasıyla ilgili tehlikelerden gelecek nesillerin korunması için iş birliği yapılması gerekmektedir.

Anahtar Kelimeler: Hava Taşımacılığı, Tehlikeli Maddeler, Emniyet Yönetim Sistemi, HFACS

FOREWORD

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Ali POLAT September 2024



LIST OF CONTENT

	Page
STATEMENT OF COMPLIANCE WITH ETHICAL PRINCIPLES	3
ABSTRACT.....	i
ÖZET	ii
FOREWORD	iii
LIST OF CONTENT	iv
LIST OF TABLES	vii
LIST OF ABBREVIATIONS	x

INTRODUCTION

A. Research Problem.....	1
B. The Aim of the Research and Its Importance	3
C. Research Method	5
D. Limitations	7
E. National and International Studies on the Subject.....	7

CHAPTER I

DANGEROUS GOODS

1.1. Classification of Hazardous Substances.....	10
1.1.1. Explosives.....	11
1.1.2. Gases	12
1.1.3. Flammable Liquids.....	12
1.1.4. Flammable Solids	13
1.1.5. Oxidizing Agents and Organic Peroxides	14
1.1.6. Poisonous (Toxic) and Infectious Substances.....	14
1.1.7. Radioactive Substances.....	15
1.1.8. Corrosive Substances	16
1.1.9. Other Hazardous Substances Including Environmentally Harmful Substances.....	16
1.2. Transportation of Dangerous Goods	16

1.3. Legislation Concerning Dangerous Goods Transportation in Air Transport	17
1.3.1. IATA Dangerous Goods Regulations	19

CHAPTER II

SAFETY MANAGEMENT SYSTEM AND VALUJET AIRCRAFT CRASH ANALYSIS WITH HFACS

2.1. Safety and Safety Management System in Aviation	20
2.2. Importance of Dangerous Goods in Aviation in the SMS	21
2.3. Dangerous Goods Transportation Accidents in Aviation.....	23
2.4. Examining Accidents from SMS Perspective.....	27
2.5. Safety Management System and HFACS.....	29
2.6. Analysis of ValuJet Aircraft Crash with HFACS.....	33
2.7. Strategies for Reducing Risks Caused by Dangerous Goods	36

CHAPTER III

CONCLUSION

REFERENCES.....	44
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VITAE.....	Hata! Yer işareti tanımlanmamış.
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LIST OF TABLES

Page

Table 1: Fatal DGR Accidents Related to Air Transportation 15



LIST OF FIGURES

	Page
Figure 1. Classification of explosives	11
Figure 2. Classification of gases	12
Figure 3. Flammable liquids	13
Figure 4. Risk label for flammable solids	13
Figure 5. Number of hazardous material incidents and accidents in airline industry	24
Figure 6. HFACS framework	31
Figure 7. Potential solutions to prevent accidents of dangerous good transportaion by air	37

LIST OF ABBREVIATIONS

Air OPS: Air Operations

DGR: Dangerous Goods Regulations

DOT: Department of Transportation

CRM: Cockpit Resource Management

ECQCL: External Cavity Quantum Cascade Lasers

EU: European Union

FAA: Federal Aviation Association

HMTA: Hazardous Materials Transportation Act

HMTUSA: Hazardous Materials Transportation Uniform Safety Act

IATA: International Air Transport Association

ICAO: International Civil Aviation Organization

MOFs: Metal-Organic Frameworks

SHGM: General Directorate of Civil Aviation

QE-LPAS: Quartz Enhanced Laser Photoacoustic Spectroscopy

SMS: Safety Management System

UN: United Nations

INTRODUCTION

A. Research Problem

Dangerous substances can be defined as solid, liquid and gaseous substances that may harm or endanger the environment and others during production, use, transportation, storage and transportation (Bali and Göztepe, 2014: 672; Fox, 1999: 54). The damage caused by a hazardous substance results from its properties such as flammability, explosiveness, toxicity, causticity, contagiousness, spontaneous combustion, radioactivity, corrosion and burning when wet. Dangerous goods apply to all substances that can harm humans, natural life and the environment (Erkut, Tjandra, and Verter, 2007: 539). In other words, hazardous substances, due to their natural properties, are harmful to all living and non-living things, general order, security and the environment during transportation (Asgarov, 2012: 21; Fox, 1999: 5).

When the history has been reviewed it is obvious that there were accidents and incidents related to transportation of dangerous goods (Turan ve Karagöz, 2022). Air transportation plays a critical role in global trade in terms of speed and efficiency. However, hazardous materials carried by air pose serious risks. If hazardous materials are not transported properly, packaged incorrectly or adequate security measures are not taken, flight safety can be seriously compromised and may cause major accidents. In this context, the safe transportation of hazardous materials in both passenger and cargo transportation is regulated by national and international legislation. However, the effectiveness of these regulations and problems in implementation frequently come to the fore.

Hazardous materials can cause chemical reactions, fires, explosions and toxic leaks inside the aircraft. The risks are particularly high in the transportation of

flammable, explosive or toxic materials. Changes in cabin pressure during flight can disrupt the stability of these materials and lead to unexpected accidents.

Cargo-carrying aircraft are at greater risk in the transportation of hazardous materials. In addition, the transportation of such materials in cargo on passenger aircraft necessitates additional security measures.

Accidents involving hazardous materials are generally caused by insufficient information, inadequate packaging, failure to implement appropriate security procedures and human error. For example, the fire caused by lithium batteries on a UPS cargo plane in 2010 was a significant example of the potential risks of hazardous materials in air transportation.

Such accidents not only endanger the lives of flight crews and passengers, but can also cause major financial losses and reputational damage to the airline industry.

The transportation of hazardous materials in air transportation is regulated by the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA). These institutions have set strict rules for the identification, classification, packaging, labeling and transportation of hazardous materials.

In Turkey, these regulations are carried out by the General Directorate of Civil Aviation (SHGM) and are prepared based on the IATA Dangerous Goods Regulation (DGR).

However, the adequacy of this legislation, the difficulties in implementation and the additional risks brought about by the rapid growth in air transportation lead to questioning the effectiveness of the regulations.

Although the regulations regarding the transportation of hazardous materials are strict and comprehensive, various problems arise in practice. Especially small airlines or some transportation companies may not be able to fully comply with these regulations.

Lack of training, false declarations, and neglecting safety procedures to reduce costs are the most common causes of accidents that occur during the transportation of hazardous materials.

In addition, inadequate inspections and controls cause various risks to increase in international transportation.

It will be investigated whether accidents that occur during the transportation of hazardous materials by air are caused by deficiencies in the implementation of existing legislation and what kind of regulations should be made to make these regulations more effective. What are the main problems encountered during the transportation of hazardous materials and what measures should be taken at the international and national levels to solve these problems?

Problem Questions:

What are the most common risks in the transportation of hazardous materials and what are the sources of these risks?

What are the main causes of accidents caused by hazardous materials in air transportation?

Are the regulations regarding the transportation of hazardous materials at the national and international levels sufficient?

How can more effective legislative regulations and implementation controls be carried out to prevent accidents related to hazardous materials?

It is expected that this research will contribute to a better understanding of the current risks related to the transportation of hazardous materials in air transportation. In addition, recommendations for national and international legislative arrangements will be presented to minimize accidents occurring during the transportation of hazardous materials, and new safety measures that can be implemented in this area will be emphasized.

B. The Aim of the Research and Its Importance

This thesis aims to make both academic and practical contributions to the safe transportation of dangerous goods in air transportation by analyzing past incidents related to the air transportation of hazardous substances and to propose solutions to mitigate associated risks. It also aims to create a basic framework for further research and development in this field.

The safe transportation of hazardous materials in air transportation is a critical issue for the smooth progress of national and international trade and travel safety.

Accidents that occur during the transportation of hazardous materials can not only affect the airline industry but also have serious consequences that endanger human life. Therefore, a comprehensive examination of the risks and security gaps related to hazardous materials transported by air is of great importance.

The greatest importance of this study is that it reveals the problems encountered in the implementation of existing national and international regulations and makes the necessary recommendations for the more effective implementation of these regulations. The transportation of hazardous materials in air transportation poses a great risk not only for the aviation sector, but also for international trade, logistics and even environmental safety. Minimizing these risks, improving existing regulations and making transportation processes safer will contribute to increasing security at both national and international levels.

Another important aspect of the research is that it examines the basic factors behind accidents that occur during the transportation of hazardous materials and includes recommendations on how these factors can be prevented. Since air transportation is a rapidly growing sector, regulations and security measures regarding the transportation of hazardous materials need to be constantly updated and improved. This study will discuss in detail what steps should be taken to increase the security of current procedures used in air transportation and how these processes can be made more efficient. Finally, this research can be a useful guide for various actors related to air transportation (airlines, transportation companies, cargo operators, airport security units, etc.). Concrete suggestions will be presented on issues such as better training of personnel working in the transportation of hazardous materials, development of risk management strategies, and strengthening of inspection mechanisms. In this context, the results of the study can be a valuable resource for both practitioners and policy makers in the sector and contribute to the development of new regulations and policies aimed at increasing security in the air transportation sector.

The aim of this thesis is to examine the risks that may arise in the logistics processes of dangerous substances transported by air and the effects of accidents caused by these substances, as well as to understand how current legislative regulations shape and regulate these processes. Within the scope of this general purpose, the following sub-goals will be focused on:

Risk Analysis: To determine the potential risk factors encountered in the logistics chain of dangerous goods transported by air and to evaluate the magnitude of these risks.

Examining Accidents: To analyze hazardous material accidents occurring in air transportation through case studies and to examine the causes, results and effects of these accidents.

Review of Literature: To understand the reason of incidents and accidents of dangerous goods transportation, the literature has been reviewed.

Improvement and Suggestions: Based on the findings, to evaluate the existing security measures for the transportation of dangerous goods by air and to offer improvement suggestions.

C. Research Method

The qualitative method was used in the research. As it is known, qualitative research can be defined as research in which qualitative data collection methods such as observation, interview and document analysis are used and a qualitative process is followed to reveal perceptions and events in a realistic and holistic way in a natural environment (Akpınar ve Kaymakçı, 2012).

Research Design

In this thesis, a case study research design was used as a qualitative approach. Case study research provides detailed and in-depth descriptions of a specific phenomenon, situation, environment, system, or organization. The main purpose is to understand the process by seeking answers to the questions of what, how, and why regarding a phenomenon in a specific situation.

The advantages of case study research include presenting a specific aspect of the phenomenon being studied directly and in detail to the reader, possessing high explanatory power in understanding the phenomenon, and the researcher not being dependent on highly structured or predetermined data collection methods. However, since the results obtained from a case study are facts related to the phenomenon, their generalizability is limited. Similar case studies can be repeated to enhance the generalizability of the findings (Gürbüz and Şahin, 2018: 110, 111).

The event can involve an individual, a role, a small group, an organization, a society, a decision, a process, or an unexpected situation. A case study may be preferred for various reasons. One of the most important is when the researcher aims to find answers to the questions of “how” and “why” about the subject (Gürbüz and Şahin, 2018: 414). Since this study investigated factors causing accidents related to hazardous materials, and since these accidents were unexpected, the case study design was chosen and the analysis was deepened through a sample accident. The ValuJet Flight 592 (1996) accident, which resulted in the highest number of deaths due to hazardous materials, was selected due to the magnitude of its impact. As accidents mostly occur due to human factors in practice, the Human Factors Analysis and Classification System (HFACS) technique, frequently used in accident analyses, was employed, and data were obtained through document analysis.

Data Collection Tool

Document analysis is a scientific research method defined as the collection, review, questioning, and analysis of various documents as the primary source of research data. While this method often serves as a complement to other research methods in the literature, it can also be used as a stand-alone approach. Document analysis, also known as documentary scanning, involves obtaining data by examining existing records and documents. This process includes finding, reading, taking notes, and evaluating sources for a specific purpose (Sak et al., 2021: 228, 230).

As a qualitative research method, document analysis meticulously and systematically analyzes the content of written documents. It is a systematic method used to examine and evaluate all types of documents, including printed and electronic materials. Like other methods employed in qualitative research, document analysis requires the examination and interpretation of data to derive meaning, create an understanding of the relevant subject, and develop empirical knowledge. Documents contain texts and images recorded without the intervention of a researcher.

Types of documents that can be utilized in research include advertisements, agendas, attendance records, invitations, meeting minutes, guides, notes, books, brochures, diaries, magazines, program records, letters, memorandums, maps, charts, newspapers, works of art, program details, radio and TV scripts, organizational reports, survey data, various public records, notebooks, photo albums, etc. These provide

valuable data for researchers. Document analysis may involve different processes depending on the researchers (Kıral, 2020: 173, 174). Generally, this process can be summarized as reading and interpreting original documents after accessing them.

Although document analysis has its strengths, it also presents limitations and challenges. Researchers should consider these factors and conduct their studies based on scientific evidence, the research problem, and the conceptual framework. The purpose, context, and target audience of the examined documents should be taken into account; data must be analyzed objectively and meticulously. Additionally, researchers should adhere to their ethical responsibilities, ensuring that their studies are completed and published without compromising academic integrity (Kıral, 2020: 186; Sak et al., 2021: 237-240).

Document analysis is quite suitable for the purpose of this research. Because the information and data related to the aviation sector are archived by various national (e.g. SHGM, Ministry of Transport) and international (e.g. ICAO, IATA) official organizations. In this study, data obtained from the reports and records published by these organizations were used.

Validity and Reliability

Discussions on validity and reliability for qualitative research methods include a complex diversity of ideas rather than drawing a clear framework (Özkan, 2023: 826). In this study, where data was obtained through document review, the use of institutional reports, the confirmation of the originality of the documents, and the use of officially published accident reports are important elements that ensure validity and reliability. In addition to the document analysis method, the use of a case study in the research increases validity and reliability. Another plus is that expert opinions were obtained during the interpretation process of the obtained data.

D. Limitations

In this study, there are restrictions on data and information access, trade secrets, inability to transfer information due to security and privacy concerns, and restrictions arising from legislation. The complexity of the legislation, differences in legislation between different countries and the limited number of case studies are among the other limitations of the study.

E. National and International Studies on the Subject

Zhao et al., (2018) researched that the developed a model to evaluate safety performance of the transport of the dangerous goods by air carriers. Also this study identifies five drivers for the assessment factor system: operations, emergency preparedness, organization/regulations, equipment/facilities, and training. Their results indicate that the most significant elements influencing the safety performance of dangerous products transportation by air are the control of dangerous items acceptance, the availability of adequate equipment and facilities.

Debeljak Rukavina (2015), investigated the legal framework at the international, European, and national levels that regulates the air transportation of hazardous materials. The study expounds upon the clauses of the Ordinance concerning the terms and modes of transportation of hazardous materials by air, which are entirely compliant with Annex 18 of the Convention on International Civil Aviation.

Zhang et al., (2022), in order to elucidate the significance of many causes of hazards in aviation travel, they used chromatographic analysis to ascertain the weight of each factor. They found that lithium batteries and general cargo transportation are two significant risk factors that have an impact on aircraft safety transportation, according to the assessment system analysis results.

Walton and Marion (2020), conducted research utilising the ASRS database and the SAS text miner programme to look at the different kinds of dangerous goods incidents on aeroplanes. 383 preliminary records on events involving dangerous items were included in the dataset for the ten-year period between 2010 and 2020. The records were examined using the Text Miner software to find subjects embedded within the text. The key subjects included in the ASRS dataset were revealed by the text mining analysis results, which also revealed recurrent themes on the transportation of hazardous materials by aeroplane.

Kucharek and Osiak (2017), analysed a few different security-related factors in order to the risks associated with the transportation of hazardous chemicals. As a result of the their research the investigation led to the presentation and discussion of the primary causes of flight incidents that involved air transport participants. The examples highlight the flaws and loopholes in the protocols for transporting these chemicals. Periodically, these protocols must be revised to incorporate the latest

insights gained from the incidence of defective or irregular hazardous material shipments.

Kucharek and Rojek (2016), a concentrated effort to analyze the legislation-making process regarding the transportation of hazardous materials and, based on that analysis, evaluate the activities that have been implemented. The analyzes shows that a key finding drawn from the examination of the process of developing a legal framework for the transportation of hazardous chemicals is the cooperation that now exists between organisations enforcing regulations and users.

Herc and Zakrzewska (2018), provide the most recent information available on the Polish Army's use of aeroplanes for the transportation of explosives, explain potential solutions to issues that arose throughout the transport preparation phase, and indicate areas of concern. Researcher claim that, when put into practice, the suggested remedy would improve the process of training those who handle transportation, aid to decrease errors in product labelling, and make the process of preparing transport documents easier.

The issues related to hazardous materials were focused on, the issues that are widely discussed in the literature and the importance of research in this field is increasing day by day. But the thesis, especially verbally, deals with accidents, and describes a part of human life. The risks, innovations and changes examined in the literature are clearly seen. These suggestions not only analyze the current situation, but also can help to take effective steps to prevent accidents in similar situations. The contribution of this thesis is not only to solve the problems, but also to provide this responsibility-oriented solution proposal, which most likely provides a specialized progress in reducing the related risks and protecting human life. In this way, a new perspective is developed in the literature, and it is aimed to make the studies in this field more effective and have more results.

CHAPTER I

DANGEROUS GOODS

1.1. Classification of Hazardous Substances

Over 1.25 million shipments of hazardous materials are flown every year. The amount of dangerous goods shipments will increase dramatically over the next five years, with air freight growth estimated to expand at a rate of 4.9% annually. Since so many hazardous materials are transported by air, safety rules need to be strictly adhered to. The International Civil Aviation Organization (ICAO) and IATA collaborate to identify risks and update laws so that stakeholders can handle and transport hazardous materials safely (IATA, 2022).

The goal of classifying and identifying hazardous compounds is to methodically determine the risks associated with them, alert users to those risks, and empower users to take necessary protective measures. Chemical dangers are typically classified into three categories at this stage: phytochemical, toxicological (or health), and ecotoxicological (or environmental) (Pratt, 2002).

Dangerous substances are classified into nine different classes according to their properties. The classes of hazardous substances are identified and classified as explosives, gases, flammable solids, inflammable liquids, oxidizers, organic peroxides, poisonous and polluting substances, radioactive materials, pollutants and various dangerous substances. Hazardous substances are labelled according to their grades of classification. It is based on the degree of classification in the packaging processes to be applied to hazardous substances. It also specifies the conditions for the non-packaging of dangerous substances according to their classification grades (Turan and Karagöz, 2022).

1.1.1. Explosives

Materials that are liquid, solid, or a combination of both that can react chemically to produce gases at a specific temperature and pressure quickly enough to harm the environment around them are known as explosive substances. Except for those that are too hazardous to transport, substances that by themselves are not explosives but have the potential to produce gas, fog, or dust explosions are not included in this first class (Bahreisy et al., 2022).



Figure 1. *Classification of explosives (IATA, 2016)*

According to (FAA, n.d.), explosives with a mass explosion hazard are classified as: Division 1.1. A mass explosion is one that instantly affects nearly the whole load. Explosives in Division 1.2 have a projection hazard but do not pose a risk of mass explosion. Explosives in Division 1.3 have a fire danger as well as a minor blast, minor projection, or both hazards, but not a mass explosion hazard. Explosives that pose a small risk of detonation are classified as Division 1.4. It is not envisaged that any shards of any size or range will project from the package; the explosive effects are mostly contained within it. The majority of the package's contents cannot explode almost instantly due to an external fire. The explosives in Division 1.5 are extremely insensitive. This category includes materials that have the potential to cause large explosions but are so insensitive to them that, in regular transportation circumstances, there is very little chance of either initiation or the transition from burning to detonation. The items in Division 1.6 are incredibly insensitive and do not pose a risk

of mass explosion. This category includes products that are primarily made of very insensitive materials and have a very low chance of unintentional initiation or spread.

1.1.2. Gases

During the logistics process (such as during storage and transit), all gases are compressed, which both conserves space and raises the possibility of danger. This pressure, which is created without compression, might produce a higher force that results in the same pressure and risk as in class 2 if it abruptly weakens (CGA, 2013). Gases are included in this. Three divisions exist in Class 2: Division 2.1: Combustible Gases, including Propane and Butane. Division 2.2: Non-toxic, non-flammable gases, including compressed air, liquid nitrogen, and oxygen. Toxic gases like hydrogen sulphide and chlorine are in division 2.3. (CASA, n.d.-a).



Figure 2. *Classification of gases* (IATA, 2016)

1.1.3. Flammable Liquids

Flammable liquids are one of the most prevalent danger classifications worldwide, according to the United Nations. Paints, adhesives, and petroleum compounds used as fuels, paints, and solvents are examples of flammable liquids. The quantity of combustible liquids is crucial when shipping to the European Union 27, as noted below.



Figure 3: *Flammable liquids* (IATA, 2016)

It is significant to remember that two combustible liquids are typically heavier than air. They move towards the lower regions when there is no wind. Given how long it takes for these materials to lose their properties, they might burn more easily. When it comes to combustible substances, the risk of explosion is always great (Man and Gold, 1998).

1.1.4. Flammable Solids

The essence of this class is that every fire, including the product, is very strong at high temperatures and difficult to extinguish. Other undesirable hazards may occur, such as toxic and/or aggressive waste gases. For safety reasons, substances of this class should be considered as other flammable substances and should be kept away from sources of ignition. This class consists of 3 subclasses (IMO, 2010).



Figure 4. *Risk label for flammable solids* (IATA, 2016)

These include materials that have the ability to catch fire on their own and materials that release flammable gases when they come into contact with water. Three divisions make up Class 4. Division 4.1: Combustible Solids: hexamine solid fuel tablets for campfires; chemicals that react spontaneously explosives that are desensitised Division 4.2: Materials that, in standard air transport circumstances, are capable of spontaneous combustion include: sulfur-cambrum matches Division 4.3

lists the following materials as flammable gas emitters when they come into contact with water: activated carbon, sodium zinc particles, and zinc particles (CASA, n.d.-b).

1.1.5. Oxidizing Agents and Organic Peroxides

Oxygen in the atmosphere is what starts fires. This class includes compounds that burn by containing oxygen. When these materials break down and release oxygen, they can separate. Even if they are far apart, Class 5 items cannot be carried or kept with other non-flammable products for safety reasons. These materials possess corrosive qualities as well. There are two subclasses in this class (ADR, 2017). An oxidizer (Division 5.1) is a substance that can, in general, promote or cause the combustion of other substances by producing oxygen. Division 5.2 defines organic peroxide as any organic compound that has oxygen (O) in the bivalent -O-O- structure. It can be thought of as a derivative of hydrogen peroxide, with one or more hydrogen atoms swapped out for organic radicals

While certain compounds alone may not be combustible, their combinations with other substances can have hazardous reactions. Two divisions exist for Class 5: Division 5.1: Oxidising compounds, such as hydrogen peroxide, that may not always be combustible but can easily produce oxygen and ignite other materials ammonium nitrate , potassium chloride nitrate of sodium. Division 5.2: Organic peroxides can release heat and combustible or hazardous vapours due to their thermal instability. In addition, they may decompose explosively or react harmfully with other compounds. Acetyl acetone peroxide, benzoyl peroxide, and peracetic acid are a few examples (CASA, n.d.-c).

1.1.6. Poisonous (Toxic) and Infectious Substances

These substances frequently result in unexpected disease or death. From a human perspective, class 6 chemicals can be ingested, absorbed via the skin, or consumed by one or more of these routes. In the logistics of these materials, hygiene must be crucial (UN, 2010).

These substances give infectious compounds due to the physiologic effects these compounds have on the body. The vast category of infectious agents includes

organisms, vaccinations, genetically edited bacteria employing medicinal leftovers, and corpses of humans and animals. The possibility of contamination is these compounds' most significant characteristic. There is no system in our body that detects infectious materials. As a result, these goods need to be loaded, transported, and unloaded carefully (UN, 2006).

Infectious Materials are substances that contain pathogens (section 6.2). They are micro-organisms, including bacteria, viruses, parasites and fungi, that can cause disease in humans and animals.

This class has divide two section. Division 6.1: Toxic compounds that, if inhaled, ingested, or come into touch with the skin, are known or suspected to be lethal to humans or animals. These materials are usually infectious, including viruses, bacteria, fungus, and other disease-causing microbes. Division 6.2: Infectious materials that may include poisons or infectious agents that might harm or kill people or animals. These materials could be animal carcasses, lab cultures, or medicinal or clinical waste. Hazardous products classified as Class 6 must be transported under strict regulations and with specific packaging, labelling, and documentation. It is essential to take the right safety precautions when handling and moving these materials in order to avoid contamination and exposure (Silverback, n.d.).

1.1.7. Radioactive Substances

The release of energy in the form of moving subatomic particles or electromagnetic waves is known as radiation. Numerous naturally occurring radioactive compounds that are present in soil, water, air, and the body are the source of natural radiation. People consume and inhale radiation on a daily basis from food, water, and the air. The most frequent artificial sources of radiation exposure for people nowadays are medical devices such as X-ray machines and radiopharmaceuticals used in radiotherapy or diagnostic procedures. Radiation exposure can come from unintentional events, deliberate circumstances (such as medical or work-related ones), or natural sources (such as radon in homes). Exposure can occur internally (by ingestion, inhalation, or contact with a contaminated wound), externally (via skin, hair, or clothing contamination or not), or both (WHO, 2023).

1.1.8. Corrosive Substances

Compounds that run the risk of reacting chemically with other compounds are known as corrosive substances. These materials have an impact on the other load, the transport route, the nearby materials, and—above all—the potential for shedding human tissue. The primary issue with the logistics of these materials is the lack of options for packaging that will effectively preserve the abrasives. Modern polymers are appropriate for this use (UN, 2010).

1.1.9. Other Hazardous Substances Including Environmentally Harmful Substances

The other hazardous substances (class 9) that do not contain hazardous substance risks and include substances that are harmful to the environment. It is also recognised that materials and parts belonging to this class contain materials that are crucial to reactors. In addition, they have smoke detectors, isotopes, and even light marks for therapeutic uses. Additionally, lamps and indicators may include radioactive elements. (UN, 2010).

1.2. Transportation of Dangerous Goods

The goal of regulating the transportation of dangerous products is to minimise the risk of harm coming to people or their property, as well as environmental, transportation-related, or other goods-related incidents. Regulations should be written to avoid impeding the transportation of these items, aside from those deemed too hazardous for transportation. With this one exception, the goal of laws is to minimise or completely eliminate risks in order to make transportation practicable. Thus, it is as much a question of safety as it is of making transportation easier. All forms of transportation are covered by the Model Regulations that are appended to this article. Sometimes, additional criteria may be applied for operational reasons by modal transport legislation (UN, 2010).

All across the world, hazardous materials are often and routinely transported by air. Under the terms of the Chicago Convention, each State is expected to

incorporate certain international Standards into national legislation to guarantee that they do not endanger an aircraft and its people. This method gives international harmonisation of safety standards and guarantees state control over the transportation of hazardous materials by air (ICAO, n.d-a.).

ICAO (n.d.-b), stated that, a detailed list of requirements, including those for classifying and listing dangerous commodities, can be found in the Technical Instructions. The list indicates which goods are: a) prohibited in all cases; b) prohibited on passenger and cargo aircraft in regular circumstances but may be carried in extraordinary cases with permission from the relevant State); c) prohibited on passenger aircraft but allowed on cargo aircraft in regular circumstances; and d) allowed on both passenger and cargo aircraft in regular circumstances. All hazardous materials must be packaged, and the Technical Instructions generally limit the amount per package based on the level of risk and the kind of aircraft (cargo or passenger) that will be utilised.

1.3. Legislation Concerning Dangerous Goods Transportation in Air Transport

Any product or substance that, during manufacture, processing, transportation, storage, or usage, has the potential to produce or release substances hazardous to the environment or human health is considered a hazardous material. Hazardous materials are also goods that have the potential to produce ionising radiation in amounts that could harm anyone who come into touch with them. Grupo Cabeza classifies the items prior to transportation, considering the chemical properties and degree of danger of each item (Cabeza, n. d.).

Annex 18 outlines the general guidelines for the safe transport of hazardous materials by air. One of the Standards, on the other hand, stipulates that hazardous materials must be transported in compliance with the Technical Instructions for the Safe Transport of Dangerous Materials by Air ("Technical Instructions"). Annex 18 mandates that states establish inspection and enforcement protocols to guarantee that dangerous items are transported in accordance with regulations (ICAO SAFETY, n.d.).

The Commission Regulation (European Union-EU) No 965/2012 on Air Operations (Air OPS) contains European regulations pertaining to the transportation

of hazardous materials. The EU-OPS Regulations are replaced by the Air OPS Regulation. Annexes I through VII of the Air OPS currently contain solely the regulations pertaining to non-commercial operations and commercial air travel. To finish it, the regulations pertaining to aerial work (specialised operations) will come later. Furthermore, it is the duty of national aviation authorities to approve dangerous goods training in their nations, and as such, they must set the requirements for approval. Each operator should get in touch with the national aviation authorities in their country of registration for comprehensive details on training requirements (including the kind of training interaction - computer-based training or classroom) (EASA, n.d.).

Hazardous materials transported within the borders of the United States are governed by regulations enforced by the Department of Transportation (DOT). The Hazardous Materials Transportation Act (HMTA), the Hazardous Materials Transportation Uniform Safety Act of 1990 (HMTUSA), and 49 CFR Parts 171–177 contain regulations that must be followed. The International Air Transportation Association's (IATA) Dangerous Goods Regulations (DGR), which are implemented by the Federal Aviation Association (FAA), also govern domestic and international air shipments. These regulations set out the responsibilities for institutions and individuals involved the transportation-related activities of hazardous materials and dangerous goods, which include the following hazard classes: explosives, compressed gases, flammable liquids and solids, oxidizers, reactives, poisons, infectious substances, radioactive materials and corrosive materials. In addition, the regulations specify: proper classification, packaging, labeling, security assessment, and documentation of all shipments. The regulations require training for anyone who prepares, offers, or receives materials for shipment and establishes penalties and fines for non-compliance. Failure to comply with the regulations may not only result in substantial fines and penalties for the University, but the individual(s) causing the violation can also be held personally liable (UWM, n.d.). Finally, for the safety of passengers, crew, and cargo in air transportation, legislation pertaining to dangerous commodities is essential. The handling, packing, labelling, and shipping of goods deemed hazardous or dangerous because they may present risks during air transportation are governed by these rules. The International Civil Aviation Organisation provides one of the main regulatory frameworks for dangerous commodities in aviation (ICAO). Through its

Technical Instructions for the Safe Transport of Dangerous Goods by Air, ICAO establishes guidelines and best practices. Numerous hazardous items are covered by these guidelines, such as gases, flammable liquids, flammable solids, oxidising agents, hazardous materials, infectious agents, radioactive agents, corrosive agents, explosives, and other hazardous materials.

1.3.1. IATA Dangerous Goods Regulations

The IATA Dangerous items Regulations (IATA DGR) document is used on a daily basis by airlines, freight forwarders, ground handlers and shippers just like you to ensure that dangerous items are transported effectively and securely.

The International Civil Aviation Organisation (ICAO) publishes guidelines for the safe transport of dangerous products, and these guidelines are defined in an easy-to-read handbook that is part of IATA's dangerous goods regulations. The United Nations (UN) classification of any item or substance, as well as its acceptability and requirements for air transport, are included in IATA's Dangerous Goods Regulations. IATA ensures that the strictest safety regulations are adhered to by going above and beyond the requirements set forth by the UN and ICAO (IATA, n.d.). As a summary, The product portfolio of the Dangerous Goods Regulations (DGR) includes standards that were first created by airlines to enable the safe and effective carrying of restricted products. These guidelines, which are also operational manuals and regulations, convert frequently complex legal requirements into a language that is easier for people involved in supply chain operations to understand.

CHAPTER II

SAFETY MANAGEMENT SYSTEM, ACCIDENTS CAUSED BY DANGEROUS GOODS, AND VALUJET AIRCRAFT CRASH ANALYSIS WITH HFACS

2.1. Safety and Safety Management System in Aviation

The passenger and freight sectors are expected to continue growing, which bodes well for the aviation industry's future. According to the ICAO, passenger volume might quadruple by the middle of the 1930s at an annual growth rate of 4.3%. This optimistic view is supported by a number of significant variables that are expected to propel the sector forward and lead to greater success (Etedge Insights, 2024). Safety in aviation determines the industry's continued existence. People from many different fields are involved in the complex business of aviation. Every agency, including the flight crew, passengers, maintenance, ATC, ground support, and manufacturer, contributes to the safe takeoff and landing of every aircraft. This is made possible by a complex web of protocols that guard against mistakes and omissions in addition to mechanisms designed to identify and record such instances of failure. People are operating in environments and near equipment that could present safety risks (Aviation Hunt, 2023). The safety of aviation is always increasing. This is made possible by sharing the information of makers, operators, and regulators. The cooperative approach of the organisations involved in the design and manufacture of aircraft and their equipment, regulatory monitoring, aircraft operation, air traffic control, and airport infrastructure has increased aviation safety. Increasing after the human error, loading hazardous materials and lack of the safety culture ICAO regulated the safety management principles. Safety Management System (SMS) is a methodical, preventative strategy to handling safety hazards. The

core of SMS is risk management, which includes risk assessment, risk mitigation, and identification of safety hazards. It is reinforced by a robust assurance unit that handles change management and keeps an eye on performance and compliance (CAA, 2024).

Safety management aims to prevent aircraft mishaps and accidents by proactively identifying hazards and reducing associated safety risks. An organisation can manage its operations more methodically and deliberately when safety management is implemented. An business may prioritise safety concerns, more efficiently manage its resources, and achieve optimal outcomes when it has a clear awareness of its position and contribution to aviation safety (EASA, 2024). Teske and Adjekum (2022) stated that SMS has four components. Safety policies ; defines the methods, processes, and organizational structure needed to meet safety goals. Safety assurance evaluates the continued effectiveness of implemented risk control strategies; supports the identification of new hazards. Safety risk management, determines the need for, and adequacy of, new or revised risk controls based on the assessment of acceptable risk. Safety promotion includes training, communication, and other actions to create a positive safety culture within all levels of the workforce. The implementation of SMS in aviation has been driven by regulatory requirements and the industry's commitment to maintaining high safety standards. As a result, organizations are better equipped to analyze safety data, identify trends, and develop targeted interventions. This systematic approach not only reduces the likelihood of accidents but also instills confidence among passengers and stakeholders in the overall safety of air travel. As aviation continues to grow, the SMS remains a crucial element in ensuring the ongoing safety and efficiency of the industry.

2.2. Importance of Dangerous Goods in Aviation in the SMS

The aviation sector has become a rapidly growing area with technological developments and the acceleration of global trade. This growth has also made the transportation of hazardous materials by air an important issue. Hazardous materials include potentially harmful or risky, explosive, flammable, radioactive, biologically hazardous or chemical substances. Accidents and risks that may arise during the transportation of these substances can threaten both human health and the

environment. For this reason, the effective implementation of safety management systems (Safety Management Systems - SMS) in the transportation of hazardous materials is extremely important.

Accidents that may occur during the transportation of hazardous materials in aviation can pose serious threats to flight safety. Reasons such as incorrect packaging, inadequate labeling, and unconscious or untrained personnel can lead to serious accidents. Incorrect transportation of hazardous materials can lead to consequences such as fires, explosions, leaks and poisoning. For this reason, airline companies and air cargo operators must take strict regulations and precautions for the transportation of hazardous materials.

SMS is a holistic approach implemented to continuously monitor and improve safety performance in aviation. This system aims to minimize risks that may occur in aviation operations and to identify potential threats in advance. The implementation of SMS in the transportation of hazardous materials is of critical importance in terms of preventing possible accidents and effectively managing risks.

Importance of SMS in the Transportation of Dangerous Goods:

Risk Assessment and Determination of Hazards: Potential risks that may occur during the transportation of hazardous materials are systematically evaluated thanks to SMS. SMS helps to identify, analyze these risks and take appropriate measures. The biggest risk factors in the transportation of hazardous materials are explosion, fire or chemical leaks. Therefore, SMS ensures that such risks are identified and minimized in advance.

Proactive Security Approach: Instead of focusing only on accidents that occur, SMS provides proactive safety management. This system detects potential problems in advance during the transportation of hazardous materials and puts risk management strategies into action. Thanks to this proactive approach, preventive measures can be taken before accidents occur.

Training and Awareness: SMS also includes training and raising awareness of personnel involved in the transportation of hazardous materials. Most accidents encountered in practice are caused by human error. Therefore, it is of great importance for personnel to have knowledge about hazardous materials and to know the correct

packaging, labeling and transportation procedures. Regular training is provided within the scope of SMS to ensure the safe transportation of these materials.

Monitoring and Inspection: SMS also includes continuous monitoring and inspection processes in the transportation of hazardous materials. Systems and procedures used to ensure the safe transportation of hazardous materials during air transportation are regularly inspected. These inspection processes allow for the detection of deficiencies and errors and the necessary improvements to be made.

Accident and Incident Investigations: SMS provides systematic examination of accidents and incidents that occur during the transportation of hazardous materials. These inspections allow for the necessary lessons to be learned and preventive measures to be taken to prevent similar accidents from occurring in the future.

The safe transportation of hazardous materials in the aviation sector is of great importance for the safety of all airline operations. The Safety Management System (SMS) is an effective tool for minimizing the risks that may arise during this process and for detecting potential hazards in advance. The implementation of SMS is of vital importance for human health, environmental safety and flight safety during the transportation of hazardous materials. Therefore, effective implementation of SMS by airlines and cargo operators will greatly contribute to the prevention of accidents related to hazardous materials and the provision of a safe transportation process.

2.3. Dangerous Goods Transportation Accidents in Aviation

From 2015 to 2019, the U.S. Bureau of Transportation Statistics recorded a total of 6,601 hazardous material incidents on aircraft in the United States, with 37 of these incidents being directly related to accidents. Throughout this period, there have been notable instances of accidents involving both cargo and passenger aircraft attributable to the presence of dangerous goods (Walton and Marion, 2020).

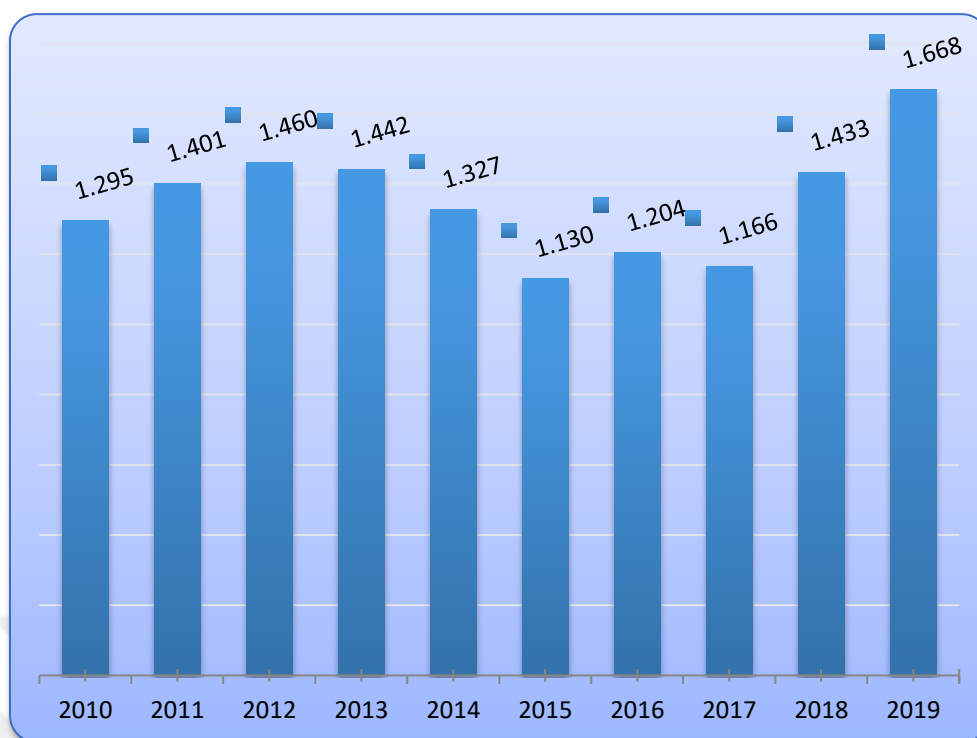


Figure 5. *Number of Hazardous Material Incidents and Accidents in Airline Industry* (Hazmat, 2024)

The diagram delineated as Figure 5 presents a comprehensive overview of the incidence and accidents within the airline industry spanning the years 2010 to 2019. Analysis of the data reveals that in 2010, there were 1295 reported incidents and accidents. Subsequently, a discernible decline in occurrences was observed between the years 2014 and 2017, in contrast to the preceding years of 2011, 2012, and 2013. However, there was a notable resurgence in 2018, with the recorded incidents and accidents escalating to 1433 (Hazmat, 2024).

Upon scrutinizing the incidence and accident rates, it becomes evident that this pattern underscores the critical significance of transportation of hazardous materials and safety protocols within the aviation domain, thereby necessitating a more profound inquiry into the fundamental determinants precipitating these fluctuations.

In pursuit of this goal, the study seeks to scrutinize previous occurrences pertaining to the aerial conveyance of hazardous substances and to offer practical solutions aimed at reducing related risks. Within this context, the research focuses on investigating fatal accidents involving hazardous materials in air transportation.

Table 1 provides an inventory of fatal accidents linked to the transportation of hazardous materials by air, categorized by year, incident cause, and the number of fatalities incurred.

Table 1

Fatal DGR Accidents Related to Air Transportation (Fishman, 1999; Matthews and Kauzlarich; 2000; IATA,2016; Walton and Marion, 2020)

Year	Accident	Reason	Number of Deaths
1996	ValuJet Flight 592	Improperly stored and labeled oxygen-generating canisters caused fire in cargo hold	105
2010	Cargo Flight B747	A significant fire erupted in palletized cargo consisted of a variety of items, notably including a substantial quantity of lithium batteries along with other flammable materials.	2
2010	UPS Airlines Flight 6	Onboard fire believed to have started from lithium-ion batteries in cargo	2
2011	Asiana Airlines Flight 991	Onboard fire caused by hazardous materials, including lithium-ion batteries	3
2011	Cargo Flight B747-400F	Fire caused by lithium batteries	2

Valujet Flight 592: It met a tragic end on May 11, 1996, when it crashed in the Florida Everglades, claiming the lives of 105 passengers and five crew members. The crash was attributed to a fire ignited by the explosion of one or more oxygen generators in the cargo compartment. Subsequent investigations by government agencies revealed lapses in regulatory compliance by both Valujet and SabreTech, the airline maintenance company involved, regarding the handling, storage, and transportation of hazardous materials by air (Fishman, 1999; Matthews and Kauzlarich; 2000).

2010 Cargo Flight B747: During takeoff, a package containing lithium batteries caught fire as the plane was climbing. The fire spread to other packages, and it continued for twenty-three minutes. The crew noticed the smoke and requested urgent assistance. The plane attempted to return to Dubai Airport, where it had taken off from, but due to the flames engulfing the aircraft, it crashed onto the highway, resulting in the loss of two pilots' lives (IATA,2016).

UPS Airlines Flight 6: In 2010, a fire believed to have started from lithium-ion batteries in the cargo resulted in 2 fatalities near Dubai International Airport.

2011 Cargo Flight B747-400F: In 2011, a Cargo Flight B747-400F faced a dire situation when a fire broke out, attributed to the presence of lithium batteries among the cargo. The fire ignited in the palletized cargo area, particularly around positions 4 or 5 on the main deck, within Fire Zone 3. The cargo held a mixture of goods, including a significant quantity of lithium batteries, known for their susceptibility to combustion. This incident underscored the hazards associated with transporting lithium batteries and the urgent need for stringent safety measures in handling and transporting such volatile materials aboard aircraft (IATA, 2016).

Asiana Airlines Flight 991: In 2011, the aircraft involved the loss of aircraft and crew on board. The cause of the accident was determined to be an onboard fire on or near a pallet of dangerous goods. The fire was so intense that it caused the fuselage to separate in midair as the crew was attempting to divert to Jeju International Airport (Walton and Marion, 2020).

In addition to the fatal accidents mentioned above, there have also been DGR related accidents/incidents that caused numerous serious consequences. On April 22, 2013, at 18:58 (Singapore time), Singapore Airlines flight SQ446 took off from Singapore Changi Airport with an Airbus A330 registered 9V-STO and headed towards Dhaka, Bangladesh. Eighty-four minutes into the flight, the flight crew received a smoke warning indicating a possible issue with the rear cargo compartment (which consisted of an aft cargo compartment for cargo containers and pallets and a bulk cargo compartment, separated by a cargo net), while they were cruising at 36,000 feet over the Gulf of Thailand, approximately 8.1 NM off the coast of Thailand. The investigators discovered ethanol, an ignitable substance that may have started the fire, but they were unable to identify the heat source required to ignite the ethanol (Aviation Accidents, 2018).

On October 27, 2019, a Boeing 737-900 that had been pushed back at Paris CDG and was ready to taxi was alerted to an under-floor hold fire warning. All passengers were disembarked non-emergency since there was no evidence of fire in the passenger cabin or during an external inspection by emergency services. After the concerned hold was opened, it was found that the passenger wheelchair's overheated lithium battery was the cause of the fire damage. Numerous shortcomings in the relevant loading processes and the adherence to the ones that were already in place were found during the investigation (Sky Brary, n.d.).

The accidents and incidents showed that all dangerous substances can affect the flight safety and operation safety. During the handling and carrying these substances all safety procedures must be implemented meticulously.

2.4. Examining Accidents from SMS Perspective

Accidents related to hazardous issues can cause serious damage to solutions and human health. Incidents and conditions such as chemical leaks, fires and explosions can have long-term effects and create fear and anxiety in society. Therefore, precautions must be taken and safety standards must be increased.

Examining such accidents from a SMS perspective is important to understand how safety is managed and improved in the aviation industry. SMS is an approach used to identify risks in advance, manage these risks and increase security in a systematic way. Examining accidents reveals how effectively this system works and in which areas it requires improvement.

When the ValuJet Flight 592 accident is considered from the SMS perspective, one of the main problems was the violation of regulations regarding the transportation of hazardous materials. It was revealed that SaberTech company delivered flammable oxygen generators to ValuJet without properly labeling them and transporting them in accordance with regulations. This incident revealed the lack of effective communication between organizations and the tragic consequences of not applying regulations correctly. In this case, it is understood that the risk analysis and hazardous material management processes within the scope of SMS are not effective enough. Such deficiencies are related to the lack or incorrect implementation of the management system.

2010 Cargo Flight B747, the fire that occurred on this cargo plane taking off from Dubai, shows that the risks related to the transportation of hazardous materials in terms of SMS have not been adequately analyzed and preventive measures have not been taken against it. It is understood that hazard identification and risk assessment processes, which are one of the basic elements of SMS, did not work effectively in this incident. The lithium batteries that caused the fire were not transported in accordance with certain safety standards, which led to the fire. In terms of identifying and

managing risks, physical measures such as fire-resistant cargo compartments may not have been taken.

September 3, 2010, UPS Air Cargo Flight 6 in Dubai, United Arab Emirates, crashed as a result of an in-flight cargo fire. The autoignition of a pallet of lithium batteries was determined by the accident investigation to be the source of the fire (Walton and Marion, 2020). In the UPS Flight 6 crash, it was determined that the fire was caused by lithium-ion batteries. This incident highlights the importance of regulations regarding the transportation of hazardous materials and their implementation in the field. When viewed from the SMS approach, it is seen that UPS does not take sufficient precautions in the dangerous goods transportation processes and its risk management system remains weak. Additionally, the difficulties faced by the crew in the event of a fire indicate that emergency procedures and crew training may not be sufficient. The need to make fire detection and extinguishing systems more effective can also be considered as an SMS improvement suggestion.

In 2011, an accident involving a fire on or near a pallet containing hazardous materials on an Asia Cargo Boeing 747-400F resulted in the loss of both aircraft and crew (Araib, 2015). 2011 Cargo Flight B747-400F, this incident also involved a fire caused by lithium batteries. The starting point of the fire and the way the fire spread indicate that the significant risks associated with the transport of hazardous materials on cargo flights are not adequately controlled. In the SMS approach, it is essential to analyze the potential risks of each flight in detail and develop appropriate procedures accordingly. In this case, the fire indicates that a systematic risk analysis was missing. Factors such as inadequacy of fire extinguishing systems and improper transportation of hazardous materials were effective in the occurrence of the accident.

In the Asiana Airlines Flight 991 accident, inadequate precautions in the transportation of hazardous materials and failure to intervene effectively against the fire can be considered as a serious SMS deficiency. The fact that the fire was caused by hazardous materials in the cargo compartment reveals the weakness of risk management systems. The lack of an effective control and monitoring mechanism during the transportation of hazardous materials has led to the failure to prevent such accidents. The reason why SMS is incomplete in such events is that the risks are not adequately analyzed and the control measures are inadequate.

All these accidents reveal the disasters that can occur if IMS is not implemented correctly. Hazard identification, risk assessment, compliance with regulations and continuous improvement processes, which are the basic elements of IMS, were missing in these incidents. Areas for improvement include:

Hazardous Materials Management: Stricter regulations and control mechanisms should be implemented when transporting high-risk materials such as lithium batteries.

Training and Awareness: Training should be increased so that the crew can respond quickly and effectively in emergency situations.

Fire Extinguishing Systems: More advanced fire detection and extinguishing systems should be used in cargo compartments.

Compliance with Regulations: Airline and maintenance companies must ensure full compliance with international regulations.

As a result, effective implementation of SMS is critical to preventing such accidents. These accidents show that systematic risk management, full compliance with regulations and a culture of continuous improvement are vital.

2.5. Safety Management System and HFACS

1972 saw the introduction of the Human Factors model by Edwards, a significant development that laid the groundwork for the SHELL model. Developed by Hawkins, this model initially did not offer an effective solution for managing errors, but it played a significant role in enhancing aviation safety (Helmreich, 1999). During this period, Human Factors gained prominence as an interdisciplinary field aimed at improving safety. The SHELL model, with its emphasis on the need to analyze human errors through various classifications, particularly the interaction between humans, technology, and the environment, played a crucial role in this evolution (Isaac et al., 2002). Following major accidents, Cockpit Resource Management (CRM) was adopted as a critical component in accident prevention, and it remains integral in CRM training today, helping aviators reduce human errors (ICAO Doc. 9859, 2013; Helmreich, 1999).

A significant shift in safety thinking occurred with James Reason's concept of "organizational error" (1995). This framework transformed the understanding of safety, highlighting that error reduction is not solely an individual responsibility but a shared duty across all levels of an organization. It stressed recognizing mistakes and addressing organizational issues at multiple levels. As a result, top management support and safety awareness became essential for building a robust safety culture, which is now considered the most effective way to identify and prevent safety risks (ICAO Doc. 9859, 2013).

Historically, human errors were often attributed to individual shortcomings or lack of knowledge. However, a more modern perspective, championed by Reason (1995), suggests that human errors are a natural part of behavior and that understanding these errors requires considering organizational factors. This shift in thinking calls for a broader approach to error analysis that incorporates organizational and managerial aspects (Isaac et al., 2002).

In recent years, global aviation safety standards have steadily improved, but the growing volume of air traffic necessitates continuous progress. The aviation community must ask, "What is the next step?" (Reason, 2000). Given that human error is inevitable, extending the root cause analysis of errors to include organizational factors is critical (Helmreich, 1999). The term "organizational accident" emerged to describe incidents where failures in organizational decisions and attitudes contribute to accidents (Reason, 1995).

The Safety Management System (SMS) is a systematic approach that has significantly contributed to improving safety at the organizational level. It employs both proactive and reactive methodologies to collect and analyze data, monitor known safety risks, and detect emerging issues (ICAO, 2013). The SMS framework lays the foundation for the transition to a comprehensive safety management approach. Additionally, the Human Factors Analysis and Classification System (HFACS) provides a detailed method for analyzing human errors, emphasizing that accidents result from a combination of individual errors and broader organizational and managerial failures (Shappell & Wiegmann, 2000). HFACS categorizes these errors into four key areas: organizational influences, supervisory errors, preconditions for unsafe acts, and unsafe acts themselves (Reason, 2000).

This study seeks to analyze an aviation accident using the HFACS model to explore how human errors occur. By examining organizational decisions, supervisory lapses, environmental factors, and individual errors, the HFACS model is an effective tool for understanding the root causes of accidents and preventing future incidents (Shappell & Wiegmann, 2000; ICAO, 2013).

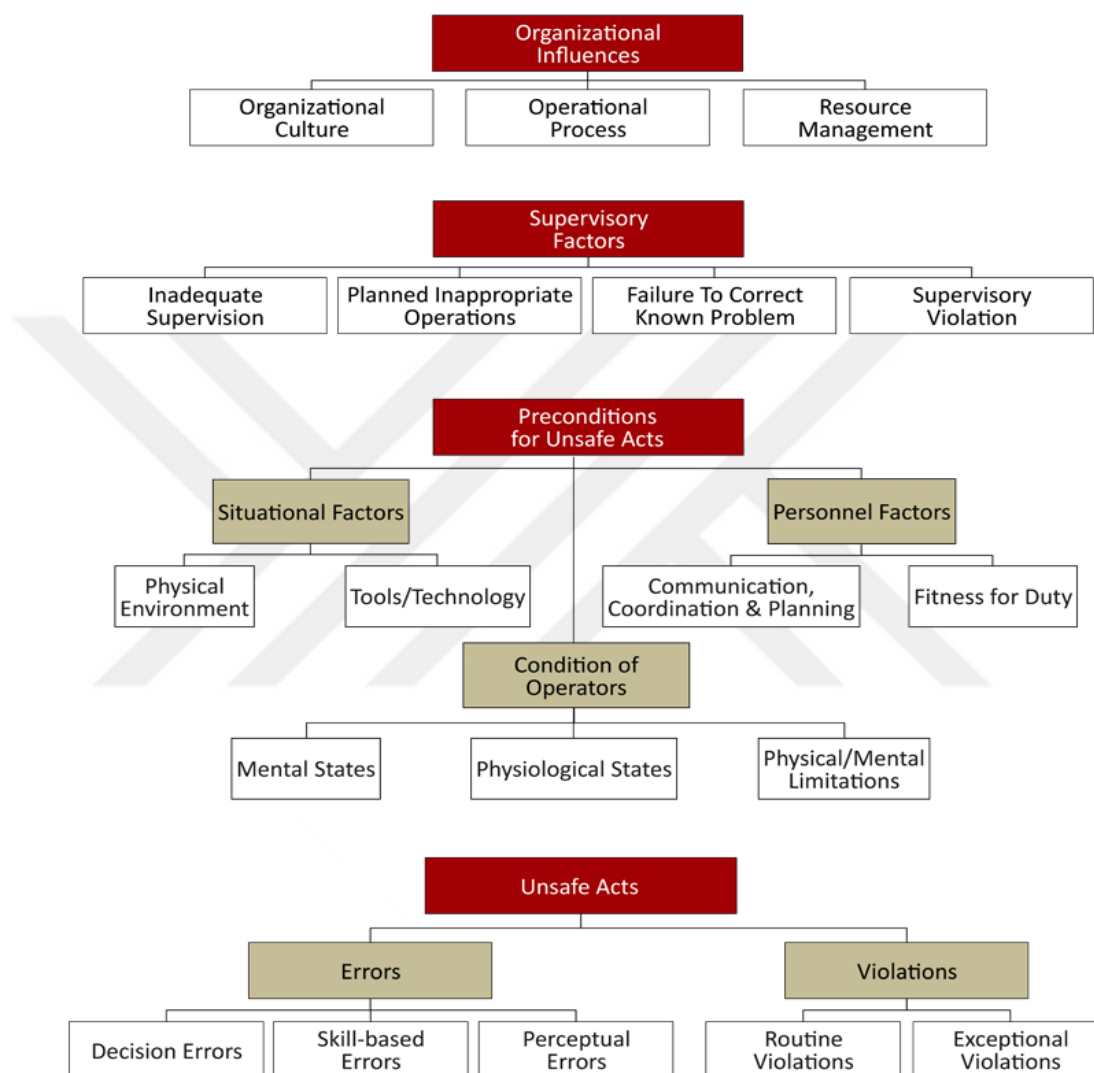


Figure 6. *HFACS framework*, (<https://www.hfacs.com/hfacs-framework.html>)

HFACS is a comprehensive framework used to analyze human errors. It was developed specifically to determine the root causes of accidents in aviation and other high-risk industries. HFACS examines not only the apparent causes of accidents or incidents, but also their deeper causes, in four main categories: supervisory errors, organizational effects, dangerous actions, and security vulnerabilities. This system is schematically expressed in Figure 6.

The descriptions were adapted from Wiegmann and Shappell (2003), incorporating changes to Australian English and explaining the external influence category (Australian Transport Safety Bureau, 2010).

i. Unsafe Acts of Operators

Operators' (aircrew) unsafe acts can be classified into two main categories: errors and violations (Reason, 2000). Although typical, they differ significantly when considering an organization's rules and regulations. Errors represent authorized behavior that fails to achieve the desired result, while violations refer to deliberately disregarding rules and regulations. HFACS categorizes errors into three types (decision, skill-based, and perceptual) and violations into two types (routine and exceptional).

Errors

Decision Errors:

These errors involve intentional actions that go according to plan, but the plan is flawed or inappropriate. These are often termed "honest mistakes" and manifest as poorly executed procedures, wrong choices, or misinterpreting relevant information.

Skill-Based Errors:

Skill-based errors occur without conscious thought and are related to automatically performing tasks. These "doing" errors result from failures in attention or memory and can appear as omitted checklist items, forgotten intentions, or accidental activation of controls.

Perceptual Errors:

Perceptual errors occur when the sensory input is degraded, such as in poor weather or night flying. These errors arise from misjudging distances or altitudes due to incomplete or imperfect information.

Violations

Routine violations are habitual and often tolerated by supervisory systems. Exceptional violations are rare, and unlike routine violations, they are neither typical

of the individual nor condoned by management. Routine violations involve slight rule-bending, while exceptional violations involve serious breaches, like flying beyond the authorized limits in hazardous weather.

ii. Preconditions for Unsafe Acts

Merely addressing unsafe acts is like treating symptoms without addressing the underlying cause. Therefore, it is necessary to explore the preconditions leading to unsafe acts. HFACS identifies three categories of preconditions.

Operator Conditions

Operators' mental, physical, and emotional states can significantly impact their performance. For instance, loss of situational awareness, fatigue, or distraction can affect decision-making. Similarly, physical conditions such as hypoxia, illness, or spatial disorientation can lead to errors during flight.

Environmental Factors

The physical environment (weather, terrain, altitude) and technological environment (aircraft controls, automation) also play crucial roles. Poor weather conditions or a lack of clear visual cues can cause disorientation, while poorly designed controls or automation can lead to errors in operation.

iii. Unsafe Supervision

Supervisors play a critical role in ensuring safety. Failures in supervision, such as inadequate training, improper crew pairing, or failure to address known issues, can lead to unsafe conditions for flight crews.

iv. Organizational Influences

Upper management decisions regarding resource allocation, safety policies, and operational procedures have far-reaching effects on safety. Poor resource management, conflicting policies, or unclear procedures can create environments where errors and accidents are more likely to occur.

2.6. Analysis of ValuJet Aircraft Crash with HFACS

This analysis underscores the importance of systematically addressing human factors within safety management systems. It illustrates how these factors contribute

to aviation accidents and how they can be effectively analyzed using the HFACS model. It's important to note that errors leading to accidents are not confined to individual pilot mistakes; organizational and managerial failures also play a critical role. The HFACS model is a highly effective tool for identifying the root causes of human errors and preventing accidents.

The application of the HFACS model can be further exemplified through real-life cases where these elements converged to result in catastrophic outcomes. One such case is the ValuJet Flight 592 crash, which demonstrates how individual and organizational failures contributed to the disaster. This tragic event underscores the significance of the HFACS model in understanding and preventing such incidents.

The ValuJet Flight 592 crash occurred on May 11, 1996, when a McDonnell Douglas DC-9 crashed into the Florida Everglades shortly after takeoff from Miami International Airport, claiming the lives of all 110 passengers and crew on board. Upon investigating the causes of the crash, it became clear that multiple factors, including the airline's practices, the transport of hazardous materials, and human errors in maintenance, all played a role. In this analysis, the root causes of the crash will be evaluated in detail using the HFACS model.

1. Organizational Influences: At this level, the company management strategies, resource usage, and organizational culture that led to the crash are addressed.

Resource Management: ValuJet operated as a low-cost airline, which caused the company to keep its safety and maintenance budgets to a minimum. Aircraft maintenance services were outsourced to inadequately equipped and trained external suppliers, which led to serious deficiencies in maintenance quality.

Organizational Climate: The company's rapid growth and pressure to meet low cost targets led to a lack of safety protocols. The safety culture was weak, and flight safety decisions were made with financial constraints in mind.

Management Decisions: ValuJet's senior management knew that safety procedures were not being followed adequately on the aircraft and that hazardous materials were being handled incorrectly, but they did not intervene. This lack of oversight resulted in poor maintenance and safety standards.

2. Supervisory Failures: Supervisory failures include managers' lack of control over personnel and organizational oversight failures.

Improper Supervision: The aircraft responsible for the accident had previously experienced maintenance problems, but the methods employed by the company's maintenance supplier, SabreTech, were not adequately supervised. Lack of training and incorrect practices, particularly regarding the handling of hazardous materials, were ignored.

Failure to Prevent Improper Actions: SabreTech improperly packaged and labeled the oxygen generators carried on the aircraft. These generators started the fire that was the direct cause of the accident. Although the control mechanisms were aware of this dangerous situation, no corrective action was taken. **Planning Errors:** Hazardous materials carried on the aircraft were not transported according to proper procedures. Although the instructions on how these generators should be transported were clear, lack of control and implementation led to the accident.

3. Preconditions for Unsafe Acts: This layer evaluates individual human errors and environmental factors.

Environmental Conditions: Improper handling of oxygen generators caused an in-flight fire. Oxygen generators were known to be fire-sensitive, but proper safety precautions were not taken to prevent the fire.

Human Errors: SabreTech employees allowed the generators to be carried on the aircraft without realizing they were dangerous and without following the required procedures. Lack of training on hazardous materials caused these employees to fail to follow proper procedures.

Communication Issues: Maintenance workers and managers were not effectively communicating how to handle hazardous materials. Lack of training and communication within the company led to improper practices that led to the accident.

4. Unsafe Acts: This layer evaluates human errors that directly led to the accident.

Intentional Actions (Errors): SabreTech employees failed to properly label and package oxygen generators carried on the aircraft. This negligence caused the generators to act as a igniter that caused the aircraft fire.

Unconscious Violations: Existing legal regulations and safety protocols regarding the transportation of hazardous materials were violated. Oxygen generators were not carried properly and necessary warnings were not made. This situation was among the negligences that directly affected the accident.

The ValuJet Flight 592 accident clearly shows how human factors can cause a chain reaction accident. This analysis using the HFACS model reveals that the accident was not only a technical or individual error, but also organizational errors, lack of control and wrong decisions. The lack of stricter controls and effective management practices, especially in critical areas such as maintenance services and hazardous material transportation, play a major role in preventing such accidents.

The HFACS model is a valuable tool for deeply analyzing the root causes of accidents and preventing similar errors from recurring. The ValuJet accident is an important lesson in how human errors can become systemic and lead to major tragedies, especially in the aviation sector.

2.7. Strategies for Reducing Risks Caused by Dangerous Goods

With the proliferation of hazardous chemicals in circulation, the risk of accidental leakage, fires, and explosions escalates across various stages, including production, storage, transportation, utilization, and waste disposal. These incidents result in casualties, economic setbacks, and ecological harm, underscoring the urgent need for stringent safety measures and preventive strategies (Deng et al., 2020). The widespread presence of hazardous materials makes their transportation a significant concern in industrialized societies across all stages (Liu et al., 2018).

This study which examines fatal accidents resulting from the air transportation of hazardous materials underscores that incidents in the air transportation of hazardous substances primarily arise from human error, technical malfunctions, and regulatory deficiencies (Fishman, 1999; Matthews and Kauzlarich; 2000; IATA, 2016; Walton and Marion, 2020). Human error, attributed to miscommunication, inadequate training, and fatigue, significantly contributes to incident occurrence while technical malfunctions, encompassing equipment failures and mechanical errors (Dumitru and Boşcoianu, 2015).

Given the inherent risks associated with transporting hazardous materials, including the potential release of dangerous substances leading to fatalities and environmental damage, it is essential to undertake proactive measures to minimize these risks as much as possible (Ghazinoory and Kheirkhah, 2008). To address these issues, potential solutions have been provided in Figure 7 below.

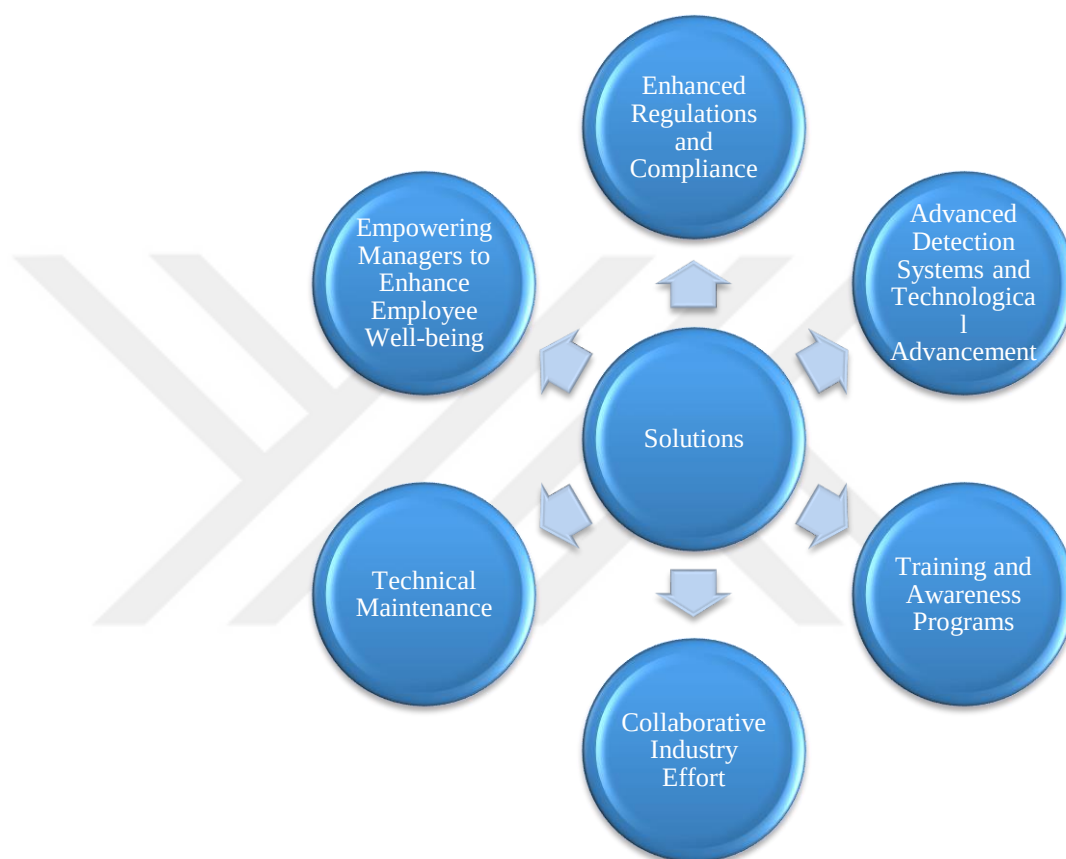


Figure 7. *Potential Solutions to Prevent Accidents of Dangerous Good Transportation by Air* (Ghazinoory and Kheirkhah, 2008; Liu et al, 2018; Wang et al., 2022; Dumitru and Boşcoianu, 2015; Mathavara and Ramachandran, 2022)

As evident from the provided information, potential solutions to prevent accidents in the transportation of dangerous goods by air include (Ghazinoory and Kheirkhah, 2008; Liu et al, 2018; Wang et al., 2022; Dumitru and Boşcoianu, 2015; Mathavara and Ramachandran, 2022):

- Enhanced Regulations and Compliance
- Advanced Detection Systems and Technological Advancement
- Training and Awareness Programs

- Collaborative Industry Effort
- Technical Maintenance
- Empowering Managers to Enhance Employee Well-being

Enhanced Regulations and Compliance: Enhancing scientific safety production supervision and strengthening regulations governing the transportation and handling of hazardous materials, including lithium batteries, are both vital strategies for preventing and managing risks associated with the transportation of dangerous goods. Governments must prioritize the implementation of stricter laws and regulations to standardize transportation practices and enforce rigorous measures such as labeling, packaging, and storage requirements. These measures aim to minimize the risk of accidental ignition and other potential hazards, ultimately ensuring public safety and reducing the likelihood of environmental damage or harm to individuals. By comprehensively regulating the transportation of hazardous materials, authorities can mitigate risks and enhance overall safety in the transportation industry (Liu et al, 2018).

Furthermore, all operations involving the transportation of dangerous goods by air must adhere to the instructions outlined in Annex 18. This international agreement establishes comprehensive guidelines for ensuring the safe handling and carriage of hazardous materials. Specifically, one of its standards mandates compliance with the Technical Instructions for the Safe Transport of Dangerous Goods by Air. Furthermore, Annex 18 requires states to establish robust inspection and enforcement procedures to verify that dangerous goods are transported in accordance with these instructions. By strictly adhering to the provisions of Annex 18, operators can uphold the highest safety standards in the transportation of hazardous materials by air, thereby minimizing risks to both aircraft and occupants (ICAO,2024).

Advanced Detection Systems: Implementing advanced detection systems is paramount for enhancing safety in air transportation, particularly within aircraft cargo holds where fire incidents pose significant risks. Advanced fire detection and suppression systems are crucial for swiftly identifying and containing such incidents, minimizing damage, and ensuring overall safety during air transport. Additionally, ongoing innovations targeting the safety of lithium batteries through novel designs and packaging materials play a vital role in risk mitigation efforts. Luminescence-based sensors utilizing metal-organic frameworks (MOFs) offer heightened sensitivity and

precise identification of hazardous substances, representing a significant advancement over traditional methods and holding promise for further enhancing safety protocols in air transportation. Moreover, the emergence of Standoff Quartz Enhanced Laser Photoacoustic Spectroscopy (QE-LPAS) technique and the utilization of external cavity quantum cascade lasers (ECQCL) in detection systems showcase continuous innovation in detecting hazardous chemicals, biological agents, and explosives, further bolstering safety measures (Zhao et al., 2022; Sharma et al., 2013; Sun et al., 2022). Furthermore, recent studies have explored the use of ground robotics equipped with sensors to assess situations in enclosed unventilated rooms, demonstrating innovative approaches to detecting gas distributions and enhancing safety measures in various environments (Zhao et al., 2022; Sharma et al., 2013; Sun et al., 2022 ; Gerhardt, 2014).

Training and Awareness Programs: Many accidents occur owing to decision-making failures in accident prevention. Training and awareness programs play a crucial role in addressing this issue by providing comprehensive training to airline personnel and ground handlers on the proper handling and storage of hazardous materials. These programs educate employees about the various psychological, physiological, and cognitive factors that influence their decision-making processes when dealing with hazardous materials. By enhancing their understanding of these factors, personnel can make more informed decisions and identify potential error-prone situations, thus mitigating risks effectively. Moreover, increasing awareness of potential hazards and best practices enables employees to make better decisions in emergency situations, leading to prompt and effective responses. Through interactive workshops and simulations, participants develop the skills needed to navigate human factors effectively, contributing to improved safety, accident prevention, and emergency response effectiveness in the aviation industry (Wang et al., 2022; Dumitru and Boşcoianu, 2015).

Collaborative Industry Efforts: Assessing and managing the risks associated with hazardous materials requires collaboration across various scientific disciplines and governmental policy branches, as emphasized by Thomson (1999). International cooperation is vital to ensure the effectiveness of hazard assessments and the development of comprehensive solutions for aviation safety, particularly concerning the transportation of hazardous cargo. This collaboration involves airlines,

regulatory bodies, manufacturers, and other stakeholders. Furthermore, multi-sectoral collaboration, as highlighted by Wei et al. (2020), is essential for improving regulatory success rates, promoting legal operations in enterprises, and enhancing government supervision. Such collaboration helps reduce regulation costs, increase departmental supervision enthusiasm, and impose reasonable fines for illegal transportation. Kokkinos et al. (2012) underscore the importance of collaboration in balancing risks and costs in achieving system objectives. Moreover, the National Research Council (2005) stresses the shared responsibility among shippers, carriers, regulators, and emergency responders at all levels of government and industry in ensuring the safe and secure transportation of hazardous materials. Thus, collaboration in research and across sectors is imperative for building a robust and secure system for hazardous materials transportation (Thomson, 1999; Wei et al., 2020; Kokkinos et al., 2012; National Research Council, 2005).

Technical Maintenance: Emphasizing the significance of regular maintenance is crucial in mitigating risks associated with technical malfunctions, including equipment failures and mechanical errors. Despite the transportation industry's commendable safety record, accidents involving hazardous materials can occur, leading to significant consequences due to the nature of the cargo. To reduce risks associated with hazardous material (hazmat) transportation, various measures can be implemented. These include driver training and ensuring regular vehicle maintenance, among others. Such proactive measures play a pivotal role in enhancing safety standards and minimizing the likelihood of accidents during the transportation of hazardous materials (Erkut et al., 2007).

Empowering Managers to Enhance Employee Well-being: Top management should create a supportive work environment aimed at mitigating both physical and mental stress among employees. It's widely recognized that individuals exposed to emotional stressors like pressure, distraction, fatigue, and stress are prone to making judgment errors in their tasks. Therefore, management ought to foster a culture that promotes open communication and transparency, encouraging employees to report errors without fear of reprisal. Many employees may hesitate to disclose unintentional mistakes due to concerns about job security, underscoring the importance of building trust and psychological safety within the organization (Mathavara and Ramachandran, 2022).

By addressing these underlying factors and implementing proactive measures, the aviation industry can significantly reduce the occurrence of accidents attributed to transportation of dangerous materials by air, thereby enhancing passenger safety and operational resilience.



CHAPTER III

CONCLUSION

The ValuJet Flight 592 accident is a stark reminder of how human errors and organizational deficiencies in aviation can have fatal consequences. The HFACS model analysis demonstrates that these kinds of accidents are not solely the result of individual errors but rather a culmination of systemic failures, including flawed decisions, inadequate inspections, and insufficient safety practices at the organizational level.

This tragedy was initiated by inspection deficiencies, insufficient training, and incorrect decisions, particularly in hazardous materials transportation and maintenance processes. The accident underscores the critical need for a safety culture in aviation that extends beyond technical competence, encompassing organizational practices, management decisions, and individual responsibilities. The ValuJet disaster is a powerful warning that neglecting safety measures in favor of cost-saving strategies can result in the loss of human life. To prevent such disasters in the future, the aviation industry must implement stricter inspections, foster a stronger safety culture, and ensure the effective execution of comprehensive training programs. The in-depth analysis provided by the HFACS model offers valuable guidance for developing proactive strategies to prevent similar accidents.

While vital to modern logistics, the transportation of dangerous goods is fraught with risks that can have catastrophic consequences for both human life and the environment. This research delves into the harsh reality of fatal accidents involving hazardous materials, particularly within air transport. By reviewing the literature and analyzing past incidents, this study sheds light on the urgency of implementing proactive risk mitigation strategies. The fatal accidents examined in

this research highlight the consequences of lapses in safety protocols and regulatory oversight. From catastrophic explosions to environmental damage, these incidents reveal the loss of life and systemic failures in risk management within the transportation industry. This research provides critical insights for civil aviation researchers, focusing on incidents caused by hazardous materials. It includes a detailed analysis of the ValuJet accident using the HFACS model. Future studies can build upon these findings to propose preventive measures. This research analyzes contributing factors in previous accidents to identify areas in dire need of improvement. It emphasizes the importance of comprehensive risk assessments and rigorous safety protocols aimed at empowering stakeholders to take proactive steps to prevent future tragedies.

Beyond academic inquiry, this research's findings have significant implications for public policy, industry practices, and regulatory frameworks. By increasing awareness of the inherent risks associated with dangerous goods transportation, this study advocates for meaningful actions to enhance safety standards. This includes the adoption of advanced technologies, the development of robust training programs, and the creation of stringent oversight mechanisms to ensure compliance with safety protocols. Additionally, this research highlights the intricate relationship between regulatory frameworks and operational practices in shaping hazardous material transportation safety. By exploring this dynamic, the study offers opportunities for regulatory reform and collaboration within the industry to reduce risks and prevent accidents.

In conclusion, this study's findings emphasize the urgent need to address the risks associated with the transportation of hazardous materials. By highlighting the severe consequences of fatal accidents, this research seeks to inspire collective efforts to build a safer and more sustainable future. Through collaboration, proactive risk management, and a commitment to safety, the transportation industry can minimize the dangers posed by hazardous materials and protect the well-being of current and future generations.

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