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Human Factors in Air Cargo Operations: An Analysis Using HFACS

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Abstract

Human factors are the primary causal factor of freight-aircraft accidents. Despite dramatic improvements in flight safety, the number of accidents in air cargo transportation remains stubbornly high. The present paper aimed to classify the causal factors of freight-aircraft accidents. In this study, we examined investigation reports of 15 freight-aircraft accidents that occurred over the past decade. For the analysis of causal factors, HFACS (Human Factors Analysing and Classification System) was used as a comprehensive human error framework. To the best of our knowledge, this is first the work that examined the causal factors of freight-aircraft accidents by using HFACS. Based on the results, skill-based errors were the primary contributing factors, followed by inadequate supervision and the technological environment as the second and third most significant contributing factors. The results presented here may provide important insights into the causality of freight-aircraft accidents and help organizations (e.g., airlines and air-cargo operators) and individuals (e.g., pilots, loadmasters, and ground handling staff) to prevent similar occurrences in the future.

Keywords: Accident Investigation, HFACS, Human Factors, Air Cargo, Aviation Safety
JEL Classification: L91, L93, Y80

Hava Kargo Operasyonlarında İnsan Faktörleri: HFACS ile Bir Analiz

Öz

İnsan faktörleri kargo uçağı kazalarına sebep olan başlıca faktörlerdendir. Uçuş emniyetindeki çarpıcı gelişmelerine rağmen, hava kargo taşımacılığında meydana gelen kazaların sayısı yüksek seviyededir. Bu makalenin amacı kargo uçağı kazalarına sebep veren faktörleri sınıflandırmaktır. Bu çalışmada, son 10 yıl içinde meydana gelen 15 kargo uçağı kazası incelenmiştir. Kazalara sebep olan faktörlerin analizi için kapsamlı bir insan faktörleri analiz aracı olan HFACS kullanılmıştır. Bu çalışma bildiğimiz kadarıyla kargo uçakları kazalarını HFACS ile inceleyen ilk çalışma özelliğini taşımaktadır. Elde edilen sonuçlara göre kazalara sebep veren faktörler arasında birincil faktör olarak yetenek hataları bulunmuştur. Yetersiz yönetim ve teknolojik çevre ise ikinci ve üçüncü en yüksek oranlara sahip faktörlerdir. Burada sunulan bulgular kargo uçaklarının kazalarına sebep veren faktörlerin iç yüzünün anlaşılmasını sağlayabilir ve şirketlerin (örn. havayolları ve hava kargo şirketleri) ve kişilerin (örn. pilotlar, kargo yükleme uzmanları ve yer hizmetleri görevlileri) benzer kazaları önlemelerine yardımcı olabilir.

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Anahtar Kelimeler: Kaza Araştırmaları, HFACS, İnsan Faktörleri, Hava Kargo, Havacılık Emniyeti
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INTRODUCTION

Air cargo transport plays a vital role in the economic development of countries (Kasarda and Green, 2005; ICAO, 2015). The demand for the air freight industry has been increased dramatically over the past two decades (Boeing, 2018). To meet the increased demands, the growth of global air cargo operations has shown a twofold increase every ten years since 1970 (Chang et al., 2007). Furthermore, air cargo volumes registered a significant global growth rate (3.5%) in 2018 (IATA, 2018a). Based on the forecast published by IATA, the number of world's freighter aircraft will increase from 1770 to more than 3000 in the following 20 years (IATA, 2018b). In parallel with these growths in the air freight industry, the number of cargo aircraft accidents has been increased (IATA, 2020a).

The Airline industry suffered twenty fatal accidents in 2019. 6 of the 20 accidents were cargo airplane accidents. 21% of the 316 accidents occurred between 2014-2018 involved freighter operation. Moreover, nearly half of the 41 fatal airliner accidents were freighter aircraft accidents (Jackman, 2020). A large and growing body of literature has examined the development strategies for the air freight industry, the dangerous goods airfreight, and air cargo security (Chang et al., 2007; Huang et al., 2019; Hoffman, 1998). However, far too little attention has been paid to the causality of air cargo accidents. Previous studies have primarily concentrated on the causality of commercial passenger airline accidents (Mizrak and Mizrak, 2020; Li et al., 2008; Daramola, 2014). However, to the best of the authors knowledge, no previous study has investigated the causality of freighter aircraft accidents by using HFACS. With these considerations in mind, this study aims to examine the contributing factors to those freighter aircraft accidents mentioned above.

HFACS is one of the most frequently used conceptual frameworks for the investigation of human error in aviation accidents (Shappell and Wiegmann, 1997; Havle and Kılıç, 2019). This analytical tool has also been utilized to analyze accidents and incidents in different disciplines such as medicine (Diller et al., 2014), mining (Lenné et al., 2012), railway (Zhan et al., 2017), emergency medical transport (Boquet et al., 2004), surgery operations (El Bardissi et al., 2007), and maritime (Chauvin et al., 2013). Furthermore, the HFACS method has been applied to examine contributing factors of training flight accidents and hot-air balloon accidents recently (Kilic, 2019; Kilic, 2020).

In this paper, the contributing factors (active and latent failures) of air cargo accidents have been examined and classified by implementing the HFACS method. This study provides an exciting opportunity to advance the understanding of causality of air cargo accidents and may help to improve the overall safety of aviation.

1. LITERATURE REVIEW

1.1. Air Cargo Operation

Air cargo operation has become an indispensable part of aviation by direct routing and minimizing transport time since the world's first cargo flight took place on 7 November 1910 from Dayton to Columbus, Ohio (Allaz, 2005). It has been suggested that 52 million metric tons of goods were transported in 2016 by airlines. This movement of air cargo accounted for more than 35% of global trade. (IATA, 2015). Moreover, air cargo traffic is projected to increase twofold in volume in the next 20 years (Boeing, 2018).

Along with this significant growth in air cargo operation, however, air cargo operators face serious challenges due to the type of goods that are carried by cargo aircraft (IATA, 2020b). The transport by air of dangerous goods, perishables, pharmaceuticals, high-value items, and live animals are the most challenging goods that possess some risks to operators and aircraft (Huang et al., 2019). Furthermore, the transportation of the above-mentioned goods is associated with some risks such as fuel-cost management, restrictions and regulations, on-time delivery, and safety issues regarding air cargo operations (Feng et al., 2015). FedEx Express, United Parcel Service (UPS) Airlines, and DHL Express Group are the major companies that mostly dominates the air cargo sector (Air Cargo World, 2017). Table 1 demonstrates the top 10 air cargo carriers ranked by scheduled freight tonne-kilometers flown (IATA, 2019).

Table 1. Top 10 Air Cargo Carriers- Scheduled Freight Tonne- Kilometers Flown

Rank	Airline	Millions
1	Federal Express	17,499
2	Emirates	12,713
3	Qatar Airways	12,695
4	United Parcel Service	12,459
5	Cathay Pacific Airways	11,284
6	Korean Air	7,839
7	Lufthansa	7,394
8	Cargolux	7,322
9	Air China	7,051
10	China Southern Airlines	6,597

Source: IATA, 2019

It is also remarkable that cargo operations are intrinsically different from passenger operations. A great number of differences between cargo and passenger transport have been reported (Bartodziej et al., 2009; Leung et al., 2009). One of the main differences between cargo and passenger airline pilots is the work schedules (Bartodziej et al., 2009). It is highly likely that cargo pilots perform mainly night flights which may give rise to circadian rhythm disorders among pilots (BAA Training, 2018). It is a well-known fact that pilots suffering from circadian rhythm are prone to make failures and may threaten flight safety (Caldwell, 2012).

Cargo aircraft accidents are generating considerable interest over the past decade. According to the statistical summary of commercial jet airplane accidents published by Boeing, passenger flights are safer than cargo ones (Scheiderer and Eberman, 2010). Previous research has revealed that cargo flights pose several risks such as explosive and hazardous materials, aircraft hijacking and sabotage, and cargo crime which may contribute to an accident (Elias, 2009) More recently, the aviation safety network (ASN) gave a comprehensive review on the number of fatal hull-loss accidents in the last 10 years (Table-2).

Table 2. Number of Fatal Hull-Loss Accidents Per Year

Year	Passenger	Cargo	% of Cargo
2019	14	6	30
2018	11	3	21,42
2017	4	5	55,55
2016	9	5	35,7
2015	5	3	37,5
2014	7	10	58,82
2013	14	8	36,36
2012	11	7	38,8
2011	23	9	28,12
2010	22	8	26,66

Source: Flight Safety Foundation, 2020

In 2010, the rate of fatal cargo aircraft accidents among all airliner accidents was 26,66 percent. Cargo aircraft accidents account for 30% of the airliner accidents occurred in 2019. The percentage of cargo aircraft accidents in all airliner accidents remains stubbornly high.

1.2.Accident Causation and Analysis

Human error is accounted for 70-80 percent of accidents in aviation. Operators (pilots, air traffic controllers, load masters, cabin crew employee who are on duty for the flight operation) faces numerous challenges. The main challenges faced by pilots are psychological conditions (e.g., stress, complacency, and overconfidence)(Havle and Kilic, 2018; Kilic and

Ucler, 2019) and physiological conditions (e.g., hypoxia, medical illness, dehydration, and visual illusions)(Kilic and Soran, 2020) which may give rise to errors and violations.

To prevent future accidents, contributing factors of accidents related to human error have been identified and analyzed by human error frameworks such as Management Oversight and Risk Tree Model (MORT), HFACS, Swiss cheese model, and Accimap model (Vincoli, 2014; Shappell et al., 2006; Reason, 1990; Waterson et al., 2017). Among these accident analyses models, HFACS is one of the most widely used technical models in the literature for the investigation of human factors (Wiegmann and Shappell, 2003). It was developed based on James Reason's Swiss cheese model (Reason, 1990). This conceptual framework has been used to analyze accidents and incidents in various disciplines such as medicine (Diller et al., 2014), maritime (Celik and Cebi, 2009), oil and gas industry (Aas, 2008), construction (Xia et al., 2018), railway (Zhan et al., 2017), mining (Lenné et al., 2012), security (Fu et al., 2020) and aviation (Ancel and Shih, 2012; Li et al., 2008). Furthermore, this comprehensive analytical tool, HFACS, has been employed for investigation of contributing factors to aviation accidents and incidents by the FAA and the Australian Transport Safety Bureau (ATSB) (Shappell and Wiegmann, 2000; ATSB, 2004). The HFACS framework illustrates two levels of active failures (L1- unsafe acts and L2-preconditions for unsafe acts) and two levels of latent failures (L3-unsafe supervision and L4-organizational influences) (Figure-1). This comprehensive framework examines an accident within 4 levels and 19 subgroups. By implementing the HFACS method, both active and latent errors of an occurrence can be found out. Furthermore, it aids researcher and safety experts in anticipating accidents, being prepared, and in decreasing the number of accidents. Namely, proactive accident prevention can be accomplished by using the HFACS framework for the analysis of accidents and incidents. The contributing factor classification in HFACS is more practical than other accident analysis methods (e.g., the 24 model and the Swiss cheese model)(Fu et al., 2017; Kilic and Soran, 2019). With these considerations in mind, the HFACS model was implemented to analyze the causality of air cargo accidents.

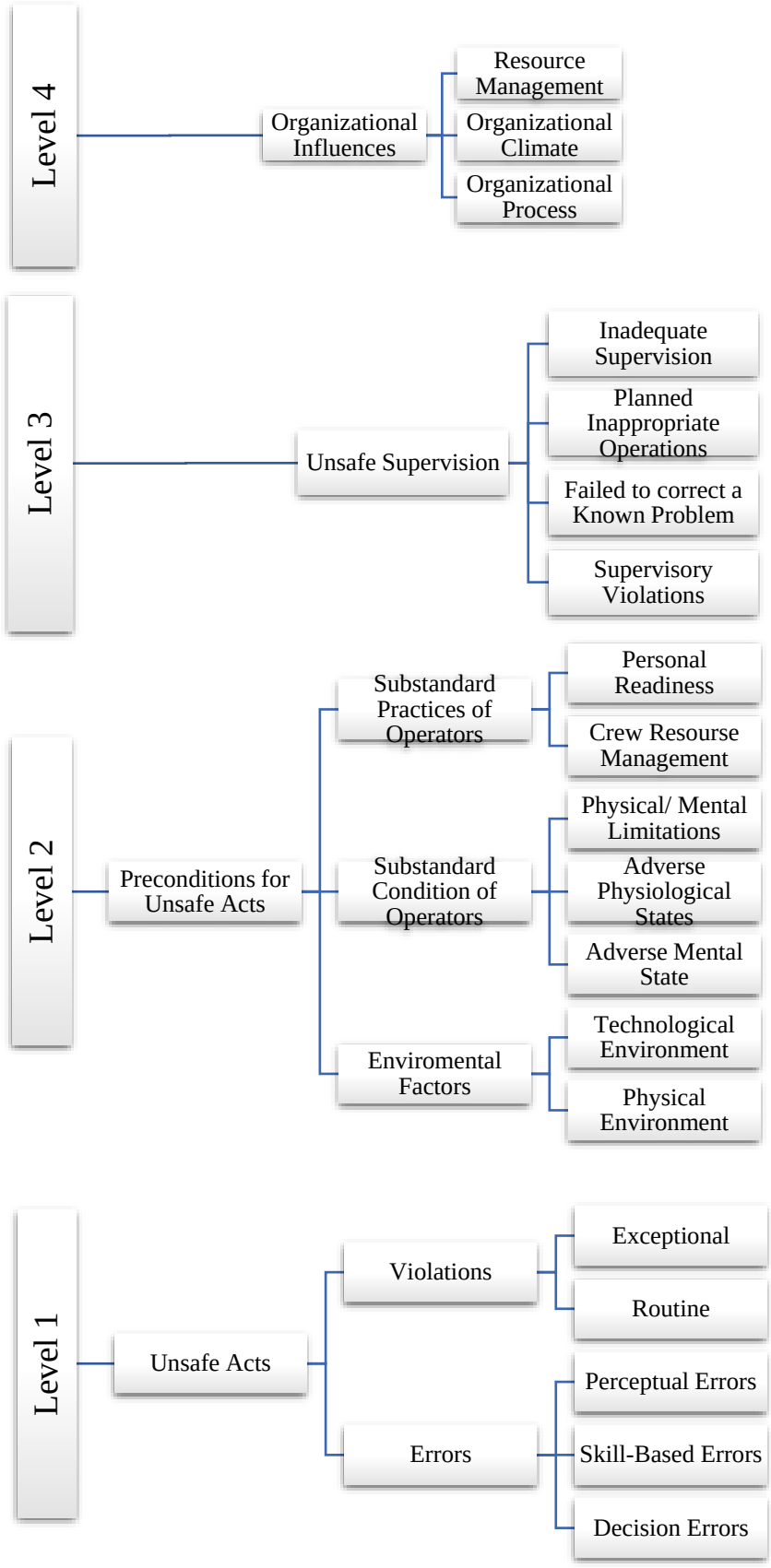

Figure 1. The HFACS Framework

2. METHOD

Air cargo accident data from the year 2010 to the year 2020 were taken from the NTSB accident and incident database. The following criteria were selected to run the query:

- Type of occurrence: Accident
- Operation: Part 121-Air Carrier
- Aircraft Category: Airplane
- Purpose of Flight: All
- Schedule: Non-scheduled
- Report Status: Probable Cause
- Injury Severity: Fatal & Non-fatal

Based on the query selection criteria mentioned above, 21 accidents were displayed. Out of 21 accidents, 6 were excluded from the study since they were non-revenue and non-scheduled flights. The accident report of 15 air cargo accidents was examined in total. We performed a coding process by using two codes (code 0 for the absence and code 1 for the presence of the contributing factors). During the data analysis, we used only the causal factors reported by the NTSB to prevent infusing conjecture, unwanted opinion, and guesswork into the coding process.

3. FINDINGS

In this work, 50 contributing factors underlying 15 cargo aircraft accidents were coded. The classification of contributing factors was carried out by using the HFACS framework. The results obtained from the HFACS analysis are set out in Table 3.

Table 3: The percentages of contributing factors by HFACS

HFACS Level	**HFACS Category**	**Frequency**	**Percentage of all accidents**
L1	Skill Based Error	8	**53,3**
L1	Decision Error	5	33,3
L1	Perceptual Error	3	20
L1	Routine Violation	2	13,3
L1	Exceptional Violation	0	0
L2	Physical Environment	5	33,3
L2	Technological Environment	6	**40**
L2	Adverse Mental State	0	0
L2	Adverse Physiological State	1	6,66
L2	Physical/Mental Limitation	1	6,66
L2	Crew Resource Management	2	13,33
L2	Personnel Readiness	3	20
L3	Inadequate Supervision	7	**46,66**
L3	Planet Inappropriate Operation	0	0
L3	Failed to correct a known Problem	0	0
L3	Supervisory Violations	0	0
L4	Resource Management	1	6,66
L4	Organizational Climate	0	0
L4	Organizational Process	5	33,3

The data analysis was performed by implementing an excel spreadsheet. The skill-based errors have the highest percentage of accident occurrence (53.3%). The second-highest percentage of causality (46.6%) was associated with inadequate supervision. The third-highest percentage of contributing factors (40%) resulting in cargo aircraft accidents was the technological environment.

4. RESULTS AND DISCUSSION

The finding of the present study suggests that human factors play a pivotal role in air cargo operations. The most significant contributing factors to cargo aircraft accidents are skill-based errors (e.g., failure to maintain the thrust manually, improper loading of the cargo pallets, and improper restraint of the cargo by loadmasters). This finding seems to be consistent with other studies that found that skill-based errors are the most common causal factors contributing to aviation accidents (Daramola, 2014; Kilic, 2020; Kilic, 2019). The second significant causal factor is inadequate supervision (e.g., inadequate technical inspection, failure to perform scheduled maintenance checks, and inadequate procedures). The third common causality of cargo aircraft accidents is the technological environment (e.g., fatigue failure of the main fuselage, corrosion and wear in the landing gear, and aircraft systems' malfunction).

The present findings also suggest that decision errors (e.g., decision to continue an unstabilized approach and perform a landing without completing the abnormal checklist for the malfunctioning system) were associated with more than 30% of cargo aircraft accidents. 20 percent of the accidents within the present analysis were associated with perceptual errors (e.g., failure to monitor the decaying airspeed) which were very much in-line with previous results (Kilic, 2020). 13.3% of the cargo aircraft accidents occurred due to routine violations (e.g., descent and fly below the minimum approach altitude). This was in good agreement with previous findings (Shappell et al., 2006). Contrary to the findings of Kilic, physical environment (e.g., gusty wind and ceiling prevailed at the airport) is associated with less than half of the accidents within the present study (Shappell et al., 2017; Kilic, 2020).

What is interesting in this data is that the technological environment gave rise to 40 percent of the accidents. This is not in-line with previous findings (Shappell et al., 2006)(Kilic, 2020). In contrast to earlier findings, however, no evidence of contributing factors which classified within the category of supervisory violation was detected (Kilic, 2020; Havle and Kılıç, 2019). The most striking results to emerge from the data is that inadequate supervision (inadequate technical inspection, failure to perform scheduled maintenance checks, and

inadequate procedures) resulted in 46,6 percent of the cargo aircraft accidents which is good agreement with findings of past studies (Cline, 2018; Daramola, 2014). Five accidents (33%) involved contributing factors (e.g., inadequate oversight of cargo operation, non-standard operator's overhaul limit) which are classified in the subcategory "organizational process". Inappropriate training and documentation for ground personnel are associated with only one accident and classified in the subcategory "Resource management".

Out of the 15 accidents examined, 5 involved substandard practices. 2 (13%) accidents were associated with the subgroup crew resource management (e.g., communication problem between crewmember). We found much higher values for crew resource management with respect to those reported by Filho et al. (2019). In 2019, Kilic reported that only 4,29 percent of the training flight accidents occurred due to personal readiness (Kilic, 2019). Contrary to the findings of Kilic, 3 (20%) accidents were associated with the subgroup personnel readiness (e.g., lack of knowledge on procedures and regulations and the knowledge level of loadmasters and cargo operators). Surprisingly, it is found that physical and mental limitations accounted for 6,6 percent of the accidents and only one accident (6,6%) occurred due to adverse mental states. These findings significantly differ from previous results reported in the literature (Kilic, 2020; Wiegmann and Shappell, 2001). Of the 15 accidents within the present study, 2 (13,3%) resulted in fatalities.

5. CONCLUSIONS

The purpose of the current study was to analyze the contributing factors of cargo aircraft accidents. To the best of the authors' knowledge, this is the first work that examines the causality of cargo aircraft accidents by using HFACS. We have been able to demonstrate that skill-based errors, inadequate supervision, and technological environment were the most significant factors resulting in cargo aircraft accidents. Findings from the analysis of accident reports demonstrated the need for proper oversight of cargo operations and core supervisory competencies. It was also shown that proper training and documentation for loadmasters and cockpit crewmembers are the first priority for a safe air cargo operation.

A limitation of this study is that the cargo aircraft involved in accidents within the present analysis were relatively older aircraft such as Boeing 727, Douglas DC-9, and Douglas DC-10. These aircraft have been used in operation for very long periods. This longer aircraft operating time is highly likely the reason of technical issues (e.g., fatigue, wear, and corrosion) addressed in accident reports. Future research regarding the association between contributing factors would be interesting.

We believe that these results provide considerable insights into the causality of air cargo accidents. Furthermore, we believe that our findings might be useful for organizations, aviation professionals, and decision-makers to take preventive actions and improve aviation safety.

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