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Systematic Analysis and Classification of the Literature Regarding the Impact of Human Factors On Unmanned Aerial Vehicles (UAV)

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Abstract

The use of unmanned aerial vehicles (UAVs) in military and civilian areas is increasing day by day. Increased usage reveals risks related to accidents and crimes. Human factors are among the most important causes of accidents and crimes in aviation. Understanding the impact of these factors on unmanned aerial vehicles (UAV) operations is vital to prevent accidents and crimes. In this study, the literature on human factors in unmanned aerial vehicles is systematically reviewed and classified. As a result of the classification, it is aimed to understand which subjects are deficient or inadequate. In this way, it is tried to make recommendations for future research.

Keywords: Unmanned Aerial Vehicles (UAV), Human Factors, Literature Review, Classification

1. Introduction

Unmanned aerial vehicles (UAV) are defined as an aircraft class which can fly without a pilot being on board [1]. According to ICAO (2011), unmanned aerial vehicles are divided into two main groups as remote and automatic [2]. The first studies on unmanned aerial vehicles started in the military field during the First World War. In the Second World War, the use of unmanned aerial vehicles increased in that field [3]. Today, unmanned aerial vehicles are frequently used in military missions such as reconnaissance, attack, defense against other UAVs, targeting military training and demining [4].

In addition, unmanned aerial vehicles are used in many civilian areas. Civil areas of use include tracking natural disasters and search and rescue activities, monitoring agricultural areas and agricultural spraying, photography and video shooting from the air. In addition, unmanned aerial vehicles are preferred for many activities such as

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cartography, environmental observation, urban structuring, archeology, monitoring forest fires or public areas [3], [4].

As of August 2020, the number of unmanned aircraft registered only in the United States has exceeded 1.600.000. Approximately 480.000 of them are registered for commercial use and the rest are for entertainment purposes. Until this date, approximately 187.000 unmanned aerial pilots have been certified in US [5]. The use of unmanned aerial vehicles is predicted to be increasing all over the world in the future. For example, the volume of the world military unmanned aerial vehicle market is expected to reach $26.8 billion in 2025 [6]. The military and civilian unmanned aerial vehicle market in the world reached a total of $ 9.3 billion in 2019. This market is expected to increase by 15.5% annual compound growth rate and reach 45.8 billion dollars in 2025 [7]. Therefore, it is clear that the use of unmanned aerial vehicles will increase in all areas of the world in the next five years.

Intense use of unmanned aerial vehicles may lead to increased accidents and incidents if necessary precautions are not taken. While the number of unmanned aircraft accidents reported to the United States Federal Aviation Administration (FAA) was only 50 in February 2014, this number exceeded 200 in December 2016 [8]. The fact that unmanned aircraft usage will increase constantly indicates a possible rise in the number of accidents and incidents. Human factors play an important role among the factors that cause accidents and incidents. In this context, a better understanding of human factors on unmanned aerial vehicles will be very useful in preventing accidents and incidents in the future.

The purpose of this study is to review and systematically classify studies on human factors in unmanned aerial vehicles. In this way, it is aimed to understand the missing areas in the literature and make suggestions about future studies, which will result in a much better understanding of human factors in unmanned aerial vehicles.

2. Methodology

In this study, the literature published between 1945-2020 on human factors in unmanned aerial vehicles is initially reviewed. Among the studies found, duplicates and irrelevant studies are eliminated. In the next step, a content analysis is conducted to classify the studies in order to give the literature a systematic perspective. As a result, studies in the literature are systematically gathered in the main and subgroups. The analysis process used in this study is summarized in Figure 1. After the classification, literature is discussed in order to find out the missing areas and shed light on future research.

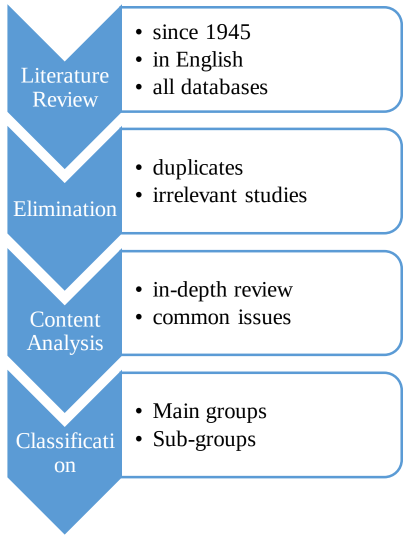

Figure 1. Analysis process

In the literature scanning phase, scientific journal articles, conference papers, books and book chapters published since 1945 have been included in the scan in order to make the widest possible screening. "Web of Science Core Collection", "KCI-Korean Journal Database", "Russian Science Citation Index" and "SciELO Citation Index" databases are covered by selecting "all databases" option. Search was made by selecting 1945-2020 as the scanning time interval and English as the scanning language. A series of searches have been carried out to find studies on human factors in unmanned aerial vehicles. The keywords “human factor” and “human error” are searched in combination with keywords “unmanned aerial vehicle”, “UAV”, “ unmanned aircraft”, “unmanned aviation system”, “unmanned aircraft system” and “UAS” in the “title”, “author keywords” and “abstract” fields of the studies. The study by Zhang et. al. (2018) was used as a guide for the selection of the keywords [9].

In the next step, all studies found are reviewed to identify duplicates and irrelevant ones. When duplicates and irrelevant ones are removed, the number of studies to be examined is 69. The number of scientific journal articles, conference papers and book chapters among these studies are given in Table 1.

Table 1. Number of Studies By Type

Type	Number of Studies
Scientific journal articles	40
Conference papers	27
Book chapters	2
TOTAL	**69**

3. Analysis and Results

After the scanning and elimination stages, a content analysis with an in-depth review of 69 studies is carried out. In this process, some common issues that the researchers focused on are tried to be determined. Shapell et. al. (2007), Chang and Wang (2010) and Wiener and Nager (2014) are used to define the classification of the studies [10]–[12]. In addition, the study by Zhang et. al. (2018) is taken into account for guidance in this process [9]. As a result of the content analysis, the studies in the literature are gathered in 4 main groups, and then the sub-groups that constitute each group are established by using the same method. The names of the main groups and the number of studies in each group are given in Table 2.

Table 2. Main Groups of Studies

Main Groups	Number of Studies
Familiarization of Human Factors	34
UAV Design and Ergonomics	18
Crew Members	11
Operational Issues	6
TOTAL	**69**

Main Group 1 – Familiarization of Human Factors

When the studies in the literature are reviewed, it is noteworthy that a significant part of them investigates the basic variables of human factors. There are studies on unmanned aircraft investigating variables such as workload, situational awareness, decision making and cooperation, which are also frequently studied in the field of human factors in aviation. For this reason, studies investigating the basic variables of human factors in relation to unmanned aerial vehicles are included in this main group. Then, sub-groups called "workload", "situational awareness", "decision making and autonomy", "fatique" and "collaboration, team harmony and coordination" are created and studies are distributed into the relevant subgroups.

However, some studies are exploring more than one of these factors simultaneously. For example, a study explores fatique, stress and vigilance at the same time. Another one examines fatique, crew size, and workload in the same research. Also, there is one that investigates situational awareness and workload. Because of this reason, such studies are gathered in a different subgroup called "Multiple factor research".

Another group of studies investigates accidents and incidents made with unmanned aerial vehicles. Some of these studies even investigate unsafe situations that can lead to an accident, called near-miss situations. The general purpose of these studies is to anatomize such events and find out the human factors contributing to the event. Researches that attempt to identify the human factors behind accident, incident or near-miss events are included in the subgroup named "Accident, incident and near-miss investigations".

The rapid increase in the use and number of unmanned aircrafts encourages researchers to study issues related to safety. The relationship between the human factors and safety, risk or emergency in unmanned aerial vehicles are deeply examined by some researchers. Some of the studies in this group address safety-related issues and man-made risks in terms of maintenance, improper selection of aircraft or airspace, and incorrect assessment of weather reports. Another study suggests anti-collision lighting and transponder systems that will increase the visibility of unmanned aerial vehicles and keep the safety above a certain level. Another study provides a theoretical framework on how unmanned aircraft systems can react quickly and safely to emergency situations and flight anomalies. These studies are different from ones in other groups, because they address human factors issues directly in terms of safety, risk or emergencies and make suggestions on how to improve safety and reduce risks. So, these studies are covered in a subgroup called "Safety, risk and emergency".

In the next subgroup, studies examining some personal parameters of unmanned aircraft operators are gathered. A study in this subgroup examines pilots' changing moods and emotional states under different conditions during the flight operations. In other studies heart rates, respiratory rates, inter-beat intervals and eye tracking datas of pilots are examined as anatomical responses of pilots' body to different filight situations. The subgroup containing these studies is called "Personal variables".

The studies in the last subgroup specifically explore the effects of human factors during multiple unmanned aircraft flights. Simultaneous operation of more than one unmanned aerial vehicle may create problems different from the individual flights. Many factors such as workload, cooperation, coordination and decision making may lead to very different consequences. The researchers who are aware of this examine those variables on multiple unmanned aircraft operations. For example, some studies in this subgroup investigate what and how the operator's performance, mental workload, and situational awareness are affected in multiple unmanned aerial flights. Some studies examine the operator's cognitive processes on multiple flights, how these processes change, and the operator's cognitive demands. So, these studies are gathered in the subgroup called "Human factors in multiple UAV operations".

The studies in each subgroup are given in Table 3 with references.

Table 3. Studies on Familiarization of Human Factors

Sub-groups	Reference
Multiple factor research	[13]–[16]
Workload	[17]–[20]
Decision making and autonomy	[21]–[23]
Situational awareness	[24]
Fatique	[25]
Collaboration, team harmony and coordination	[26]
Accident, incident and near-miss investigations	[27]–[31]
Safety, risk and emergency	[32]–[36]
Personal variables	[37]–[39]
Human factors in multiple UAV operations	[40]–[46]

Main Group 2 – UAV Design and Ergonomics

The studies in this group are exploring the effects of human factors on unmanned aerial vehicle design and ergonomics. They are also divided into two subgroups. The first group of studies deal with the effect of human factors on the design of user interfaces and displays of unmanned aerial vehicles. The effects of user interface and display designs and ergonomic structures on variables such as workload, situation awareness, and decision making are investigated. Many of these studies are focused on the development of optimal design or ergonomic structures that will reduce workload, increase situational awareness, affect the perception positively or help operators in making the right decision.

The studies in the second subgroup carry out a similar design and ergonomics approach on the control units and other systems of unmanned aerial vehicles. The effects of design and ergonomic structure of unmanned aircraft components such as flight management systems, navigation systems, avionics systems on human factors are deeply examined in these studies.

The common purpose of the studies in this group is to design unmanned aerial vehicles in a way that eliminates the negative effects of human factors. As a result of the developments in the design and ergonomic structure, it is aimed to ensure that the unmanned aerial vehicles are used more efficiently, effectively and safely by the operators. The studies in this group are given in Table 4 with their references.

Table 4. Studies on UAV Design and Ergonomics

Sub-groups	Reference
User interface and display design	[47]–[55]
Control units and other systems design	[56]–[64]

Main Group 3 – Crew Members

The studies in this group deal with crew issues in terms of human factors. They are divided into three subgroups. Studies in the first group examine crew behavior and behavioral responses under different conditions and scenarios. It is aimed to create crew behavior profiles based on human factors variables by evaluating crew responses to different situations. In this way, possible changes in the crew behavior as a result of the changing conditions may be predicted. In addition, behavioral routes that can lead the crew to make mistakes are investigated and at what stage and how these mistakes can prevented is examined.

The studies in the second subgroup view the crew selection, performance evaluation and crew competencies from a human factors perspective. Some of these studies address the crew's performance and competencies in terms of physical competence, medical condition, and even language proficiency. Some studies provide human factors-oriented suggestions for performance and competency assessments of unmanned aircraft pilots. In addition, human factors issues to be taken into consideration during the selection of people who will be trained as crew members are also examined in this sub-group.

The studies in the last subgroup focus on the training processes of unmanned aircraft pilots. In these studies, research is made on optimizing the training by using motion sensor simulators and similar devices. The aim of the studies is to contribute to the training processes, in order to train pilots who have positive attitudes, approach and behaviors in terms of human factors. The studies in this group are given in Table 5 with their references.

Table 5. Studies on Crew Members

Sub-groups	Reference
Crew behaviors	[65]–[67]
Selection, evaluation and competences	[68]–[72]
Training	[73]–[75]

Main Group 4 – Operational Issues

Studies in this group examine the actual flight operations and related tasks performed with unmanned aerial vehicles in terms of human factors. Only one study in this group suggests a system that will automatically and continuously control the degree to which operators comply with the flight procedures and checklists. For this reason, the mentioned study is taken into a different subgroup named “procedures and checklists”.

Other studies are included in the sub-group called "flight operations". Some of these studies are looking for ways to improve certain tasks of unmanned aerial vehicles such as package delivery, search and rescue and public services in terms of human factors. In addition, studies in this subgroup explore topics such as calculating the optimum number of aircraft an operator can control and distributing task parts between operators and systems. In addition, mathematical models are presented to prepare operators' working schedule in the most appropriate way to minimize the negative effects of human factors. The studies in this group are given in Table 6 with their references.

Table 6. Studies on Operational Issues

Sub-groups	Reference
Flight operations	[76]–[80]
Procedures and check lists	[81]

4. Discussions and Future Research

With the introduction of unmanned aerial vehicles in many fields and in recent years, the role of human factors in this field is gaining importance rapidly. Knowing the impact of human factors on unmanned aircraft operations is becoming more and more critical in terms of safety. In this study, a systematic overview of the literature on the human factor issues in unmanned aerial vehicles is presented. The studies are classified into groups and subgroups according to the subjects they deal with. In this way, it is aimed to understand what kind of work is being done, which topics are examined and what kind of work can be done in the future. In addition, it has been tried to determine in which subjects the studies are insufficient and in which subjects it will be beneficial to study more.

A clear result of the classification made in this study is that in the relatively new field of unmanned aerial vehicles, human factor studies are not yet sufficient in terms of number and depth. Moreover, it is striking that there are very few studies on variables such as workload, decision making, situation awareness, and fatigue, which are the main subjects of the human factors field. Investigation of how these variables change under different conditions, how they affect the effectiveness, efficiency and safety of flight operations will be beneficial for the future of unmanned aerial vehicles.

In addition, the complexity of missions performed with unmanned aerial vehicles requires multiple aircraft and crews to be involved in operations simultaneously. This poses many new challenges for flight safety and the effectiveness of the operation. Multiple unmanned aircraft operations can create significant problems, especially in terms of workload, situational awareness, cooperation, coordination and compatibility. In the literature, it is seen that very few studies only examine the variables of workload, situational awareness and cognitive process. However, in flight operations involving more than one unmanned aerial vehicle, the cooperation, coordination and harmony of aircrafts and operators become vital. Furthermore, even the smallest mistakes in following procedures and instructions can have serious negative consequences in these operations. In this regard, there are lots of issues to be studied regarding multiple unmanned aircraft operations.

Besides, operational issues such as creating the calendar that will allow the crew to work most efficiently, managing handover processes and checking compliance with procedures and checklists are becoming more critical in complex tasks. Studies to address these issues in a systematic way are almost nonexistent. Efforts to incorporate solutions of such problems into operational processes in a way that eliminates the negative effects of human factors will help increase the efficiency, effectiveness and safety of operations.

The negative effects of human factors have the potential to emerge much more strongly when there are errors or omissions in systems, design or ergonomy of the aircraft. In this regard, the design and ergonomic structure of aircraft and its related systems should be evaluated together with the effects of human factors. Although the studies in the literature suggest some improvements, it is noteworthy that there are not enough studies in quantity and quality. Moreover, these studies appear to be of a more general nature. However, it will be useful to design the vehicles to be produced for specific purposes with a similar approach. Because unmanned aerial vehicles that will perform certain special tasks must have some vital features for the efficiency and safety of their operations. For example, the design and ergonomics of unmanned aerial vehicles should be explored in detail to perform certain tasks, such as complex search and rescue operations that require a long stay in the air, or cargo delivery flights in residential areas. However, such a study has not been found in the literature yet and there is a serious deficiency in this regard. Considering the tasks expected to be performed more frequently by unmanned aircraft in the future, studies investigating the basic design components of the aircraft to be used in these missions should be conducted.

Ethical Approval

Not applicable.

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