AN INVESTIGATION FOR MATURITY LEVEL AND ROADMAP OF UNMANNED AERIAL VEHICLE TECHNOLOGIES IN TURKEY

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ABSTRACT

AN INVESTIGATION FOR MATURITY LEVEL AND ROADMAP OF UNMANNED AERIAL VEHICLE TECHNOLOGIES IN TURKEY

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This research aims to investigate problems, needs of the UAV industry, and required actions for the future in Turkey, to determine technological maturity criteria, and to prepare a technology roadmap. Qualitative data collected through interviews with actors from institutions/enterprises operating in the UAV industry is analysed, and inferences about the Turkish UAV industry are made, and suggestions for findings are developed. Twenty statements prepared to determine the technology goals for the Turkish UAV industry are evaluated using the Delphi technique in two rounds, and a technology roadmap is developed on intelligent flight management of UAV swarms that are resistant to adverse conditions. Technology roadmap and maturity model are built through expert interviews. The maturity model proposed presents descriptive and prescriptive roles. The current state of the Turkish UAV industry is evaluated, conducting an application of the maturity model through a survey. The outputs of the study are presented with technical details, assessment of researcher, and policy recommendations.

Keywords: Unmanned Aerial Vehicle, Unmanned Aerial Vehicle Technologies, Maturity Model, Technology Roadmap.

ÖZ

TÜRKİYE’DE İNSANSIZ HAVA ARACI TEKNOLOJİLERİNİN OLGUNLUK DÜZEYİ VE YOL HARİTASI İÇİN BİR İNCELEME

Türk, Afşar
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Bu araştırma Türkiye’de İnsansız Hava Aracı (İHA) endüstrisinin sorunlarını, ihtiyaçlarını ve gelecek için yapılması gerekenleri değerlendirmeyi, teknolojik olgunluk kriterlerini tanımlamayı ve bir teknoloji yol haritası hazırlamayı amaçlar. İHA endüstrisinde faaliyet gösteren kurum/kuruluşlardan aktörlerle gerçekleştirilen görüşmeler ile toplanan nitel veri çözümlenerek Türk İHA endüstrisine ilişkin çıkarımlarda bulunulmuş ve bulgulara yönelik öneriler geliştirilmiştir. Türk İHA endüstrisi için teknoloji hedeflerini belirlemek amacıyla hazırlanan 20 adet ifade, iki turda Delfi tekniğiyle değerlendirilmiştir ve olumsuz koşullara dayanıklı İHA sürülerinin zeki uçuş yönetimi üzerine bir teknoloji yol haritası geliştirilmiştir. Teknoloji yol haritası ve olgunluk modeli uzman görüşmelerinden yararlanılarak hazırlanmıştır. Önerilen olgunluk modeli tanımlayıcı ve yol gösterici rolleri sunmaktadır. Olgunluk modelinin bir uygulaması yapılarak Türk İHA endüstrisinin mevcut durumu değerlendirilmiştir. Çalışma çıktıları teknik detaylarla, araştırmacının değerlendirmelerini ve politika önerilerini içerecek şekilde sunulmuştur.

Anahtar Kelimeler: İnsansız Hava Aracı, İnsansız Hava Aracı Teknolojileri, Olgunluk Modeli, Teknoloji Yol Haritası.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADS-B Automatic Dependent Surveillance-Broadcast

AGL Above Ground Level

AI Artificial Intelligence

ARM Anti-Radiation Munition

ATM Air Traffic Management

BLOS Beyond Line of Sight

C2 Command and Control

COMINT Communications Intelligence

COTS Commercial Of The Shelf

DF Direction Finding

EASA European Aviation Safety Agency

ELINT Electronic Intelligence

EO Electro-Optic

ESM Electronic Support Measures

EVLOS Extended Visual Line of Sight

EW Electronic Warfare

FAA Federal Aviation Administration

GCS Ground Control Station

GNSS Global Navigation Satellite System

GPS Global Positioning System

HALE High Altitude Long Endurance

HKK Turkish Air Force

HMI Human-Machine Interface

ICAO International Civil Aviation Organization

IFR Instrument Flight Rules

IR Infra-Red

ITU International Telecommunication Union

IW Information Warfare

LiDAR Light Detection and Ranging

LOS Line of Sight

MALE Medium Altitude Long Endurance

MAV Micro UAV

MEMS Micro Electro Mechanical System

ML Machine Learning

MSL Mean Sea Level

MTI Moving Target Indicator

MUAV Mini UAV

NASA National Aeronautics and Space Administration

NATO North Atlantic Treaty Organization

NAV Nano Air Vehicles

R&D Research and Development

RF Radio Frequency

RPAS Remotely Piloted Aircraft System

SAR Synthetic Aperture Radar

SATCOM Satellite Communications

SESAR Single European Sky ATM Research

SHGM General Directorate of Civil Aviation

SIGINT Signals Intelligence

SLAM Simultaneous Localization and Mapping

SME Small and Medium-sized Enterprise

SSB Presidency of Defence Industries

SSM Under Secretariat of Defence Industries

STB Ministry of Industry and Technology

SWaP Size Weight and Power

TCAS Traffic Collision Avoidance System

TDZ Technology Development Zone

TRL Technology Readiness Level

TSK Turkish Armed Force

TUAV Tactical or Medium-Range UAV

TUSAŞ Turkish Aerospace

TÜBİTAK Scientific and Technological Research Council of Turkey

UAV Unmanned Aerial Vehicle

UAS Unmanned Aircraft System

UCAR Unmanned Combat Armed Rotorcraft

UCAV Unmanned Combat Air Vehicle

UGV Unmanned Ground Vehicle

UMV Unmanned Marine Vehicle

US DoD United States Department of Defense

VFR Visual Flight Rules

VLOS Visual Line of Sight

VTUAV Vertical Take-off UAV

CHAPTER 1

INTRODUCTION

1.1. Statement of Problem

Application areas of UAVs are expanding depend on technologies which ensure presenting more effective, efficient, sustainable, and safe solutions compared to other systems such as manned air vehicles, satellites, and various systems and increasing needs. UAVs are extensively used in civil and military areas, and global competition will be getting higher in this industry. UAVs can be used for many applications such as R&D, disaster recovery, search and rescue, communications, border surveillance, precision agriculture, military missions, sea patrolling, traffic management, media, photography, entertainment, critical infrastructure monitoring, logistics, mapping and photogrammetry, environment and climate monitoring, and archaeology. New application opportunities are always available for UAVs in different fields. Volpe National Transportation Systems Center (VNTSC) (2013) expects that operations with UAVs will exceed operations with manned aerial vehicles, for both military and commercial domains by 2035. UAV industry experts such as from the Teal Group to the Association for Unmanned Vehicle Systems International (AUVSI), estimate the global UAV market is worth $6 billion to $12 billion, and commercial UAVs account for about 10%. The VNTSC also forecasts that the US commercial UAV market will reach $5 billion annually by 2035. It is expected that the global commercial UAV market will easily be several times that size for UAVs (Wyman, 2015). The US is the most important UAV actor in the world as the owner of 20% of the world's recorded projects with its 42 design centres. The US UAVs fleet contains 6,000 vehicles, ranging from micro UAV to HALE platforms. Future production values for the US are foreseen as $17.9 billion over the next ten years, and approximately half of the total production value on payload and Ground Control Station (GCS). US firms have approximately 66% of the world market. Turkey, with a geopolitical situation driving requirements, and blocked by technology transfer through purchasing US systems has a $4 billion requirement for UAVs over the next ten years and is developing a domestic industry to satisfy this requirement (Hayward, 2013). The UAV is considered as one of the most essential eight emerging technologies (Quindazzi, 2016; Eckert, 2016).

How the Turkish UAV industry can be developed should be examined, foresighted technology areas should be determined, and improvement measures should be investigated. Accordingly, this thesis seeks to answer the following research questions:

Main Research Question: How could the Turkish UAV industry be improved until 2035?
RQ 1: How can the technological maturity of the UAV industry be assessed in Turkey?
RQ 2: What should be the roadmap of foresighted UAV technologies until 2035 in Turkey?

1.2. Objective of the Research

Firstly, it is aimed to investigate the problems, needs of the Turkish UAV industry, and required actions for the future. A technology roadmap of the selected area is another objective of this research. Another aim is a maturity model that sets out the principles for evaluating the maturity of competencies of the Turkish UAV industry.

1.3. Significance of the Research

The outputs of the dissertation have implications for the state, UAV companies, Technology Development Zones (TDZs), research institutes, universities, and investors. This study, which examines the problems and needs of the industry, and required actions for the future, determines foresighted UAV technology areas and proposes a maturity model to evaluate Turkish UAV industry, is very important for the literature and Turkish UAV industry due to holistic and comprehensive approach.

1.4. Organisation of the Dissertation

Chapter 2 briefly reviews the history and technologies of UAVs.

Chapter 3 presents the UAV research in the world and Turkey. Studies are quoted from the literature. Conducted studies in Turkey are presented via developed platform samples and thesis studies.

Chapter 4 is a literature review on the technology roadmap. The methods used to develop technology roadmaps and sample roadmap studies in the field of UAV are presented in this section.

Chapter 5 includes maturity models. It is presented what the maturity model is, what are its features and how to develop.

Chapter 6 explains the research methodologies, techniques, and tools.

In Chapter 7, the research process and findings are included. The steps and results of the research are presented in this section.

Chapter 8 presents the conclusion of the research.

CHAPTER 2

UAV AND ITS TECHNOLOGIES

A UAV is an air vehicle that operates without an onboard human pilot. There are different terms such as UAV, Drone, Unmanned Aircraft System (UAS), and Remotely Piloted Aircraft System (RPAS) in literature. The Drone term was chosen in 1936 as the name of the target air vehicle project launched by the US Navy and started to be used as the general name of all target air vehicles. As the year 2010 approaches, the UAS term emerged. A UAS is a system that has several subsystems such as airframe, propulsion, navigation, flight control, communications systems, Ground Control Station (GCS), and payloads. In 2011, the International Civil Aviation Administration Organization (ICAO) restricted fully autonomous UAV systems from the scope, and RPAS term entered the documents (Fahlstrom & Gleason, 2012; Karaağaç, 2016). UAV term is used as a whole in this dissertation.

2.1 Historical Perspective

The idea of the flying machine was the first emerged approximately 2,500 years ago, in ancient Greece and China (Dalamagkidis, Valavanis, & Piegl, 2012). Pythagoras, Archimedes, and others studied the use of autonomous mechanisms for a variety of applications. The first reported autonomous flying machine is attributed to Archytas (Valavanis, Vachtsevanos, & Antsaklis, 2007).

Figure 1 A Picture of Flying Pigeon by an Artist

In 425 BC, Archytas built a mechanical bird, which was called as the “flying pigeon”. The flying pigeon was made of wood, balanced with weights and flew using air (possibly steam) enclosed in its stomach (Gellius, 1927 as cited in Dalamagkidis, Valavanis, & Piegl, 2012). It is reported that Archytas’ pigeon nearly flew at 200 meters until all energy was used. The pigeon could not fly again unless the mechanism were reset. During the same era in Ancient China at about 400 BC, the Chinese documented the idea of vertical flight. The Chinese applied this idea by top consisted of feathers on the end of a stick. The stick created enough lift before the free flight by hand spinning (Dalamagkidis, Valavanis, & Piegl, 2012). In 1483, Leonardo Da Vinci designed an air vehicle that is called Aerial Screw. The Aerial Screw that is capable of hovering had 5 meters in diameter. Aim of the Aerial Screw was to rotate the shaft, and enough force was applied to the machine could turn and fly. It is commented that this machine as the ancestor of today’s helicopter (Hiller Aviation Museum, 2004 as cited in Dalamagkidis, Valavanis, & Piegl, 2012). In 1508, Da Vinci also invented a mechanical bird that could flap its wings through a double crank mechanism (Dalamagkidis, Valavanis, & Piegl, 2012).

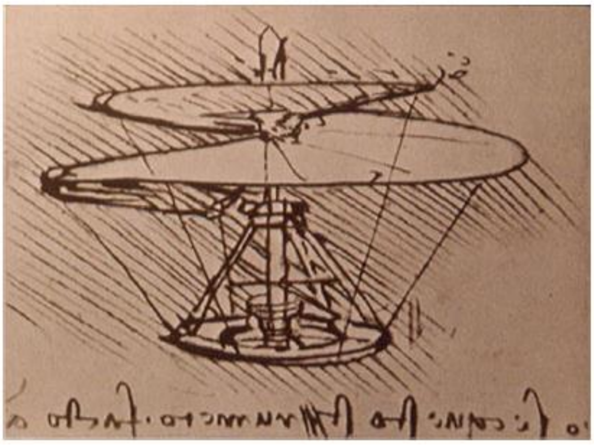

Figure 2 Da Vinci’s Aerial Screw

Figure 3 Hewitt-Sperry in 1916

In the 20th century, the first UAV was manufactured by the Americans Lawrence and Sperry in 1916 (Nonami, Kendoul, Suzuki, Wang, & Nakazawa, 2010). Several remotely controlled air vehicles were developed during and after World War I. Military applications continued to grow and promote UAVs in its early stages of development between World War I and the 1940s. After World War II, the success of UAVs led to use in other areas (VNTSC, 2013).

2.2 Classification of UAVs

There are different classifications in the literature; some of them are presented in this section.

- High Altitude Long Endurance (HALE): These UAVs operate at over 15,000 meters altitude with more 24 hour endurance. They conduct extremely long-range reconnaissance and surveillance missions.
- Medium Altitude Long Endurance (MALE): MALEs have 5,000 - 15,000 meters altitude and 24 hours of endurance.
- Medium Range or Tactical UAV (TUAV): TUAVs' range is between 100 and 300 kilometres. These UAVs are simpler systems than HALE and MALE.
- Close-Range UAV: These UAVs usually operate at ranges up to about 100 kilometres.
- Mini UAV (MUAV): MUAVs' weight is generally below 20 kilograms. Their range is up to 30 kilometres.
- Micro UAV (MAV): These UAVs are generally launched by hand. Winged versions have wingspan shorter than 150 millimetres, and have small wing loads. These UAVs are very vulnerable to atmospheric turbulence.
- Nano UAV (NAV): NAVs are generally used in swarms form for purposes like radar confusion. If cameras, propulsion, and communications subsystems can be made miniature enough, they can conduct ultra-short range surveillance missions.
- Vertical Take-off and Landing UAV (VTUAV): These UAVs are capable of vertical take-off and vertical landing, so this capability has operational advantages like hover flight. Rotary-wing UAVs are also less susceptible to air turbulence than fixed-wing UAVs.
- Unmanned Combat Air Vehicle (UCAV) and Unmanned Combat Armed Rotorcraft (UCAR): UCAVs usually carry weapons such as bombs, missiles, and laser guns. With the growing need for requirements, UAVs are armed and converted into UCAVs. UCAVs are broadly used for reconnaissance, surveillance, the direction of artillery fire, gathering intelligence, lasing targets, and post-strike damage assessment missions. UCAR is an advanced technology development program

launched by the Defense Advanced Research Projects Agency (DARPA) and the US Army. UCAR systems perform armed reconnaissance and attack missions.

- Balloon-Assisted UAV and Airship-Based UAV: A specific UAV design type is the lighter than air systems or airships. These UAVs have significantly higher endurance with their large size than other systems, and they fly at low speed. This advantage makes them ideal for a variety of operations, such as persistent area surveillance, meteorological data collecting, environmental monitoring with an airborne sensor platform (Austin, 2010; Nonami, Kendoul, Suzuki, Wang, & Nakazawa, 2010).

Another classification of UAVs are evaluated in four main categories according to their types (Limnaios, Tsourveloudis, & Valavanis, 2012):

- Fixed-wing UAVs: These UAVs need a runway to take-off and land. They can fly for a long time and at high speed according to the propulsion system.
- Rotary-wing UAVs: These UAVs that can take-off and land vertically have hover and high manoeuvre capability. These capabilities are particularly suitable for operations such as robotic tasks, monitoring specific area, delivery services.
- Blimps: These UAVs, such as balloons, airships can fly for a long time and at low speed. They can carry heavy payloads for long-endurance missions.
- Flapping-wing UAVs: They are UAVs that have flexible and flapping-wings and use a flying method similar to birds.
- Hybrid or interchangeable designs: These UAVs are designed as a mixture of the main categories.

Table 1
NATO UAV Classification[1]

Class	Category	Operating altitude (feet)	Range (km)	Duration (hour)
Class I (less than 150 kg)	Micro < 2 kg	AGL+200	5 (LOS)	1
	Mini 2-20 kg	AGL+3,000	25 (LOS)	< 2
	Small > 20 kg	AGL+5,000	50 (LOS)	3-6
Class II (150 kg to 600 kg)	Tactical	AGL+10,000	50 (LOS)	6-10
Class III (more than 600 kg)	MALE	AGL+45,000	Unlimited (BLOS)	24-48
	HALE	AGL+65,000	Unlimited (BLOS)	24-48
	Strike/combat	AGL+65,000	Unlimited (BLOS)	> 48

According to SHT-İHA published by SHGM on 21 April 2016, UAVs are classified under four classes in terms of their maximum take-off weights.

Table 2
SHGM UAV Classification (SHGM, 2016)

Class	Weight
UAV0	500 g (included) – 4 kg
UAV1	4 kg (included) – 25 kg
UAV2	25 kg (included) – 150 kg
UAV3	150 kg (included) and more

Also, SHT-İHA determines the mandatory equipment that the UAVs in these classes should have. According to this;

a) Equipping with technical device, system and payload components of a UAV which is in UAV0 class is up to the choice of the UAV operator/owner/pilot or manufacturer.

b) UAV in the UAV1 class must be equipped with at least the following specifications, equipment and system components:

[1] www.japcc.org/wp-content/uploads/UAS_CONEMP.pdf, Last access: 02.05.2020

- Urgent landing or flight termination capability in case of loss of Command and Control (C2) link,
- Monitoring of battery power/fuel level,
- Strobe lamp,
- Automatic flight recording system at UAV or GCS.

c) UAV in the UAV2 class must have the following equipment and characteristics as well as the necessary equipment for UAV1 class:

- Lighting lamps instead of strobe lamps,
- Redundant navigation system or redundant flight control system or computer,
- Redundant C2 data link,
- Appropriate communications systems to communicate with the air traffic unit when necessary.

d) In the UAV in UAV3 class, it must be equipped with the following system components as well as the necessary equipment for UAV2 class:

- Mode-S transponder,
- Sense and avoid systems such as TCAS (Traffic Collision Avoidance System), ADS-B (Automatic Dependent Surveillance-Broadcast).

Besides, the UAV, which is included in the UAV0 class that is intended to be used for commercial purposes, must be equipped with technical features, equipment and system components belonging to the UAV1 class at least (SHGM, 2016).

2.3 UAV Technologies

As a minimum, a typical UAV system is composed of an air vehicle, GCS, payloads, and data link. Some systems include launch and recovery subsystems, air vehicle carriers, and other ground handling and maintenance equipment (Fahlstrom & Gleason, 2012).

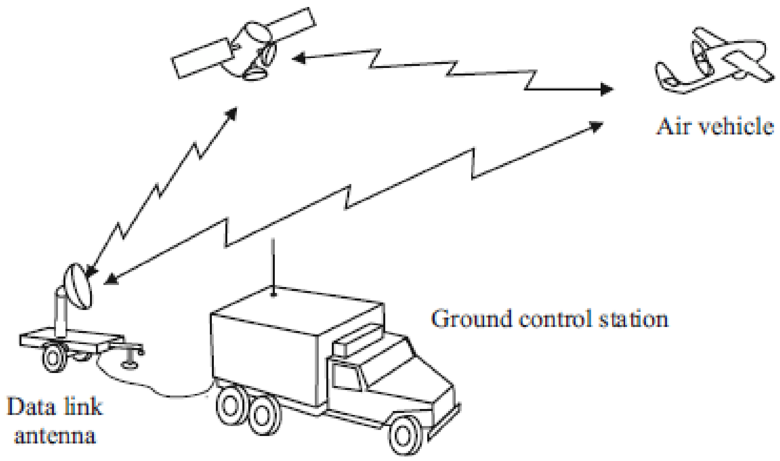

Figure 4 Generic UAV System (Fahlstrom & Gleason, 2012)

2.3.1 Air Vehicle

The air vehicle is the airborne part of the UAV that includes the airframe, propulsion, flight control, and electric power systems. The air data terminal is mounted in the air vehicle and is the airborne part of the communications data link. The payload is onboard the air vehicle, but the payload is defined as an independent subsystem that designed to accomplish one or more missions. The air vehicle may be a fixed-wing, rotary-wing, flapping-wing, a ducted fan, or hybrid. Airships and balloons are also termed as UAVs.

Propulsion is the source of power to produce thrust and lift, which is generated by the engine that moves a propeller or rotor or fan.

Batteries supply power for UAVs and the limit of batteries' energy-storage capacity affects the endurance of the UAVs. Batteries having a higher energy density are the subject of intense research.

Fuel cells allow the energy stored in a fuel to be converted directly into electricity, without intermediate steps such as burning fuel to generate heat energy and to convert heat energy to mechanical energy (Fahlstrom & Gleason, 2012).

2.3.2 Ground Control Station

GCS is the operational control centre of the UAV where command, various sensor and telemetry data from the air vehicle are processed and displayed. The GCS shelter incorporates a mission planning, control and display consoles, video and telemetry instrumentation, a computer and signal processing system group, the ground data terminal, communications system, environmental control and survivability equipment.

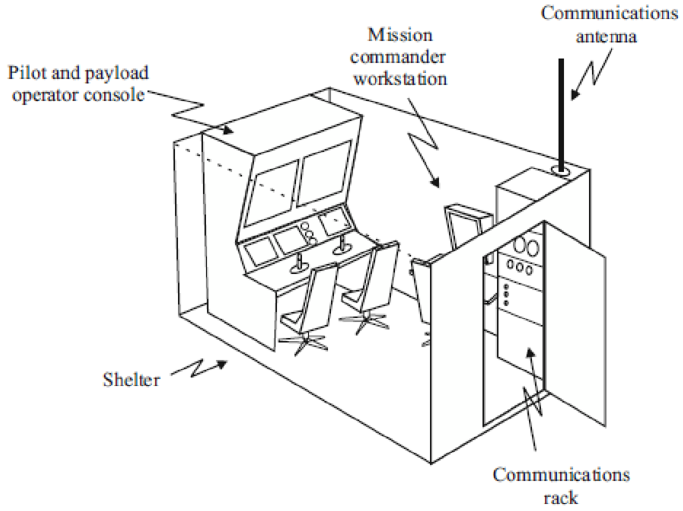

Figure 5 A Typical GCS (Fahlstrom & Gleason, 2012)

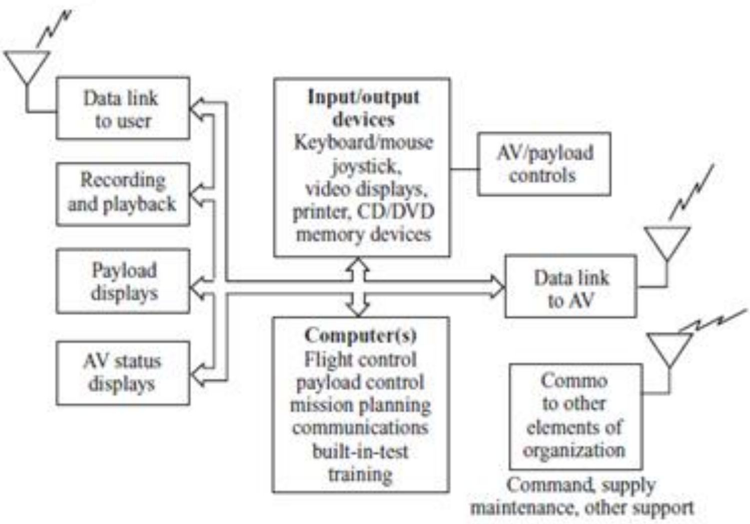

Figure 6 GCS Block Diagram (Fahlstrom & Gleason, 2012)

The GCS can also serve as the command post for the operator who performs mission planning, receives mission assignments, and reports acquired data and information, intelligence, or C2. In small UAVs, the GCS is contained in a box that can be carried in a backpack. GCS consists of remote control and a display, and these components are generally combined on a laptop or tablet. On the other hand, some GCSs are located in permanent structures far from where the UAV is flying, using satellite relays to maintain communications with the UAV (Fahlstrom & Gleason, 2012).

2.3.3 Navigation and Flight Control Systems

The flight control systems employ a feedback function. The actual state of the UAV such as flight path, attitude, altitude, airspeed is measured and electrically feedback and compared to the desired state. The error signal (i.e. difference) is amplified and used to position the appropriate control surface, which creates a force that causes the air vehicle to return to the desired state, bringing the error signal to zero. A functional block diagram of a closed-loop automatic control system is shown in Figure 7.

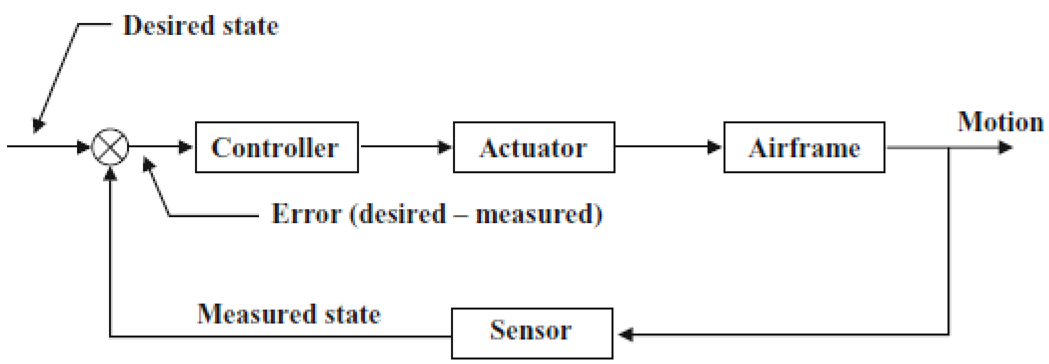

Figure 7 Block Diagram of the Control Loop (Fahlstrom & Gleason, 2012)

The sensors measure the UAV’s attitude, angular rate, airspeed, heading, altitude, and other functions. Measured parameters such as attitudes, altitudes are compared to desired situations, and if the parameters deviate beyond a predetermined amplitude, an error signal is generated that is used to move a control surface to compensate the deviation. The comparison function is conducted in the flight controller.

Actuators generate the force to move the control surfaces when commanded with signals from the flight controller. As the control surfaces move, actuators create forces that cause the UAV to respond. Sensors detect this response or UAV motion, and when the attitude, speed, or position remains within specified limits, their error becomes zero, and the actuators stop moving surfaces. The error signal is compensated so that the desired position or attitude of the UAV can be ensured. The system continuously searches for and adjusts to disturbances so that the UAV smoothly can fly. The navigation system operates in a similar manner, but the sensors are compasses, inertial systems, radar, and GPS receivers. Primary stabilisation is accomplished in the UAV in its determined attitude, altitude, and velocity state. Also, there is an outer loop that performs the task of manoeuvring and navigating the UAV. The outer loop is also used to capture guidance beams for electronically-assisted, namely automatic recovery. Flight control system block diagram is shown in Figure 8.

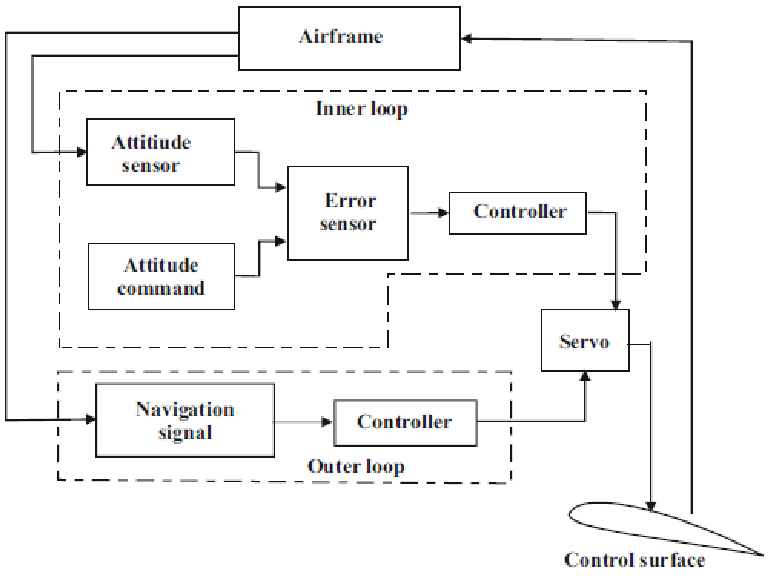

Figure 8 Flight Control System Block Diagram (Fahlstrom & Gleason, 2012)

The GPS makes it possible to determine altitude, airspeed, attitude, and UAV position based on satellite navigation signals rather than the variety of mechanical sensors (Fahlstrom & Gleason, 2012).

2.3.4 Communications Systems

The data link provides two-way communications for a UAV. An uplink provides a channel for control of the UAV flight path and commands to its payloads. The downlink provides a channel to acknowledge commands and transmit status information about the UAV for payloads data such as camera, radar.

Data links should have anti-jamming and anti-deception capabilities. The ground data terminal provides communications between the GCS and the UAV and transmits guidance and payload commands and receives flight status information and mission payload data. The air data terminal is the airborne part of the data link. This terminal includes the transmitter and antenna for transmitting payload and UAV data and the receiver for receiving commands from the ground (Fahlstrom & Gleason, 2012).

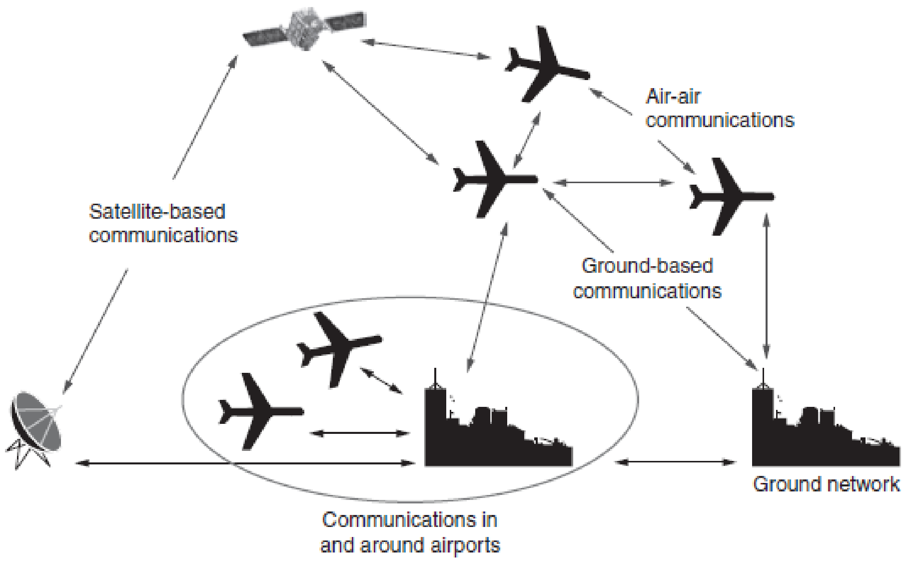

Figure 9 Data-Link Attributes (Fahlstrom & Gleason, 2012)

Interference from other emitters on the range might be encountered, but could be controlled based on operating frequencies. A UAV data link must be robust enough to operate anywhere that the user might need to test and operate in the absence of jamming. It requires that the link operates on frequencies that are available for assignment at any locations and that it is able to resist disruption by interference. On a battlefield, the UAV system may confront Electronic Warfare (EW) threats such as Direction Finding (DF) used to target artillery on the GCS, Anti-Radiation Munitions (ARMs) that home on the emissions from the ground data terminal, interception, exploitation, deception, and jamming of the data link. The data link should provide resilient security against these threats (Fahlstrom & Gleason, 2012).

2.3.5 Payload Technologies

Payload term explains the subsystems that are equipped to perform operational missions. The payloads include some systems such as sensors, weapons that perform missions such as reconnaissance, surveillance, EW.

The payload capacity of a UAV depends on Size, Weight, and Power (SWaP) optimisation to perform mission functions. UAVs usually include camera payloads for imaging for reconnaissance and surveillance missions. Radar sensors, often using Moving Target Indicator (MTI) and SAR technology, are also significant payloads for UAVs conducting reconnaissance and surveillance missions.

Another significant payloads category includes EW systems. Other sensors such as meteorological and chemical sensing devices are proposed as UAV payloads. Armed UAVs carry weapons or ammunition as payloads. Another use of UAVs is as a platform for communications relays to extend the scope and range of Line of Sight (LOS) (Fahlstrom & Gleason, 2012).

Radar

A radar system is simply based on reflected light or emitted energy from the target. Radar sensors can measure range to the target, based on the roundtrip time of the radar signal (Fahlstrom & Gleason, 2012).

EW

EW payloads are used to detect, exploit, and prevent enemy use of the electromagnetic spectrum. EW is an action involving the use of electromagnetic energy to determine, exploit, reduce, or prevent enemy manipulation of the electromagnetic spectrum and action which protects friendly use of the electromagnetic spectrum. The conducting of EW can be organised into the following three categories:

1. Electronic Support Measures (ESM) that involve interception and localisation enemy signals and analysing them. Intelligence gathering related to intercepted signals is known as SIGINT. If the signals are radar signals, the procedure is called Electronic Intelligence (ELINT), and Communications Intelligence (COMINT). The most common ESM payload used with current UAV systems is the radio direction finder. A typical DF system consists of an antenna and signal processor that sense the direction of received signals.
2. Electronic Countermeasures (ECM) are actions taken to prevent the hostile use of the electromagnetic spectrum. These actions often take the form of jamming. Jamming is the deliberate radiation of electromagnetic energy to compete with a hostile's incoming receiver signals. A jammer's energy can be concentrated on the receiver frequency. There is a great deal of potential for the use of UAVs, integrated with other systems, to provide jamming.
3. Electronic Counter-Countermeasures (ECCM) are actions taken to prevent hostile forces from conducting ECM against to friendly forces. UAVs may require ECCM techniques to protect their payloads and data links (Fahlstrom & Gleason, 2012).

Chemical and Nuclear Radiation Detection Sensors

The purpose of chemical detection payloads is detecting the presence of chemicals anywhere. Nuclear radiation sensors can perform two types of missions:

1. Detection of radioactive leaks in the atmosphere, to provide data for prediction and warning.
2. Detection of radiation signatures of weapons in storage or weapons production facilities, monitoring the nuclear distribution systems (Fahlstrom & Gleason, 2012).

Meteorological Sensors

Meteorological data is vital to all domains of life. Barometric pressure, air temperature, and humidity data and predicting future weather conditions are important for human life (Fahlstrom & Gleason, 2012).

Pseudo-Satellites

The emerging trend is the concept of UAVs that fly at very high altitudes with very long endurance can loiter over a wide area to provide a platform with characteristics of satellites. Some of the missions that are considered are:

- Forrest fire monitoring,
- Weather monitoring,
- Communications relay,
- Wide-area surveillance (Fahlstrom & Gleason, 2012).

CHAPTER 3

UAV RESEARCH IN THE WORLD AND TURKEY

It is presented obstacles to the growth of the UAV industry, UAV's airspace integration and regulation issues in the world; the first UAV development initiatives in Turkey, academic studies, theses and developed sample platforms by some Turkish companies are presented in this section.

3.1 Research in the world

Council of European Union (2012) emitted commission staff working report Towards a European Strategy for the Development of Civil Applications of Remotely Piloted Aircraft Systems (RPAS) named. UAV technologies are able to create new businesses and support industrial competitiveness is enormous. However, the emergence of the civil UAV market is handicapped by the lack of concept of operations and related technical enablers as well as a supporting regulatory framework.

UAVs are subject to aviation rules in all domains. Since there is no onboard human pilot, the safety objective is aimed at the protection of third parties so UAV flies in segregated airspace. European Aviation Safety Agency (EASA) is already engaged to the safe integration of UAVs into European airspace.

It is crucial frequency spectrum requirements. UAV must be provided with communications systems to ensure the safe navigation of the UAV in the airspace. The allocation of frequency spectrum supports functions such as C2 and sense and avoid. The frequency spectrum is a scarce commodity because of sharing by civil and military air vehicles. It is allocated based on the International Telecommunication Union (ITU) frequency regulations. Frequency spectrum availability is an essential factor for the growth of UAV applications and therefore, the UAV industry.

The social dimensions of UAV issues are related to the impact of civil UAV applications on society. The social dimensions are the responsibility in the case of an accident, liability for damage, insurance requirements for UAV operators, privacy and data protection laws, and social acceptance of UAVs.

The participants of the panel conducted by the Council of European Union agreed that third-party liability for damage caused by the UAV should be developed on the basis of manned aviation principles. Higher autonomy level reveals extra complexity in terms of responsibility and liability. Authorised experts concluded that strict liability would fall on the operator of the UAVs. The authorities should ensure that the operators comply with the applicable national and European regulations.

As with manned aircraft, a prerequisite for the granting of an operating license by European Union member states should be proof of insurance. Insurance requirements for air transporters and air vehicle operators are defined by regulation European Commission (EC) No. 785/2004 that covers the liability for passenger, baggage, and cargo and the risks related to acts such as war, terrorism, hijacking, and sabotage (EU, 2012).

Another essential issue against to UAV industry is privacy and data protection. Some examples of UAV systems that could have an impact on privacy and data protection issues:

- Visual recording equipment: the UAVs may contain payload capable of storing or transmitting videos, real-time images and sound, regardless of visibility conditions (e.g. using thermal cameras) and may have facial recognition capability.
- Radio Frequency (RF) device: the UAVs may be fitted with a device allowing the capture and eavesdropping of Wi-Fi access points and cellular base stations.
- Specific sensors such as Electro-Optic (EO), thermal cameras, Infra-Red (IR) scanners may be used to identify any objects and obtain information about objects under any condition (Cloud Security Alliance, 2016).

Societal impacts and acceptance affect the diffusion of UAV technologies. The public still feels uncomfortable with UAV because their predominant use concerns military missions. Therefore, the policymaking process supporting the development of civil UAV applications needs to be transparent and involve the consultation of stakeholders. Additionally, a certain range of uses of UAV could be defined to increase the citizens' confidence. Guidelines for specific civil applications of UAV would be based on a privacy and data protection impact assessment and involve related stakeholders.

An insurance market for large UAVs is emerging. In the current, the insurance framework is based on the framework for the manned air vehicle. This situation might cause obstacles for the insurance of light UAVs; therefore, an insurance scheme for small UAVs should be developed. Security researches could be useful for UAV state applications such as disaster relief, sea patrolling, border surveillance, public security.

Single European Sky Air Traffic Management Research (SESAR) Joint provides the link between standardisation frameworks, Air Traffic Management (ATM) regulations, and technology development. It is advisable that SESAR plays a role in researches for insertion of UAVs to airspace.

It was military the first to use UAV technology, and it is essential to avoid duplication in terms of resources and to benefit from the knowledge and development obtained in the defence industry for the development of the civil UAV domain. European Defence Agency and the European Space Agency are undertaken to advance UAV technologies. This situation indicates the usefulness of a streamlining of UAV Research & Development (R&D) at the European level to accelerate progress towards the objective of UAV air traffic integration. It could be done with the development of a research roadmap for UAV. This roadmap will ensure the development of standards and regulations with a comprehensive approach while ensuring overall coordination of UAV researches (Council of European Union, 2012).

Council of European Union's workshop (2012) identified the main technology developments required to support secure C2, data links, bandwidth allocation, insertion of UAVs into the ATM system, sense and avoid, situational awareness, and weather awareness.

According to De Garmo (2004), it is possible to mention about issues concerning the integration of UAV in civil airspace and they are summarised in Table 3.

Table 3
Issues for Integration of UAV in Civil Airspace

Issue	Factors
Safety	Collision avoidance, system reliability, human factors, weather
Security	Ground infrastructure, communications signal security, data security
Air Traffic	ATM, systems interoperability, information networks, communications, navigation, equipage, emergency flight recovery, airspace, surface operations
Regulation	Definition and classification schemes, standards, regulations, airworthiness certification, pilot certification
Socio-economic	Insurance liability, public acceptance, government investment, market, labour, and users

Since UAV are different from conventional air vehicle, there are some issues to be deliberated for risk management to integrate UAVs into urban airspace.

- Technology: Technological issues are complex systems, C2 link loss, and reliability of autonomous UAVs.
- Operation environment: It should be considered operations such as flying in non-ideal weather conditions (e.g. rain, strong wind), high altitude operations, flying in highly urbanised and congested areas with like high buildings.
- Performance: Determining the performance and capability of UAVs, such as climbing speed, endurance.
- Human Factors: Complexity of operational roles, human-machine interface issues, and human factors on safety.
- Security: UAVs are vulnerable to cybersecurity events such as hacking, interference from unwanted elements (Pathiyil, Low, Soon, & Mao, 2016).

Market barriers for civil UAV applications are presented below.

- Incomplete or immature airspace regulations,
- Liability for civil operations,
- No secure non-military frequencies,
- Negative consumer perception,
- Lack of operator training/safety standards,
- Limited payload capacity and space restrictions (Rosenberg, 2009; Zaloga & Palmer, 2008 as cited in Cavokian, 2012).

Cloud Security Alliance (CSA) (2016) presents issues on establishing safe and secure municipal UAV programs. The main UAV system challenges are:

- There is need for UAV manufacturers to improve security by integrating security practices into their development and manufacturing activities.
- It is the identification and handling of several integration issues within a city-wide UAV domain that can be used to attack like a cloud-based software service.
- Regulations are needed to recognise possible measures to deal with, such as fraudulent UAVs, evidence collection options, no-fly zones.
- It should be considered on the use of new, as yet unproven, algorithms to support automated operations and cooperation between UAVs.
- The fact that UAVs will eventually be authorised for pervasive BLOS, operations and security experts should plan to protect against threats of integrating UAVs into airspace.
- UAVs pilots can operate with anonymity. It may be challenging to locate the pilot as well as to identify the UAV.

The regulatory difficulties of emerging UAV industry provide some crucial lessons:

- Technology progresses more quickly than the regulatory process. Regulators had better set up initial rules so the industry can keep moving forward, rather than delay until more complex and comprehensive regulation schemes are developed. This approach should also be applied to complex privacy and data protection issues.
- Safety regulation should be risk-based. In the US, small UAVs operated by hobbyists are allowed to operate with minimal regulation, while the same UAVs

operated by businesses are prohibited. According to the Federal Aviation Administration (FAA)'s proposed rules, the two situations will continue to be treated differently. That is not a risk-based approach. The focus of limited regulatory resources should be on larger UAVs with more excellent capabilities and higher risk.

- New technologies require new regulations suited to the situation. Implementing manned flight regulations to manage small UAVs will not result in problems-compliant regulations. Imposing a Line of Sight (LOS) limitation on even the smallest UAVs does not support technological advances in remotely controlled navigation.
- An essential part of the regulatory process should be educating UAV operators and the public on safe operation. No system of fines and prohibitions will replace the need for UAV operators and the public to understand and support common-sense rules of operation such as distances from airports, maximum altitudes.
- UAV technology industry must engage with the regulators. Technology executives may have little interest in the regulatory process, but they must cooperate with regulators. In the absence of industry engagement, what the industry needs to be successful may be overlooked (Wyman, 2015).

United Nations Office for the Coordination of Humanitarian Affairs (OCHA) (2014) proposes some policies on humanitarian responses by UAVs. The future of the humanitarian use of UAVs is unclear. The regulatory issues are a significant obstacle and are likely to result in partial solutions of countries where UAVs can be used. Nevertheless, the trends seem clear: more sophisticated and cost affordable UAVs, more civil applications and growing public acceptance, and more regular use in civil protection and disaster response.

On the technical issues, humanitarian organisations seem likely to continue to rely on small, portable UAVs for disaster response. Although small UAVs have a limited range and endurance, these systems generally have the fewest legal concerns. The focus should be on developing the best practices and guidelines for UAVs' use in disasters and emergencies.

3.2 UAV applications in the world

Alsalam, Morton, Campbell, & Gonzalez (2017) describes a modular and generic system that can control the UAV using computer vision for precision agriculture applications. A configuration approach similar to the Observation, Orientation, Decision and Action (OODA) loop is implemented to provide the system to make the onboard decision. The detection of an object of interest is performed by using computer vision technique. It provides the UAV to change flight path accordingly and approach the target in order to perform operations such as close-range inspection, herbicide, and higher resolution agricultural images collection. The tests results show that the developed system can dynamically change its target and implement an inspection manoeuvre to perform required actions. The vision-based navigation and onboard decision making were demonstrated in tests. The results are measured based on the algorithm' the sensitivity and the selectivity. The sensitivity of the algorithm is the ability to identify and detect the correct positive target while the selectivity is the capability of the algorithm to filter out the false negatives targets. Results indicate 99% sensitivity and 100% selectivity at 5 metres Above Ground Level (AGL). The system is also can detect a red target with 96% sensitivity and 99% selectivity at the same height at 5 metres. It is concluded that the system has potential applicability in precision agriculture applications such as crop health monitoring, pest detection.

Several issues should be considered when applying the onboard system with the vision-based navigation for onboard decision making in precision agriculture applications. Weed detection is based on specific characteristics of the weed, which may be affected by the sun angle and seasonal variability. The existing detection method can be modified to ensure the weed can be detected accurately at different times of the day and different stages of growth.

Suggestions to improve the detection method include:

1. Using micro multispectral or hyperspectral camera to detect weed.
2. Using machine learning methods like deep learning based on extensive data collection to train the algorithm for more precise weed detection.

Drones for Disaster Response and Relief Operations (2015) that was prepared by multi-participants such as Boeing, Lockheed Martin, FAA, US Department of Homeland Security is a comprehensive report on disasters response and relief operations through UAVs. Beneficial information from this report is presented below.

There are many humanitarians, safety, and economic reasons to use UAVs before and after disasters. Some of the most promising use cases for UAVs in disaster relief:

- Reconnaissance and mapping,
- Structural assessment,
- Temporary infrastructure/supply delivery,
- Fire detection and fighting,
- High building fire fighting,
- Nuclear, biological, radiological, chemical, and explosive events,
- Search and rescue operations,
- Logistics support.

UAV technology can reduce disaster efforts and risk exposure to unnecessary danger. UAVs fly in environments that are unsafe for humans. The Japanese Atomic Energy Agency tests UAVs that measure radiation being emitted from the Fukushima Daiichi plant. These UAVs can operate much closer than manned air vehicle and remove the possibility of pilot irradiation. UAVs also provides an assessment of buildings and structures that were damaged and are unsafe for relief workers.

UAVs enhance the effectiveness of disaster relief workers. In addition to relieving disaster responders from dangerous tasks, UAVs can perform dull, dirty, and dangerous tasks to support responders to focus on more critical problems. For example, by providing situational awareness to disaster responders after Hurricane Katrina, UAV technology allowed responders to focus on the required tasks.

UAVs provide viewing angles not possible by manned air vehicle. A team used two small rotary-wing UAVs to assess damage to cathedrals in Mirandola, Italy, after an earthquake in 2012. This assessment was impossible with manned systems.

UAV technology is highly deployable, and rotary-wing UAVs can take-off in a variety of environments without the need for a runway. In the wake of Superstorm Sandy, FEMA satellite imagery of the disaster was not available because of persistent cloud cover. UAVs could be easily deployed within minutes after disaster strikes and fly under the clouds. UAV technology is cost-efficient compare to manned air vehicle in terms of purchasing and operating. Some functions can be employed in case of emergencies are summarised below.

Reconnaissance and Mapping: The need for continuous mapping of disaster areas cannot be overstated. Flood maps support coordinate disaster response efforts after disasters. 3D topographic mapping can help identify areas that are prone to mudslides. High-resolution imaging can identify critical infrastructures that need to be secured immediately after a disaster, and advances in remote sensing technology can provide early warning signs of potential disasters. Also, UAVs are more deployable than satellites and manned air vehicle and can construct higher resolution maps. Researchers at the University of New Mexico and San Diego State University developed a UAV-based remote sensing tool that detects minimal damage to transportation infrastructure after disasters such as hurricanes, earthquakes or floods.

Structural Integrity Assessment: Natural disasters and human-made disasters may cause significant damage to the structural integrity of buildings and infrastructure. In an instance, the 2011 Virginia Earthquake caused significant structural damage, such as the Washington Monument and the National Cathedral, although it measured only 5.8 on the Richter scale.

Assessment of structural damage after a disaster discloses many potential risks. Inspectors may have to enter buildings in danger of collapse or access hard places. UAVs present their usefulness in assessing structural damage over a wide area, locally, and even in building interiors.

Temporary Infrastructure/Supply Delivery: Natural and human-made disasters may destroy critical infrastructures such as water lines, roads, bridges, gas pipelines, power plants, electricity lines, and telecommunications lines. Disruptions in the functioning of critical infrastructure may have significant effects on human security. Potential impacts:

- Disruptions in electricity, water, and oil/gas distribution,
- Road destruction or blockages, affecting deliveries of needed items,
- Telecommunications interruptions.

UAVs not only can assess critical infrastructure damage, but they can also mitigate damage by providing temporary infrastructure and delivering needed supplies to survivors and disaster responders. UAVs can also effectively provide temporary telecommunications infrastructures that are affected by disabled power lines and damaged base stations.

Fire Detection and Extinguishing: Current fire detection and extinguishing methods are based on human efforts close to intense and volatile fires. According to the US Fire Service, fires in 2013 caused 34 firefighters' death and 29,760 people's injury. UAVs can help reduce the frequency and proximity that firefighters have to make with the fire. UAVs also provide better situational awareness, so firefighters avoid getting trapped by turning off flames or other hazards.

Air vehicles must operate at low altitudes in extreme conditions characterised by high temperatures, high winds, and low visibility during fires. Flying under such conditions is dangerous, risking the safety of the entire crew. UAVs eliminate these risks by allowing the pilot to operate from a safe distance. When applying retardants, this method can allow the UAV to engage the fire more directly.

High Building Fire Response: High buildings expose extreme challenges for fire efforts. Top floors are too high to be reached from the ground by the equipment. This situation prevents accessing these higher floors to rescue survivors and spray retardant or water on the flames directly. High buildings are generally located in dense, congested urban areas, difficult for manned flight among the obstacle-filled landscape. UAVs have able to mitigate many of these extreme challenges.

Nuclear, Biological, Radiological, Chemical, and Explosive (NBRCE) events: It is disastrous events heavy industry and hazardous chemicals and fuels. Malfunctions in factories or power plants, accidents, terrorism and sabotage have the potential to create chemical, biological or nuclear disasters. These destructive events require a fast and effective response. These actions' nature is exceptionally unsafe for relief workers. Characteristics of NBRCE events are:

- Toxic/radioactive/explosive environments,
- Unprepared/disrupted surfaces,
- Rapidly changing environmental situations,
- Lack of information and data on the extent of the disaster.

UAVs significantly reduce human exposure to unsafe environments while providing continuous monitoring and data validation in the most challenging conditions. Sending UAVs into an NBRCE area can help rescue workers quickly and safely locate sources of contamination and the size of the damage, providing situational awareness. UAVs can be used to recover the damage, quickly deliver needed equipment to teams, and apply chemical retardants or dispersants.

Search and Rescue Operations. There are many dynamic challenges search and rescue operations. Searching for people or debris in large areas such as deserts, oceans, mountainous and woodland can be very time consuming and challenging. These difficulties may lead to crew fatigue, decreasing their effectiveness in searching and increasing the likelihood of pilot error. Additionally, many rescue operations are carried out in hazardous environments. The use of UAVs in these situations allows operations to be conducted without exposing a flight crew to unnecessary danger. All dull, dirty, and dangerous operations are the best suited to UAVs.

UAVs are already proven their worth in search and rescue operations in multiple cases around the world. In 2014, an amateur UAV operator used aerial imagery by rotary-wing UAV to find an 82-year-old person alive in a bean field after three days of searching with dogs, hundreds of volunteers, and a helicopter were not able to find. In 2012, Texas-based search and rescue group EquuSearch used a UAV to find the remains of a two-year-old boy missing from the pool after the initial search effort failed. The search for the ground was particularly dangerous due to the presence of crocodiles, wild boars and venomous snakes in the surrounding bayou, and armed snipers accompanied the volunteers. Both of these cases were accomplished using high-resolution visual cameras. In partnership with the Utah County Search and Rescue team, researchers at Brigham Young University conducted experiments demonstrating the capabilities of small and micro UAVs equipped with high-resolution video cameras to find missing persons in simulations.

Logistics Support. The damage to infrastructure that occurs after significant disasters is often one of the most significant obstacles to effective disaster relief. Blocked or congested roads, damaged rails, and destroyed seaports and airports may severely affect disaster recovery by delaying delivery of needed supplies and equipment. UAVs provide an alternative for logistics support. UAVs can fly above destroyed infrastructure, particularly rotary-wing UAV, do not require runways to take-off.

3.3 Studies in Turkey

In the mid-1980s, the modern period of the Turkish air vehicle industry started. Most of the projects remained on paper or came to model and pre-feasibility phase or did not come to development and marketing stage. Among them, UAV-X1 (1989-1992), the first UAV project of Turkey, single-engine reconnaissance and surveillance air vehicle TG-X1 (1995), first regional passenger air vehicle HD-19 (1990) and ZiU (2000), the first original design agricultural sprayer. On the other hand, it can be said that the roots of Anka UAV and Hürkuş turboprop training air vehicle are on these projects.

UAV-X1 project was initially launched in 1989 to keep up with new technologies emerging from Israel and western countries in this field, which did not have a specific strategy at the beginning.

Figure 10 UAV-X1 Prototype-1 (Kaynak, 2018)

Figure 11 UAV-X1 Urgent Landing (Denizli-Çardak) (Kaynak, 2018)

Figure 12 UAV-X1 Square Tour (Afyon) (Kaynak, 2018)

Within the framework of the UAV-X1 project, two prototypes were produced, and both of them were taken to flight tests. The flight tests, which started in Sivrihisar in the spring of 1992, continued in Denizli-Çardak in the summer. Issues related to the remote control of a UAV, including occasional accidents, caused the UAV-X1 team to gain experience and maturity. Finally, in the fall of 1992, the project was finished after one flight in Afyon as a square tour.

A decision was made to develop a native copy of the A-22 (optionally-piloted vehicle) developed by William Sadler. The concept of the optionally-piloted vehicle was the design of a UAV to fly both manned and unmanned so that it could prevent especially accident-breaking events that might arise during automatic flight control trials and automatic landing. The new air vehicle, which is called Assault-Surveillance-

Experimental-1 (TG-X1), was to increase the engine performance of the A-22 and make it armed. The A-22 was actually a drug and smuggling prevention air vehicle that would operate on a US-Mexico border. It would offer a very inexpensive solution compared to helicopters and turboprop air vehicles that can take-off from short runways, and also had a manned-unmanned transformation. TG-X1 was completed after a troublesome working process, but the concept of "light-armed support aircraft" was not accepted at that time in 1998 (Kaynak, 2018).

Figure 13 An Image from Flight Tests of TG-X1 (Kaynak, 2018)

TAI carried out various UAV development activities after UAV X1. Turna and Keklik are target UAV projects developed for use in air defence systems striking and tracking training. Turna/G, the advanced version of Turna, has been actively used since 2001. Baykuş and Pelikan UAV were developed for pilot training and some tests operations. Martı UAV is to investigate coastal erosion. Gözcü is short-range reconnaissance, surveillance and intelligence missions UAV (Altunok, 2010).

Figure 14 Gözcü

In 2004, a year that draws the path of Turkey's UAV systems. This year, SSM was assigned as the only authority authorised for procurement and development of UAV, and it has been decided that no foreign UAV is purchased under any circumstances other than emergency purchases from abroad. Following this decision, after the 10 IAI Heron orders, national design and development projects were given importance (Altunok, 2010; Kaynak, 2018). SSM classified the needs of Turkey, as Mini UAV, Tactical UAV, and MALE and launched development projects for each class. TAI, who has gained significant experience in the past, was given the task of developing MALE class UAV platforms.

In accordance with the planning made in 2004, Çaldıran was developed by Kale Kalıp-Baykar partnership, and Karayel was developed by Vestel Savunma in the Tactical UAV class. The purchase of Çaldıran was decided by SSM. In the Mini UAV class, a Mini VTUAV system was developed by Baykar. Vestel Defence also developed a Micro UAV called Arı, as well as a Mini UAV named Efe.

There are also UAV development studies carried out by universities. Middle East Technical University (METU) managed to fly a Mini UAV Güventürk, which can fly autonomously. It can transfer the images it takes with a camera at a distance of 10 km. METU also studied on autopilot systems, Tactical UAVs and Mini UAVs. Istanbul Technical University conducted design and prototype production activities on rotary-wing UAV systems. Also, universities, institutions and companies performed development studies on UAV system and subsystems (Altunok, 2010).

TUSAŞ

Anka

Anka is a MALE UAV development program. The program consists of conceptual design, preliminary design, detailed design and development, and test and evaluation phases. The Anka system was developed to conduct reconnaissance, surveillance, fixed/mobile target detection, identification and tracking under day and night, adverse weather conditions. It carries payloads such as EO day camera, EO/IR/Laser range finder/Laser designator, and spotter payload, SAR/MTI-ISAR (Inverse-SAR) in order to fulfil missions.

Table 4
Anka Specifications

Duration	24 hours
Maximum Altitude	30,000 feet (MSL)
Range	250 km (LOS)
Payload capacity	250 kg
Wingspan	17.5 m
Length	8.6 m

Figure 15 Anka[2]

Aksungur

This MALE UAV performs the day/night intelligence, surveillance, reconnaissance and assault missions with EO/IR, SAR and SIGINT payloads and various air to ground weapons.

Figure 16 Aksungur

[2] https://www.tusas.com/urun/anka, Last access: 08.05.2020

Table 5

Aksungur Specifications[3]

Maximum Altitude	40,000 feet
Maximum Take-off Weight	3,300 kg
Wingspan	24 m
Length	11.6 m
Attack/Sea patrolling mission	25,000 feet, 12 hours with 750 kg payload
SIGINT mission	35,000 feet, 24 hours with 150 kg payload

Şimşek

It is a high-speed target UAV and launched as an R&D project to meet the training needs of the HKK in 2009. Şimşek which has full autonomous flight capability meets the requirements of high-speed target UAV, can be used in air-to-air, surface-air, anti-UAV and missile systems and shooting and radar tracking training, with features close to the flight characteristics of UCAV and missiles. Payloads: Passive radar trace enhancer, smoke generator, radar altimeter.

Figure 17 Şimşek[4]

Turna

Turna target UAV was launched as an R&D project to meet the training needs of the HKK units in 1995. The system which has an open architecture can be configured according to customer needs. Turna has the ability to simulate enemy air vehicle and missiles, high manoeuvrability, high speed, ease of use, low mission risk, modularity and cost-effectiveness. In 2001, Turna, which was entered TSK's inventory, has been used in the training of air defence units since 2001. It is possible to define pre-

[3] https://www.tusas.com/urun/aksungur, Last access: 08.05.2020
[4] https://www.tusas.com/urun/simsek, Last access: 08.05.2020

programmed duty points up to 255 and change them during flight. Turna has automatic landing by coming to the predetermined home return point with home return and emergency landing modes, recording and playback of real-time encrypted digital flight data telemeters, and digital map automatic recognition capabilities. Payloads: Passive Radar Trace Enhancer (Luneburg Lens), Heat Source, and Trace smoke.

Figure 18 Turna[5]

Baykar Defence

Akıncı

Akıncı that can carry smart ammunition payloads is intelligent and aware of environmental conditions thanks to its AI-based system, and it offers advanced flight and reconnaissance functions to its users. Akıncı can be exploited with much more advanced payloads such as electronic support pod, satellite communications systems, air-air radars, obstacle detection radar, and SAR. Akıncı can carry out air bombardment, and it can be equipped with air-air missiles.

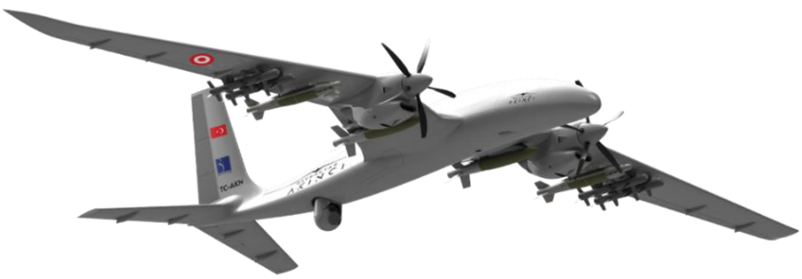

Figure 19 Akıncı

[5] https://www.tusas.com/urun/turna, Last access: 08.05.2020

Table 6
Akıncı Specifications

Altitude	40,000 feet
Take-off Weight	5,500 kg
Endurance	24 hours
Payload Capacity	1,350 kg
Communication Range	Dual-redundant SATCOM + Dual-redundant LOS (250 km)
Wingspan	20 m
Length	12.2 m
Propulsion	2x750 HP

Other detailed features are below.

- Fully automatic flight control and triple-redundant autopilot system.
- Fully automatic landing and take-off feature regardless of ground systems.
- Navigation feature with inertial sensor fusion without GPS dependency.
- Fully automatic cruise and route tracking feature.
- Automatic take-off and landing feature with internal sensor fusion support.
- Fully automatic taxi and parking feature.
- Support for semi-autonomous flight modes.
- Error tolerant and triple-redundant sensor fusion application.
- Cross-redundant GCS. Original redundant servo actuator units[6].

Bayraktar TB2

Bayraktar TB2 armed TUAV is a MALE class UAV for reconnaissance and intelligence missions.

Table 7
Bayraktar TB2 Specifications

Operational Altitude	18,000 feet
Endurance	27 hours
Take-off Weight	650 kg
Payload Capacity	150 kg
Flight Speed	70-120 knot

[6] https://www.baykarsavunma.com/iha-14.html, Last access: 08.05.2020

Other features:

- Fully automatic flight control and triple-redundant autopilot.
- Fully automatic landing and take-off feature which is regardless of ground systems.
- Navigation feature with internal sensor fusion without GPS dependency.

Figure 20 Bayraktar TB2[7]

Bayraktar DİHA

Bayraktar DİHA is a tactical VTUAV that can carry out activities for reconnaissance and intelligence missions. Bayraktar DİHA can perform automatic cruise flight, autonomous take-off, autonomous landing, and semi-autonomous cruise flight. There are three different options for landing mode: vertical landing, landing on the trunk and parachuting landing. The UAV has a flight control system that can perform automatic route tracking, target tracking, and return to home modes.

Table 8

Bayraktar DİHA Specifications

Operational Altitude	9,000 feet
Endurance	12 hours
Take-off Weight	30 kg
Payload Capacity	5 kg
Communication Range	150 km
Flight Speed	45-50 knot
Maximum Speed	80 knot
Wingspan	8 m
Length	1.5 m

Figure 21 Bayraktar DİHA[8]

[7] https://www.baykarsavunma.com/iha-15.html, Last access: 08.05.2020
[8] https://www.baykarsavunma.com/iha-17.html, Last access: 08.05.2020

Other features:

- Fully automatic flight system, which is sensor fusion-enabled fully autonomous.
- Autonomous take-off and landing system.
- Semi-autonomous flight mode.
- Triple-redundant flight control system.

Bayraktar Mini İHA

Bayraktar Mini İHA is MUAV, and it was first put into service of the TSK in 2007.

Table 9
Bayraktar Mini İHA Specifications

Communication Range	15 km
Cruise Speed	60 knot
Altitude	1,000 feet
Endurance	60-80 minutes
Wingspan	2 m
Length	1.2 m

Figure 22 Bayraktar Mini İHA

Other features:

- Shock absorber airframe structure.
- Automatic target point tracking.
- Automatic landing/Auto parachute landing.
- Semi-automatic flight with joystick support.
- Secure digital communications system.
- Automatic home return/Automatic landing feature in case of communication loss.
- Smart battery management system.
- Automatic take-off and cruise[9].

Vestel Defence Industry

Karayel system, which is a tactical UAV, can detect and identify the target with the camera system it carries in order to conduct aerial reconnaissance and surveillance and

[9] https://www.baykarsavunma.com/iha-16.html, Last acces: 08.05.2020

to direct laser-guided ammunition with the marker systems. It has triple-redundant avionics (aviation electronics) architecture and fully autonomous take-off/flight/landing capabilities.

Table 10
Karayel Specifications

Operational Altitude	22,500 feet
Endurance	20 hours
Payload Capacity	70 kg
Communication Range	150 km LOS

Figure 23 Karayel[10]

STM SAVUNMA TEKNOLOJİLERİ MÜHENDİSLİK VE TİCARET A.Ş.

Kargu

It is a rotary-wing UAV solution that can be carried by a single soldier for use in asymmetric warfare or anti-terrorism areas and can operate with autonomous or remote control. Kargu can be used effectively against fixed or moving targets with real-time image processing and deep learning algorithms.

Capabilities:

- Day and night effective operation.
- Destruction modes guided to the target selected via coordinate or image.
- Heading to the target in moving targets.
- High-performance navigation and control algorithm.

[10] http://www.vestelsavunma.com/tr/urun-insansiz-hava-araci-sistemleri, Last access: 08.05.2020

- Ability to leave the mission, return home and self-destruction.
- Destroy the target at an adjustable distance.
- Image processing based control applications.
- Embedded and real-time object detection, identification, classification, and tracking.
- 2-axis stabilise EO/IR payload options.

Figure 24 Kargu[11]

Alpagu

Alpagu is a fixed-wing combat UAV solution that can be carried by a single soldier for use in asymmetric warfare or anti-terrorism areas. Alpagu can also be fired from the launcher and can autonomously, or remotely controlled operate for reconnaissance, surveillance, and dispose of small-scale threats. Alpagu can be used effectively against fixed or moving targets with embedded and real-time image processing and deep learning algorithms. The system consists of fixed-wing UAV, launcher and GCS components.

[11] https://www.stm.com.tr/tr/urunler/kargu, Last access: 08.05.2020

Table 11
Alpagu Specifications

Range	5 km
Endurance	10 minutes
Altitude (AGL)	400 feet
Flight Speed	50 knot
Maximum Speed	65 knot
Weight	1,9 kg
Energy	LiPo Battery
Setup duration	≤ 1 minute

Figure 25 Alpagu

Capabilities:

- Day and night effective operation.
- Flight termination or self-destruction modes.
- Image processing based control applications.
- Real-time object detection, identification, classification and tracking[12].

Togan

It is a multi-rotor rotary-wing UAV solution that has task planning software, autonomous intelligence and operational capability. Togan can be carried and used by a single person with autonomous or remote control for reconnaissance and surveillance missions. Togan can be used effectively against fixed or moving objects with embedded and real-time image processing and deep learning algorithms. The system consists of rotary-wing UAV and GCS components.

Capabilities:

- Day and night effective operation.
- Moving target tracking.
- Simultaneous operations and missions with secondary Togan.
- High-performance navigation, control and guidance algorithms.
- Image processing based control applications.

[12] https://www.stm.com.tr/tr/urunler/alpagu, Last access: 08.05.2020

- Embedded and real-time object detection, identification, tracking and classification.
- 3-axis stabilise payload.

Figure 26 Togan[13]

ASİSGUARD

Songar

It is a UAV with a machine gun and shot stabilization in TSK inventory. Songar has the capacity of carrying 200 rounds per flight with the machine gun mounted on the stabilization system. It performs the task autonomously with multi-layered security until the operator is approved to fire. It has an ergonomic and user-friendly design to reduce the operator's load during tasks such as UAV return home, change of duty during flight, autonomous and remote control flight modes in communications loss.

Features:

- Multi-rotor UAV platform.
- Automatic firing stabilization system.
- UAV onboard machine gun.
- 10x optical zoom.
- Gun camera.
- GCS and mission planning.
- Day and night (optional) operation capability.
- GPS and GNSS compatible navigation feature.
- Video and data recording for post-mission analysis.

[13] https://www.stm.com.tr/tr/urunler/togan, Last access: 08.05.2020

- Maximum take-off weight: 45 kg.
- Maximum flight altitude: MSL 2,800 m, AGL 400 m[14].

Altınay Aviation and Advanced Technologies

Albatros

Cargo UAV Albatros has a modular structure and the ability to carry various payloads at the same time.

Table 12
Albatros Specifications

	Type 1	Type 2	Type 2
Take-off Weight	195 kg	370 kg	630 kg
Payload	50 kg	100 kg	150 kg
Flight Speed	65-85 km/h	70-95 km/h	70-95 km/h
Endurance	60 minutes	60 minutes	60 minutes
Range	30 km	30 km	30 km
Altitude	3,000 m	3,000 m	3,000 m

Figure 27 Albatros[15]

Sumru

Sumru is VTUAV with its high flight altitude, long-endurance and wide range.

Table 13
Sumru Specifications

Take-off Weight	120 kg
Flight Speed	120 km/h
Endurance	> 6 hours
Range	80 km
Altitude	8,000 feet
Wingspan	> 5 m

Figure 28 Sumru[16]

[14] http://www.asisguard.com/project/songar/, Last access: 08.05.2020
[15] http://www.altinay-advanced.com/projects/albatros/, Last access: 08.05.2020
[16] http://www.altinay-advanced.com/projects/sumru/, Last access: 08.05.2020

Kartal

UAV hunting UAV Kartal has been developed to prevent unwanted UAV entry into high-security areas. It can detect and eliminate the threat from a long distance by working integrated with the radar system.

Table 14
Kartal Specifications

Take-off Weight	40 kg
Payload Capacity	10 kg
Flight Speed	15 m/s
Endurance	25 minutes
Range	5 km
Altitude (MSL)	3,000 m
Wingspan	1,400 mm

Figure 29 Kartal[17]

Doğan

Armed UAV Doğan has been developed to meet the operational needs of the armed forces with its ability to shoot with high precision.

Table 15
Doğan Specifications

Take-off Weight	40 kg
Payload Capacity	10 kg
Flight Speed	15 m/s
Endurance	25 minutes
Range	5 km
Altitude (MSL)	3,000 m
Wingspan	1,400 mm

Figure 30 Doğan[18]

[17] http://www.altinay-advanced.com/projects/kartal/, Last access: 08.05.2020
[18] http://www.altinay-advanced.com/projects/dogan/, Last access: 08.05.2020

Ebabil

UAV Ebabil that leaves ammunition stands out with its efficiency, ease of use and affordable cost. It provides the opportunity to attack the same target in just a few minutes by using the products repeatedly after the attack. The fact that the systems used for surveillance purposes, which are widely used in inventory, can be turned into armed-UAV with simple modifications, maximizes the effectiveness of the system.

Table 16
Ebabil Specifications

Take-off Weight	8 kg
Payload Capacity	1 kg
Flight Speed	12 m/s
Endurance	45 minutes
Range	8 km
Altitude (MSL)	3,000 m
Setup Duration	<5 minutes
Munition	1 kg explosive effect

Figure 31 Ebabil[19]

Serçe

Surveillance UAV Serçe has features such as redundant software and hardware, safe flight capability in GPS-denied environments with advanced payload options.

Table 17
Serçe Specifications

Take-off Weight	8 kg
Payload Capacity	1 kg
Flight speed	12 m/s
Endurance	45 minutes
Range	8 km
Altitude (MSL)	3,000 m
Setup Duration	<5 minutes

Figure 32 Serçe[20]

[19] http://www.altinay-advanced.com/projects/ebabil/, Last access: 08.05.2020
[20] http://www.altinay-advanced.com/projects/serce/, Last access: 08.05.2020

Lapis Aviation Technologies Inc.

Lapis CR-01 Trogon

Lapis CR-01 Trogon can be equipped with different payloads according to different mission needs such as road safety, border security, oil-gas pipeline security, mapping, forestry applications, agricultural applications and disaster management, especially in exploration surveillance and intelligence missions. Lapis CR-01 Trogon, developed to work under challenging conditions with its high payload capacity, can work day and night with its fixed 12X day camera and removable thermal camera.

Table 18
Lapis CR-01 Trogon Specifications

Weight	1,550 gr
Endurance	>30 minutes
Flight Speed	54 km/h
Range	3 km
Altitude (AGL)	2,000 feet

Figure 33 Lapis CR-01 Trogon

Table 19
Autopilot Specifications

• Precise navigation with GPS support. • Full autonomous mission capability. • Situation awareness thanks to self-checks. • Intelligent battery management.	• GCS tracking feature. • Mission change feature in the air. • Change feature with a precision of < 1 m. • Emergency landing. • Emergency measures (e.g. GPS loss, link loss).

These autopilot features also apply to Lapis CR-02 Lap06 [21].

Lapis CR-02 Lap60

Lapis CR-02 Lap60 can be equipped with different payloads according to different task needs. It is a UAV capable of autonomous mission. Lapis CR-02 Lap60 was developed to work under challenging conditions with its high payload capacity, can

[21] http://lapishavacilik.com.tr/v1/urun.asp?id=7, Last access: 08.05.2020

operate day/night with its removable 30X optical zoom payload and 35 mm lens thermal camera payload.

Table 20
Lapis CR-02 Lap60 Specifications

Weight	5,750 gr
Endurance	>55 minutes
Cruise speed	54 km/h
Range	>5 km
Altitude (AGL)	2,000 feet

Figure 34 Lapis CR-02 Lap60[22]

The numbers of postgraduate theses on UAV from the Theses Centre were obtained. The YOK thesis database[23] was searched for "UAV" in theses abstracts. The theses, which completed in Turkey on UAV are summarised in this section.

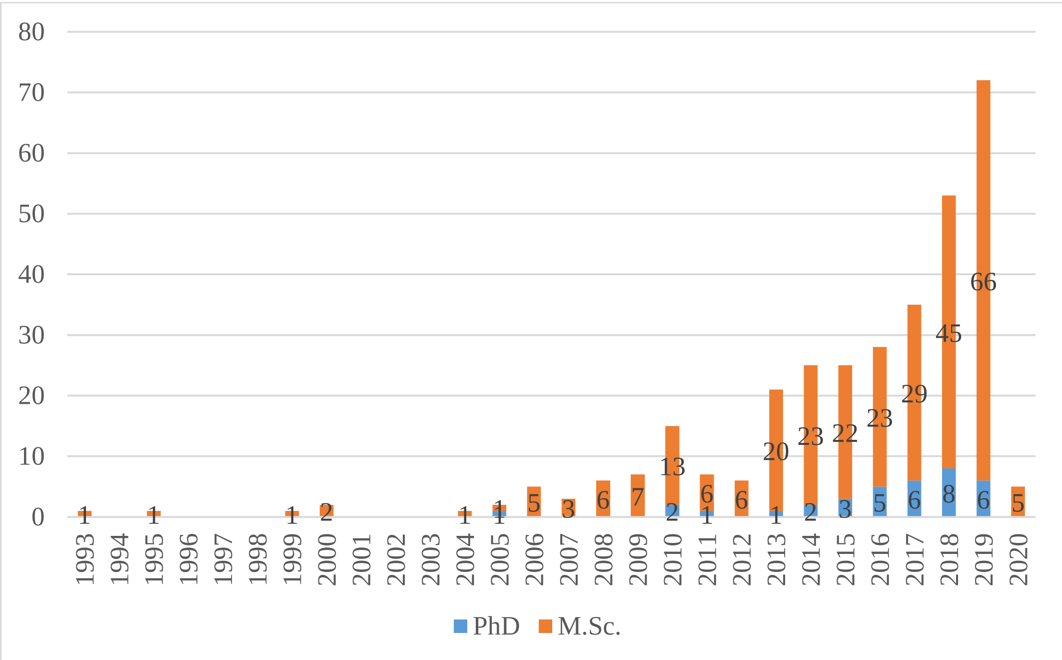

Figure 35 Theses on UAV in Turkey

[22] http://lapishavacilik.com.tr/v1/urun.asp?id=17, Last access: 08.05.2020
[23] https://tez.yok.gov.tr/UlusalTezMerkezi/tarama.jsp, Last access: 26.02.2020

The theses open to access (223 theses) were examined, the most studied topics: 46 theses on the flight controller, 29 theses on UAV design/implementation, 25 theses on UAV applications (most of them on photogrammetry), 13 theses on path planning, and nine theses on autopilot. In some thesis studies, more than one subject is covered. These theses were categorised by evaluating them according to the subject thought to be the closest to the content. The review shows the big picture in this situation.

It should be more studied autonomy, swarm intelligence, interoperability, sensor fusion, and human-machine collaboration issues in academic studies. Transformation of thesis studies into industrial applications should be ensured. For this objective, the universities and industry should study within a long-term collaboration.

It is presented that information about educational institutions and R&D institutions in Turkey regarding UAVs in this section.

Middle East Technical University (METU)

Aerospace Engineering department has the experimental facilities and equipment availability under the following disciplines:

- Aerodynamics,
    - Small Subsonic Research Wind Tunnel,
    - Supersonic Wind Tunnel,
    - Air Flow Bench.
- Aerostructures,
    - Structures laboratory,
    - Smart Structures.
- Aeropropulsion,
- Aerospace Systems Simulation, Control and Avionics (aviation electronics),
- METU Centre of Wind Energy[24].

[24] http://www.ae.metu.edu.tr/

İstanbul Technical University

Faculty of Aeronautics and Astronautics laboratories:

- Control and Avionics Laboratory: It was established to perform dynamic modelling of aircraft and spacecraft, control system design, flight instrumentation and electronics, simulation systems and experimental applications, C2 system design and applications at the fleet level. Aviation research, development and application, helicopter and aircraft simulators, manned-unmanned system teaming C2 software, micro-avionic system, picosatellite design projects are carried out.
- High-Performance Computing and Virtual Reality Laboratory: It has been established for virtual reality applications, analysing complex aerodynamic and structural problems encountered in aircraft and spacecraft design in a short time and visual evaluation of analysis results. All engineering problems requiring numerical computing, virtual reality applications, flow visualization applications, simulation applications are carried out.
- Trisonic Research Laboratory: It was established to become a science centre that produces the information that will form the basis for shaping the future at national and international level through scientific and applied research. Aerodynamic and structural analysis of objects moving in air, subsonic and supersonic air tunnel design, manufacturing and calibration, performance analysis of aircraft engine and engine elements, sensor calibration, and unmanned aerial vehicle areas can be carried out. Experiments can be conducted on flow-induced vibrations, subsonic and supersonic jet flows, supersonic and subsonic vortex rupture problems, aerodynamic analysis of unmanned aerial vehicles, rocket and projectile aerodynamics problems.
- Computational Engineering Laboratory: Complex aerodynamic and structural problems encountered in aircraft and spacecraft design can be modelled and analysed with the necessary precision. It is aimed to provide the necessary infrastructure for studies to produce cheap and fast solutions to design problems with computerized computational analysis methods. It can be used for all engineering problems where computer-aided analysis and simulation methods can be used, especially aerodynamics, fluid mechanics and structural problems.

- Reverse Engineering Laboratory: It is aimed to use three-dimensional digitization and rapid prototype devices, which are reverse engineering methods, in order to develop modelling of aircraft and space building elements and to perform quality control. In order to develop Aircraft and Space Technologies, three-dimensional digitization of existing parts and the production of concept models and prototypes can be achieved.
- Aerial and Space Systems Laboratory,
- Composites and Structures Laboratory[25].

University of Economics and Technology (TOBB ETÜ)

UAV design and development studies are carried out in the Automatic Control laboratory.

Adana Alparslan Türkeş Science and Technology University

Department of Aerospace Engineering has started education. Introduction to UAV Design course is given.

National Defence University Air Force Academy

Department of Aerospace Engineering continues to provide training. The main purpose of Material and Manufacturing Laboratory is to design and manufacture UAVs. For this purpose, there are hot-wire foam cutting machine, laser cutting machine, a different type of lathes, milling, drilling machines and other tools. In addition to manufacturing tools, there is also some measurement equipment such as microscope, weight scales, and thermometers. The lab also facilitates some course studies such as Introduction to Aerospace Science, Propulsion Systems, and Materials Science[26].

University of Turkish Aeronautical Association (UTAA)

Department of Aeronautical Engineering continues to provide training. Design of Unmanned Aerial Systems course is given. The department has the following

[25] http://www.uubf.itu.edu.tr/anasayfa
[26] http://www.hho.edu.tr/Akademik/Dekanlik/HavacilikveUzayMuhendisligi/index.php

laboratories: Aerodynamics Laboratory, Engine and Propulsion Laboratory, Rapid Prototyping Laboratory, Composite Laboratory, Computer-Aided Manufacturing Laboratory.

The department includes Unmanned Aerial Vehicle Research and Development Centre – (UAV R&D Centre)[27].

Ankara Yıldırım Beyazıt University

Department of Aeronautics and Astronautics Engineering started training. The facilities are Composite Materials Laboratory, Parallel Computing Environment, Design Laboratory (NUMECA computational fluid dynamics software, SIMULIA ABAQUS finite element analysis software)[28].

Atılım University

Department of Aerospace Engineering was founded and will begin its education in the 2020-2021 academic year.

Erciyes University

Academic studies are conducted in the Faculty of Aeronautics and Astronautics.

Tarsus University

Department of Aerospace Engineering was founded.

İzmir University of Economics

Department of Aerospace Engineering provides training. Unmanned Aerial Vehicle course is given. Within the scope of the laboratory facilities of the Department of Aerospace Engineering, there are one subsonic wind tunnel, one gas-turbine micro-jet engine for educational purposes and 15 high-performance computers and simulation computers with related software. Unmanned Aerial Vehicle course is given[29].

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[27] https://aee.thk.edu.tr/
[28] https://aybu.edu.tr/havacilik/
[29] https://ae.ieu.edu.tr/tr

Necmettin Erbakan University

Department of Aeronautical Engineering was found.

İstanbul Gelişim University

Department of Aeronautical Engineering was found.

University of Kyrenia

Department of Aeronautical Engineering continues to provide training.

SSM (2011) presents by the technology roadmap document laboratories and Research and Application Centres located at universities in Turkey.

Laboratories: Aerodynamic, Micro-electromechanical, Systems design, intelligent systems, Image processing, Robotics, Fuel cell, Embedded systems, Pattern recognition and artificial intelligence, Reverse engineering, Computer-Aided Design, Flying robots, Propulsion, Computer-integrated manufacturing, Fluid mechanics, High-performance computing and Virtual Reality, Decision Support Systems and Optimisation, Computer-Aided Manufacturing, Micro-controllers, Optoelectronics, Signal processing, Logic circuit design, Complex systems research, Alternative fuels and combustion technologies, Defence technologies and simulation.

Research and Application Centres: Robot Technologies Application and Research Centre (Bursa Technical University), Materials Research Centre (İzmir Institute of Technology), Metal Forming Centre of Excellence (Atılım University), Communication and Spectrum Management Research Centre (Bilkent University), National Nanotechnology Research Centre (Bilkent University), Signal and Image Processing Research Centre (İstanbul Technical University, Boğaziçi University), Computer-Aided Design/Production and Robotics Centre (METU), Micro-Electro-Mechanical Systems Research and Application Centre (METU), Rotorcraft Centre of Excellence (İstanbul Technical University), Advanced Technologies Application and Research Centre (Eskişehir Technical University), Computational Electromagnetic Research Centre (Bilkent University), Space Technologies Research Centre (METU, Roketsan), Machine Design and Manufacturing Research Centre (METU), Welding Technology and Non-Destructive Testing Research/Application Centre (METU), Modelling and Simulation Research and Application Centre (METU).

TUSAŞ

The R&D activities that started in March 2003 in the METU Technopark are continuing.

TUSAŞ R&D buildings (Nuri Demirağ and Vecihi Hürkuş Buildings), established on an area of approximately 4,000 square meters in the METU Technopark Defence Industry Research and Technology Development Subzone, were put into service in November 2004. R&D Activities in both buildings are currently carried out with a staff of approximately 250 people.

As of October 2017, it was established in an area of 2,341 square meters in İstanbul TDZ, located next to Sabiha Gökçen Airport. The primary establishment purpose of TUSAŞ Technopark İstanbul branch is to use universities, workforce and technology potential in unique projects in İstanbul.

Bursa R&D centre was established on an area of 174 square meters in the Ulutek TDZ located in Bursa Uludağ University Görükle Campus in December 2018. The purpose of establishment of TUSAŞ-Bursa Uludağ University R&D Centre is to produce solutions to the problems encountered in original product design by carrying out joint R&D projects with universities and important industrial organisations in Bursa and training students studying at neighbouring universities as qualified human resources within the scope of the Intern Engineer Program.

TUSAŞ-Yıldız Technopark R&D Centre is located on an area of 841 square meters in the TDZ Technopark of Yıldız Technical University (YTU) as of November 2017.

TUSAŞ Technopark İstanbul branch was established in an area of 2,341 square meters in the İstanbul TDZ next to Sabiha Gökçen Airport in October 2017. The main establishment purpose of TUSAŞ Technopark İstanbul branch is to use the universities, workforce and technological potential in Istanbul in original projects.

Baykar Defence

Baykar's capabilities cover all product life cycle stages of its systems. It has both organizational and technological competence at all stages from the formation of the system idea to research and product development, production and after-sales activities.

Baykar's R&D capabilities include the complete design and development of UAV systems, air platforms and ground components, including subsystems, and R&D activities are carried out according to relevant standards.

The design, analysis, prototype production and integration of composite, mechanical, electromechanical parts and communication and power cable sets in air platforms and ground components are carried out by Baykar.

R&D capabilities:

- Mechanical systems design and development,
- Computer-Aided Design-based UAV design and optimisation, structural part design,
- Aircraft and mechanical systems analysis and simulation (aerodynamics, control and stability, structural analysis),
- Air vehicle performance analysis,
- Propulsion, fuel and launch systems design and analysis,
- Propulsion systems integration,
- Electronic systems and avionics development,
- RF and microwave system design and analysis,
- Electrical/power systems design and analysis,
- Communication and power cables design and analysis,
- Mechatronic systems design and analysis,
- Software development,

- Object-oriented software development (interface, map and navigation systems, network-based and distributed systems, image transmission systems),
    - Embedded software development,
    - Artificial intelligence (machine learning, image processing) applications development.
- Development of flight control and guidance systems,
- Hardware in the loop simulation systems development,
- Ground support systems and test equipment design and development,
- Payload (e.g. camera, ammunition, radar, electronic support pods) electronics, mechanical and software integration and analysis.

Within the scope of R&D activities, prototype production, testing and design verification activities are also carried out.

The designed UAV systems are produced, integrated with their subsystems and components, and put into service after passing the detailed test and quality control stages[30].

HAVELSAN

HAVELSAN in corporate R&D is given great importance to sustainable development and culture, improving technology innovation policy at the global level with Turkey, both of HAVELSAN's strategic goals is to increase the competitive power of support. Within the scope of more than 70 (40 equity-funded) R&D projects carried out in four separate R&D centres, three of which are in Ankara and one in İstanbul, approximately 1,250 R&D personnel and R&D investments exceeding 450 million TL were made. The largest R&D expenditure in the history of the company has been achieved.

In the ranking made by the STB among R&D centres in 2018, HAVELSAN R&D centre ranked 25th among 296 R&D centres. According to the size group (number of R&D personnel > 250), it ranked 11th among 26 R&D centres. Within the same group,

[30] https://www.baykarsavunma.com/teknolojik-yetkinlikler.html

it was showed 7th with its R&D personnel employment and 12th place with its R&D expenditure intensity.

In order to continue this success increasingly, deepening studies are carried out in the fields of University-Industry Collaboration and Technology Management with the goals of developing technology collaborations, strengthening the ecosystem and effective use of the technology developed/acquired by HAVELSAN. In this context, cooperation studies continue with more than 30 universities[31].

ASELSAN

ASELSAN has adopted the vision of being a national technology company that maintains its sustainable growth with the values it creates in the global market, is preferred with its competitive power, is trusted as a strategic partner, and is sensitive to the environment and people. As an essential means of achieving this vision, besides development activities carried out within the scope of the contract, ASELSAN has allocated an average of 7% of its turnover to R&D activities financed by its resources.

Macunköy Facilities are established on a total area of 186,000 square meters, 110,000 square meters of which is a closed area. The Head Office, Communication and Information Technologies, Defence System Technologies and Transportation, Security, Energy, Automation and Health Systems Sector Presidencies are located in ASELSAN Macunköy facilities.

Akyurt Facilities are established on a total area of 231,000 square meters, 54,500 square meters of which is a closed area. Micro-electronics guidance and Electro-Optics business sector are located in ASELSAN Akyurt facilities.

In the facility established in Ankara Gölbaşı area; Radar and Electronic Warfare Systems Business Sector, which carries out activities for radar and electronic warfare systems for land, air, sea, space and unmanned platforms. The facility is established on a total area of 350,000 square meters, of which 75,000 square meters are closed.

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[31] https://www.havelsan.com.tr/

The ASELSAN Technopark facility, located in the METU-Technopark campus, was established on a total area of 4,500 square meters, 4,000 square meters of which is a closed area. R&D activities of the Communications and Information Technologies Sector Presidency are carried out in our ASELSAN Technopark facility[32].

Vestel Defence Industry

The structural and aerodynamic design of the autopilot system, the central control computer and the ground control station, including avionics of design, all software to production developed the system with entirely Turkish engineers conducted by UAVs to the development of Turkish aerospace and defence industry and Turkey to contribute to the strategic location is aimed.

In parallel with UAV activities, investments are made in the field of fuel cell for R&D activities that can be carried out in very few countries of the world.

Vestel Defence Industry has been operating in the field of hydrogen and fuel cell technologies since 2005. During this time, it cooperates with the most prestigious universities in the country in this field and has taken part in many national and international projects. Clean energies R&D Laboratory of Vestel Defence Industry is located in Taşpınar/Ankara. Besides, it is continued R&D studies with Niğde University within the framework of university-industry cooperation with its staff and laboratory in Niğde University Nejat Veziroğlu Clean Energy Application and Research Centre[33].

STM SAVUNMA TEKNOLOJİLERİ MÜHENDİSLİK VE TİCARET A.Ş.

Capabilities, Competencies: Utilising deep learning, machine learning and computer vision techniques, unmanned platforms containing different types of pioneering technologies are being developed to increase the autonomy of unmanned platforms, to operate autonomously in a swarm or alone in battlefields where data communication is not available.

[32] www.aselsan.com.tr
[33] http://www.vestelsavunma.com/

- High-performance navigation and control algorithms,
- Artificial intelligence applications,
- Machine learning,
- Advanced computer vision and deep learning algorithms,
- Image processing based control applications,
- Realtime object detection, identification and tracking,
- Realtime obstacle detection and avoidance,
- Embedded and realtime object detection, identification, classification and tracking,
- Interoperability,
- Original national embedded hardware and software
- Advanced and original electronic ammunition safety, arming and firing[34].

TÜBİTAK-UZAY

- Communications systems: It is conducted RF and microwave passive and active circuits, antennas, communication-specific baseband designs. The capabilities of this group include antenna designs for space and aircraft communication systems, simulating and measuring antenna performance on platform models, RF and microwave circuit design, realisation and testing for Low Earth Orbit (LEO) satellites, design, implementation and testing of high-speed transceiver systems, communication-specific. It covers the design, modelling, implementation and testing of systems that perform baseband operations such as modulation/demodulation filtering by different methods.
- Data and image processing: Data and Image Processing Department; It carries out R&D projects in semantic image analysis, image matching, 3D imaging, pattern and object recognition and high-performance computing.
- Optical systems research laboratory: TÜBITAK UZAY Optical Systems Research Laboratory (OPMER) was established to develop and produce sensitive optical components needed in many different fields, especially satellite technologies, within national capabilities and capabilities. It is providing the form of high-quality optical components that are critical for cutting-edge technology space and defence

[34] https://www.stm.com.tr/tr/cozumlerimiz/otonom-sistemler

applications, meeting surface finishing requirements, increasing surface form precision, reflective, and anti-reflective. Production and metrology systems used in coating processes are included in the infrastructure[35].

TÜBİTAK-BİLGEM (Informatics and Information Security Research Centre)

- Communications Security (COMSEC) Laboratory: COMSEC Laboratory, under the umbrella of TÜBİTAK-BİLGEM, performs testing, consultancy and training services on the compliance of information security products that process confidential cryptographic data with the national COMSEC criteria. COMSEC laboratory services are especially important for information security products to be used in TSK and NATO.
- Antenna Test and Research (ATAM) Laboratory: ATAM is a research centre established to meet the measurement infrastructure and needs in the electromagnetic and antenna fields with national facilities at appropriate time and cost, to provide antenna and radar cross-sectional area measurement services, and to continue antenna prototype design and production activities.
- Radar Systems Laboratory: In the Radar Systems Laboratory, radar system solution, advanced radar signal processing research and development studies, radar integration and radar verification-validation activities are carried out. Currently, research, application and system development activities of the laboratory are on Pulse-Doppler, Frequency-Modulated Continuous-Wave (FMCW), mm-Wave, Phased Array and Passive radars.
- RF Research and Development Laboratory: RF R&D Laboratory consists of expert personnel and infrastructure capable of designing, developing and measuring up to 110 GHz frequency band in microwave and millimetre wave. In the laboratory, various projects, which the Turkish industry needs, for radar, Electronic Warfare and communication technologies are carried out.
- Speech and Language Technologies Laboratory: In the infrastructure where various acoustic scenarios can be simulated with acoustic embedding, any sound technology developed for military or civilian purposes can be evaluated. The

[35] https://uzay.tubitak.gov.tr/tr

audience test room equipped with silent terminals and touch monitors can also be used as a “Human Factors Laboratory”.

- Electro-Optic and Laser Systems Laboratory: It was established to develop critical/national and Electro-Optic systems. High power lasers, high power laser systems, optical communication systems, Infra-Red systems, and all kinds of Electro-Optic systems can be designed and developed.
- Analytical Devices and Systems: An Analytical Devices and Systems Laboratory was established by bringing together Opto/Micro-electronics and software engineering competencies with chemistry-biology-nanotechnology expertise, and studies have been initiated to develop biosensor/biosensor-based diagnostic devices.
- Semiconductor Technologies Research (YITAL) Laboratory: It has an infrastructure that enables the realisation of integrated circuit design, mask printing, integrated circuit production, wafer probing, sheathing, circuit testing and ageing processes. YİTAL has reached its present position by developing original Complementary Metal Oxide Semiconductor (CMOS) production technologies and producing low volume military standard Integrated Circuit (IC). The mission is Turkey’s strategic semiconductor technology to develop original semiconductor production according to the needs and standards in producing integrated circuits with military technology developed in the strategic semiconductor products to ensure the independence of the country.
- Integrated Circuit Design and Training Laboratory: In the laboratory, where studies on IC design are carried out, digital design projects, random number generators and transceiver IC designs are made. Also, work on designing a safe low-power consuming processor for Internet of Things (IoT) systems and designing artificial intelligence algorithms at the hardware level (chip) are also ongoing[36].

[36] https://bilgem.tubitak.gov.tr/tr

CHAPTER 4

TECHNOLOGY ROADMAP

4.1 Technology Roadmaps

Petrick & Echols (2004) refer to technology roadmap as a tool that enables organizations to make more informed decisions, thus avoiding waste of time and resources, and helping reduce risks in technology decision-making. A technology roadmap is also frequently referred to as a "management tool" in R&D and product development projects, which involves various communications processes amongst a variety of stakeholders (Yasunaga, Watanabe, & Korenaga, 2009).

Phaal, Farrukh, & Probert (2004) define technology roadmap as a useful tool to support technological management to explore and communicate dynamic interactions between resources, organisational goals, and environmental changes.

Another definition of technology roadmap comes from Robert Galvin, the former chairman of Motorola. Galvin (1998) defines technology roadmaps as:

> *An extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field. Roadmaps communicate visions, attract resources from business and government, stimulate investigations, and monitor progress. They become the inventory of possibilities for a particular field.*

By providing a framework for connecting business to technology, the technology roadmap has become a valuable part of strategy development by firms, government agencies, and others in a wide variety of industries (Lee, Kang, & Park, 2007).

The technology roadmap approach is very flexible. Phaal (2002) states that technology roadmap architecture and development process should be customized depending on the objectives, resources, and content. Phaal, Farrukh, & Probert (2004) state that the achievements of the technology roadmap result from the development process and in this process, communication and information sharing are provided by creating interaction between different actors. Some examples are given in this study to examine the technology roadmap process.

The typical features of the technology roadmaps and the differentiations between them are presented below (Amer & Daim, 2010).

Common features of the technology roadmaps:

- Defining future aims.
- Application of methods or techniques to reveal the current state or capacity of the studied technology area.
- Investigating the issues that are thought to affect the relevant technology area in the future.
- Defining the development between the current situation and the future based on the technology area and associating them.
- Stakeholders who are consulted in the process of creating a technology roadmap are from different fields such as universities, private sector, public institutions, and organizations.
- The technology roadmap has a time-based structure.

The technology roadmaps differ in:

- Investigated technology area.
- The purpose of developing the technology roadmap.
- It can be prepared at different levels, such as national, regional, sectoral, or firm.
- Determining the stakeholders according to the technology area to be investigated.
- The stages used in the development of the technology roadmap, the ordering of these stages and the relation between them.
- Methods, techniques and tools used in the implementation of the stages and obtaining the outputs.
- Architectural representation of the technology roadmap.
- Monitoring procedures of the technology roadmap.

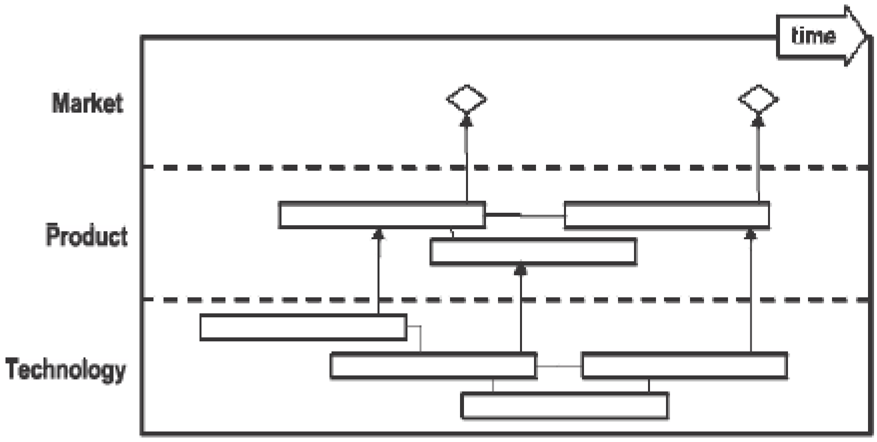

Figure 36 Schematic Technology Roadmap (Phaal, Farrukh, & Probert, 2004)

The technology roadmap schema generally shows how technology can be aligned to product and service developments, business strategy, and market opportunities.

The technology roadmap architecture generally consists of four dimensions:
Time: Periods can be used according to annually or a specific time interval depending on the need.

Layers: Construct the vertical axis of the technology roadmap and are very critical. These layers should be defined to form the desired strategic planning (such as market, products, applications, technology, competencies, knowledge, and R&D projects).

Annotation: It consists of tools such as links between objects, notes, decision points in layers.

Process: Contains the necessary steps to complete the technology roadmap (Phaal, Farrukh, & Probert, 2004).

The technology roadmaps are presented, in terms of the most intended purpose:
1. Product planning: This is the most common type of technology roadmap, relating to the insertion of technology into products.

2. Service/capability planning: This type is more suited to service-based enterprises, focusing on how technology supports organisational capabilities.
3. Strategic planning: This purpose is suitable for general strategic appraisal in terms of supporting the assessment of opportunities or threats at the business level. The technology roadmap focuses on the defining a vision of the future, in terms of such as markets, business, products, technologies, skills are identified, by comparing future vision with the current situation, and strategic options.
4. Long-term planning: This type is used to support long-term planning, extending the planning horizon. The technology roadmaps of this type are often performed at the sector or national level and can act as a radar for the organisation to identify potentially disruptive technologies and markets.
5. Process planning: This type supports the management of knowledge, focusing on a particular process area (e.g. new product development).
6. Integration planning: This purpose focuses on integration and evolution of technology with respect to how technologies combine within products and systems, or to form new technologies.

The following eight types of the technology roadmap have been identified, relating to expression format:
1. Multiple layers: This is the most common format of the technology roadmap comprising a number of layers (and sublayers), such as technology, product and market. The technology roadmap allows the evolution within each layer to be explored, together with the interlayer dependencies, facilitating the integration of technology into products, services and business systems
2. Bars: Many technology roadmaps are expressed in the form of bars for each layer. This method has the advantage of simplifying and unifying the required outputs, which facilitates communication, integration of the technology roadmaps, and the software development to support developing a technology roadmap.
3. Tables: A technology roadmap might be expressed as tables (e.g. time vs requirements). This expression is particularly suited to situations where parameters can be quantified, or if actions are clustered in specific periods.

4. Graphs: If technology performance can be quantified, a technology roadmap can be expressed as a graph. This type of graph is sometimes called a maturity curve and is closely related to technology S-curves.
5. Pictorial representations: A technology roadmap can use more creative pictorial representations to relate technology integration and plans. Sometimes metaphors like a tree are used to support the goal.
6. Flow charts: A right type of pictorial representation of technology roadmaps is flowchart typically used to relate goals, actions, and outcomes.
7. Single-layer: This form focuses on one layer of the technology roadmap.
8. Text: Some technology roadmaps are text-based. These types can entirely or mostly describe the issues with words. The mostly text-based technology roadmaps can support with graphs and charts.

The technology roadmap types can be partially attributed to a lack of clear and accepted standards for their construction. Also, it is evaluated that this also reflects the need to adapt the approach to suit the situation with respect to business objectives, available information sources, and desired use. Technology roadmaps do not always fit precisely the categories described above and may contain more than one type of item. It may need to balance both purpose and form, which is accomplished with hybrid formats (Phaal, Farrukh, & Probert, 2004).

4.2 UAV Technology Roadmaps

US DoD - Unmanned Aerial Vehicles Roadmap 2000-2025 was prepared by a multi-organisational team. Aim of this UAV technology roadmap is to excite the planning process and to provide a panel for mutual discussion. This UAV technology roadmap expresses projected capabilities for 25 years as; silent flight as fuel cells supplant internal combustion engines in some systems. Sixty percent gains in endurance due to increasingly efficient turbine engines. Rotorcraft capable of high speeds (400+ knots) or long-endurance (24+ hours) while retaining the ability to hover. Endurance of UAVs serves GPS pseudo-satellites and airborne communications nodes to provide theatre and tactical users with better connectivity, clearer reception, and reduced vulnerability to jamming (US DoD, 2001).

US DoD - Unmanned Aircraft System Roadmap 2005-2030 that was cooperatively prepared extracts interoperability as requirements; processor (100 Million MIPS - Mega Instruction Per Second by 2030), communications (improving data links for data transfer rate, better all-weather capability, network-centric communications), air vehicle technologies (airframe for light and more durable aerostructures, flight control, propulsion, reliability, survivability), payload technologies (categories of sensors such as EO, radar, signals, meteorological, Nuclear-Biological-Radioactive-Chemical, relays such as communications and navigation signals, weapons, or combinations of these) as technology issues (US DoD, 2005).

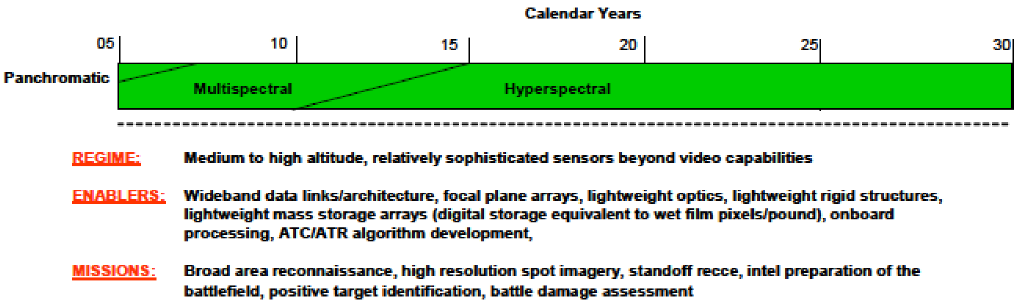

Figure 37 Imagery Sensor Technology Foresight (US DoD, 2005)

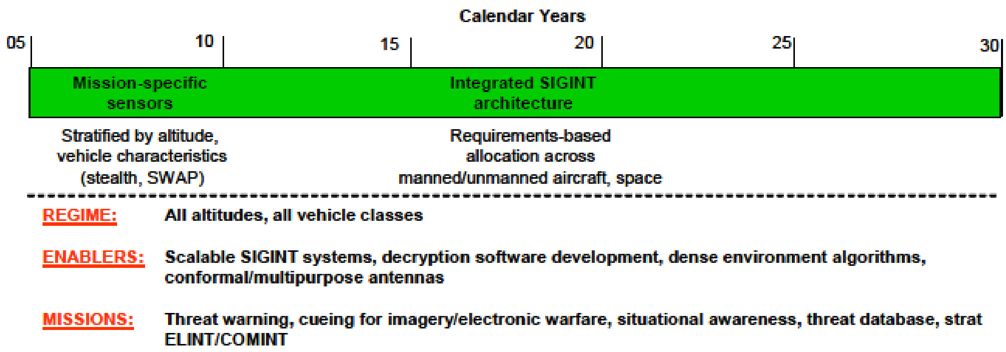

Figure 38 SIGINT Sensor Technology Foresight (US DoD, 2005)

US DoD - Unmanned Systems Integrated Roadmap 2009-2034, developed by DoD's subject matter experts, is to propose a feasible vision for unmanned systems and related technologies.

According to this technology roadmap, some key technologies that will enable future UAV to include lightweight, long-endurance battery and alternative power technology, effective bandwidth management/data compression techniques, stealth capability and collaborative or teaming technologies. A critical enabler allowing UAV access to US national and ICAO airspace will be a robust onboard sense and avoid technology. The ability of UAV to operate in airspace shared with civil manned air vehicle will be critical for future peacetime training and operations. There is a need for open architecture systems that will allow competition between different commercial UAVs and GCSs and allow interoperability. Technology enablers in propulsion systems coupled with a higher energy efficiency of payloads are required to extend loitering time and expand the missions of UAV to include electronic attack and directed energy.

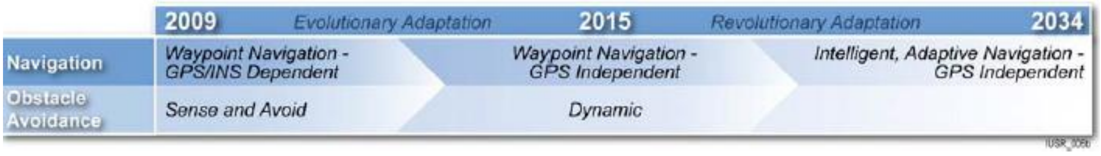

Figure 39 A Sample Progression from Roadmap (US DoD, 2009)

US DoD - Unmanned Systems Integrated Roadmap 2011-2036 shows interoperability, autonomy, airspace integration, communications, training, propulsion and power, manned-unmanned teaming as challenges facing all military services including UAV, UGV, and UMV because of similar attributes (US DoD, 2010).

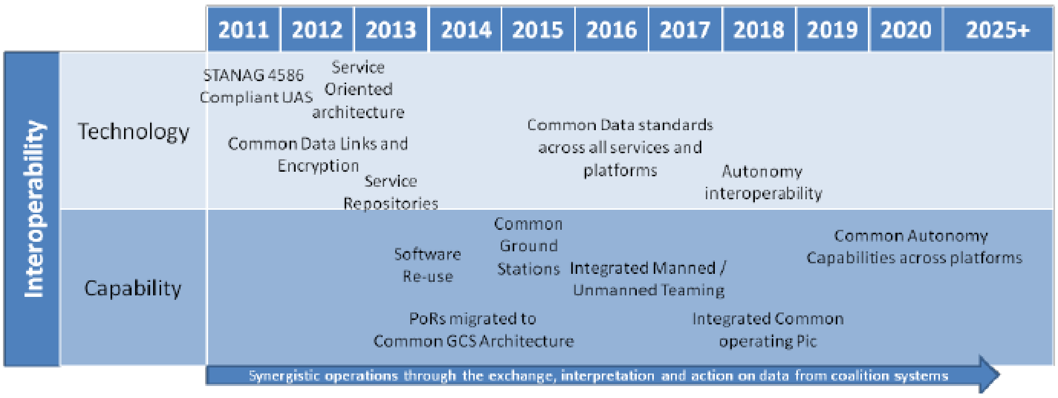

Figure 40 Interoperability Roadmap (US DoD, 2010)

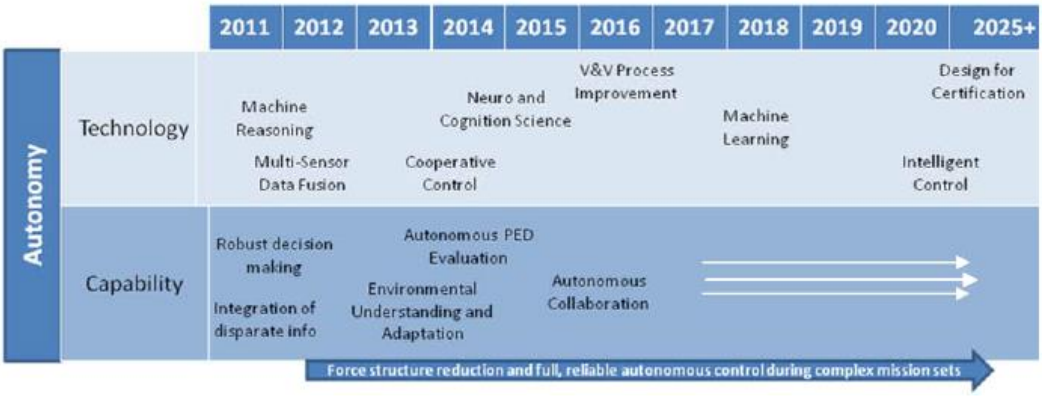

Figure 41 Autonomy Roadmap (US DoD, 2010)

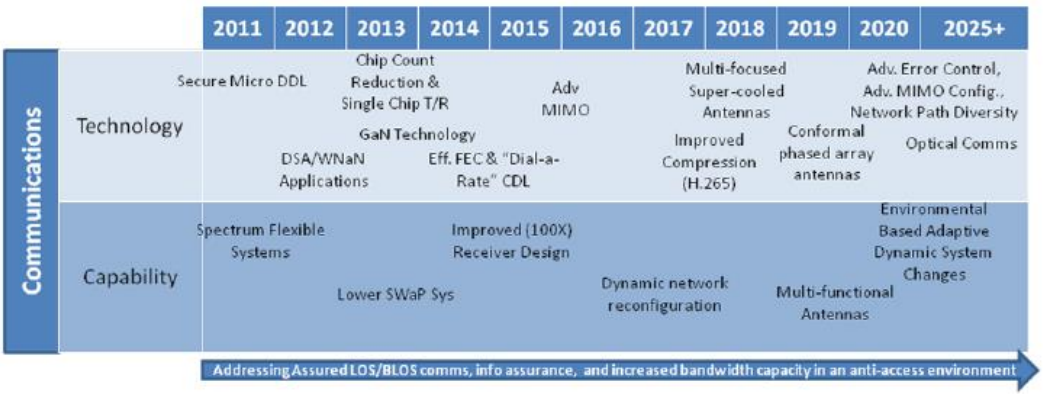

Figure 42 Communications Roadmap (US DoD, 2010)

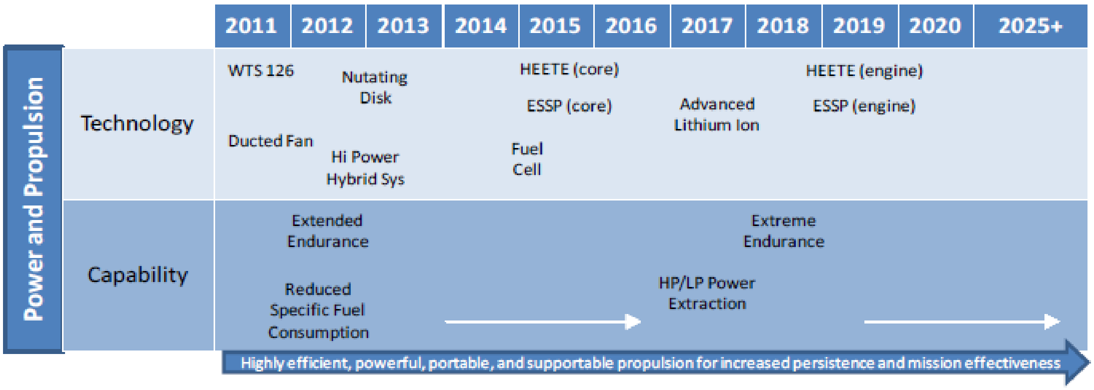

Figure 43 Propulsion and Power Roadmap (US DoD, 2010)

US DoD - Unmanned Systems Integrated Roadmap 2013-2038 considers autonomy, data protection, data exploitation, manned-unmanned system teaming policy, interoperability and modularity, communications systems, spectrum and resilience, security, autonomy and cognitive behaviour, weapons, airdrop sensor, weather sensing, high-performance computing technology issues (US DoD, 2014).

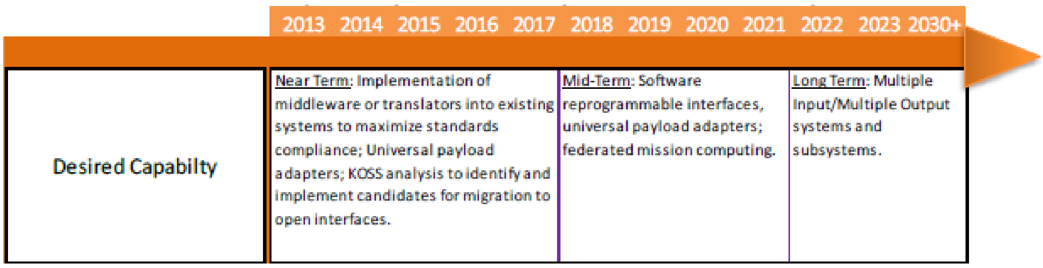

Figure 44 Interoperability and Modularity Goals (US DoD, 2014)

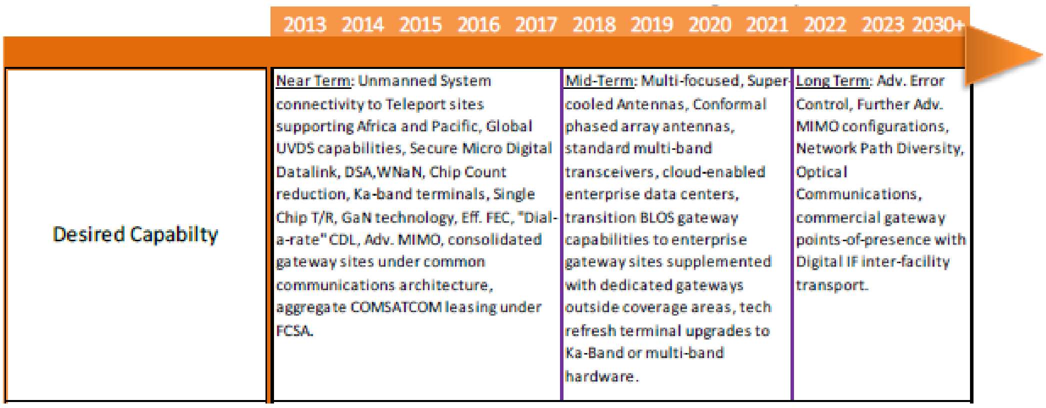

Figure 45 Communications Systems, Spectrum, and Resilience Goals (US DoD, 2014)

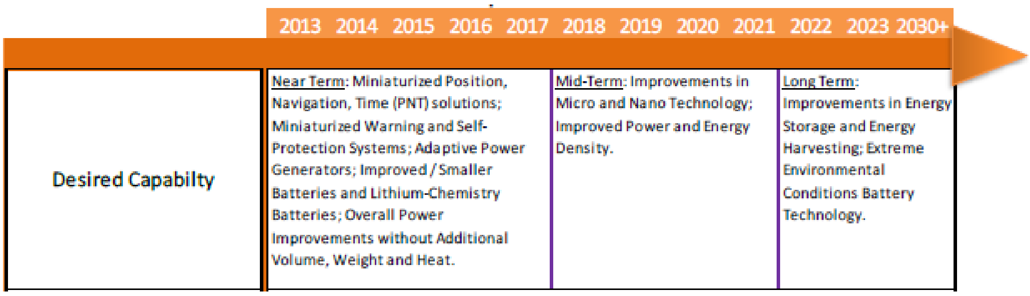

Figure 46 SWaP Goals (US DoD, 2014)

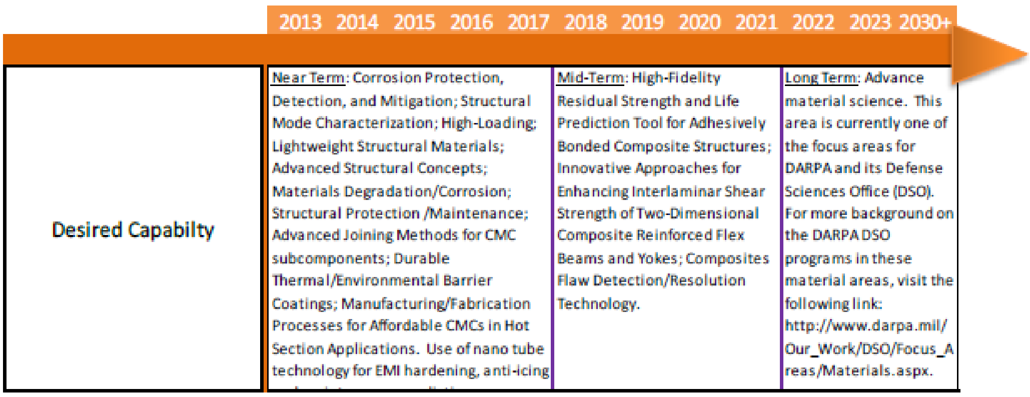

Figure 47 Structures and Material Degradation Goals (US DoD, 2014)

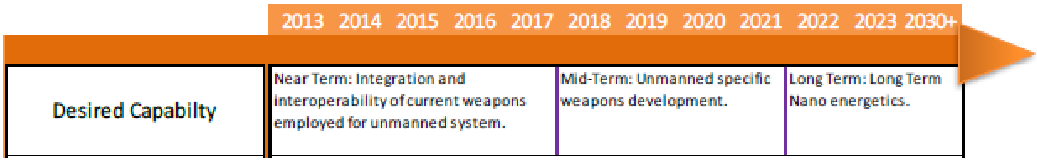

Figure 48 Weaponry Goals (US DoD, 2014)

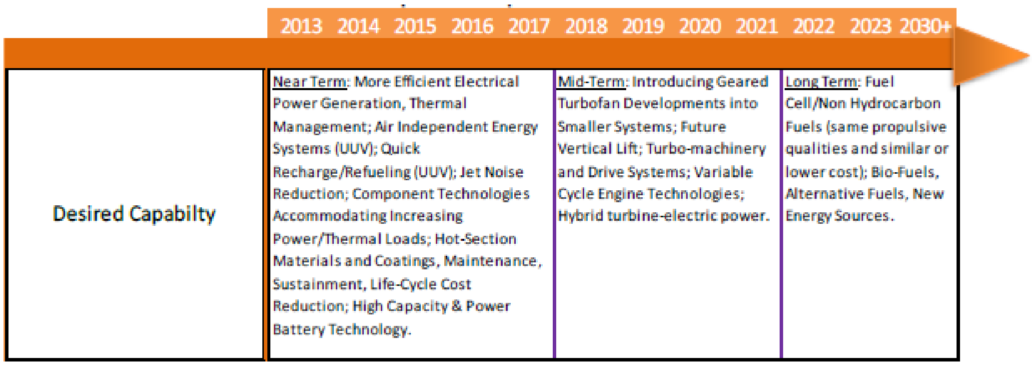

Figure 49 Propulsion Goals (US DoD, 2014)

US DoD - Unmanned Systems Integrated Roadmap 2017-2042 addresses interoperability, autonomy, network security, human-machine collaboration with significant advancements, challenges, and trends. Key technologies are identified including; robotics, prioritized common/open architectures, common data repositories, autonomous modelling and simulation, artificial intelligence, machine learning, SWaP/miniaturisation, swarming capabilities, augmented reality, virtual reality, sensor advancements, collision avoidance, GPS-denied solutions, cyber resilience and robustness, increased network and spectrum capacity, information assurance solutions, human-machine interface, autonomous data strategy adaptation (US DoD, 2018).

		2017 - - - - - - - - - - NEAR-TERM	- 2029 - - - - - - - - - - MID-TERM	- 2042 FAR-TERM
INTEROPERABILITY	Common/Open Architectures/AI Frameworks	-Standardized C2 & Reference Architectures	-Support Seamless, Agile, Autonomous Human-Machine Collaboration and inter-Machine collaboration	
	Modularity & Parts Interchangeability	-Retrofit Existing Systems -Plan Modularity into New Systems	-Rapid Upgrades and Configuration Changes	
	Compliance/ Verification & Validation	-New TEVV Approach -New V&V Tools & Techniques	-Highly Complex Autonomous Systems TEVV	
	Data Transport Integration	-Common Data Repositories -Integrated End-to-End Delivery	-Anti-Jamming - Low Probability of Intercept/Detection	
	Data Rights	-Secure Needed Data Rights -Evolve Data Rights Policy	-Maximum Mission Support Flexibility	

Figure 50 Comprehensive Roadmap for Interoperability (US DoD, 2018)

		2017 - - - - - - - - - - NEAR-TERM	- 2029 - - - - - - - - - - MID-TERM	- 2042 FAR-TERM
AUTONOMY	Artificial Intelligence/ Machine Learning	-Private Sector Collaboration -Cloud Technologies	-Augmented Reality -Virtual Reality	-Persistent Sensing -Highly Autonomous
	Increased Efficiency and Effectivness	-Increased Safety & Efficiency	-Unmanned Tasks, Ops -Leader-Follower	-Swarming
	Trust	-Tasking Guidance and Validation, Ethical Requirements for Human Decisions		
	Weaponization	-DoD Strategy Consensus -LAWS assessment	-Armed Wingman/Teammate (Human Decision to Engage)	

Figure 51 Comprehensive Roadmap for Autonomy (US DoD, 2018)

		2017 - - - - - - - - - - NEAR-TERM	- 2029 - - - - - - - - - - MID-TERM	- 2042 FAR-TERM
SECURE NETWORK	Cyber Operations	-Defense In Depth -Vulnerability Assessment	-Transition to Cyberattack Resilience -Autonomous Cyber Defense	
	Information Assurance	-Private Sector Collaboration	-Develop & Evolve IA Policies, Procedures, Techniques -Suite of IA Products/Technologies for Unmanned Systems	
	Spectrum/ Electronic Warfare	-More Efficient, Flexible, Adaptable, Agile Spectrum for Sustained Operations -Hardened Robust Electronic Protection		

Figure 52 Comprehensive Roadmap for Secure Networks (US DoD, 2018)

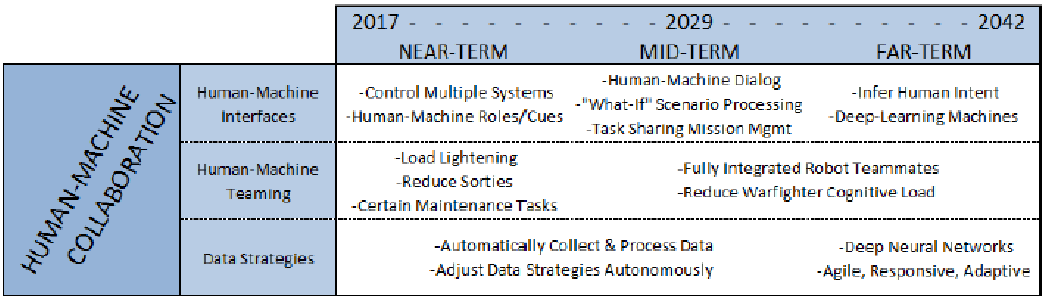

Figure 53 Comprehensive Roadmap for Human-Machine Collaboration (US DoD, 2018)

European Commission (2007) presents what vision can be drawn for Europe in UAV technology domain and what needs to be done to realise it.

It is presented the strengths and weaknesses of Europe in this document.
The strengths of Europe:

- Strong technology base,
- Strong industrial/manufacturing and systems integration capability,
- Payloads and avionics expertise,
- Growing UAV experience in the military sector,
- Workgroups which have come together to solve problems and develop the engineering and initial frameworks,
- An intensely competitive industrial ecosystem,
- European aerospace companies have well-established access to export markets,
- The large and enthusiastic home market, with plenty of room for expansion into the second and third tiers suppliers.

The weaknesses of Europe:

- Absence of regulations covering airworthiness, ATM and frequency spectrum allocation,
- The uncoordinated approach has led to the emergence and proliferation of a wide variety of consortiums, often working in similar or overlapping areas, leading to duplication of effort and the possibility of differentiation rather than convergence,

- Neglect of civil and commercial markets (dominantly on the military),
    - Insufficient R&D funding for the industry,
    - Little government support.
- Late start of suppliers (behind US and Israel) and late adopters (demand),
- Platforms. Europe was slow for the domestic design, development and production of platforms.

It is expected that civil UAV domain will grow with potential applications such as government (civil security, border security, and coastguard), fire fighting and emergency services, critical infrastructure monitoring, agriculture forestry and fisheries, earth observation and remote sensing, communications and broadcasting.

Sense and avoid: The primary technological concern is the development of the sense and avoid technology adapted for use with UAV.

Simulation: The introduction of UAV into controlled airspace is being greatly facilitated through simulation. In the simulation environment, test equipment designs and various ATM scenarios are made possible without any danger to air traffic or people.

Miniaturisation: UAV is a continuously developing technology area that is immature yet. One aspect of their evolution is a strong tendency towards miniaturisation in the entire subsystem domain.

Human Interface – GCS: UAVs come in a wide range of designs depending on GCS, manufacturers and other factors. This situation is also partly because the technology is relatively new and many systems have been put into production in a way not characteristic of the aviation industry. Interoperability is not only based on flying multiple types of platforms from a single GCS alone. There are issues to be resolved in this respect.

Fuel and Powerplant Development: Increased performance with better fuel efficiency and the improved powerplant is changing rapidly. The need to carry less fuel or a lighter battery means an increase in load. A more efficient engine boosts endurance.

Advanced Material and Aerodynamics: Developments in composites and other advanced materials are making airframes lighter, enabling more payloads and greater fuel capacity. The research is exploring the advantages of advanced aerodynamics that can maximise efficiency for different altitudes, speeds, UAV sizes and mission properties. At the nanoscale, experimental devices are tested, including ornithopters that mimic the flight of insects and birds. Research is being conducted on the possibility of using synthetic biological components.

Small and Medium-sized Enterprises (SMEs) are a vital segment of the European UAV ecosystem. They are already active as second, third and even fourth-tier companies in a market that offers enormous potential opportunities once the civil sector opens up. SMEs combine originality and agility with low R&D overheads, allowing them to enter the market in niche areas or with low-cost systems.

- Tier 1: System integrator,
- Tier 2: Manufacturers of main equipment (platforms),
- Tier 3: Subsystem manufacturers,
- Tier 4: Component producers.

Development of a Regulatory Framework

The levels of complexity involved, with the development of technical, administrative and legal issues and achieving an agreed and applicable framework of standards, rules and regulations, significantly delayed the process beyond what was initially anticipated.

Actions:

- Monitoring industry and sharing information amongst participants,
- Funding critical technology R&D programmes,

- Establishing a coordination interface between industry and regulatory authorities across Europe.

European RPAS Steering Group (2013) presents Roadmap for the integration of civil Remotely-Piloted Aircraft Systems into the European Aviation System report. This report supplies a regulatory approach, a strategic research plan, and a study on the societal impact.

List of technology gaps according to this report:

- Development of a methodology to justification and validation the RPAS safety target,
- Secure C2/data links/bandwidth allocation,
- Insertion of RPAS into the ATM system, sense and avoid (including air and ground) and situational awareness (including small RPAS), weather awareness,
- Security issues attached to the use of RPAS,
- Safe automated monitoring, support to decision making and predictability of behaviour,
- Automated take-off and landing and surface operations.

The Strategic R&D plan should support the definition and the coordination of future research programmes for RPAS integration at the EU and national levels.
R&D Activities:

- Activity 1 - Extended Visual Line of Sight (EVLOS)/Visual Line of Sight (VLOS) – RPAS activities awareness for security: This activity emphasizes the security aspect of RPAS operation for national security authorities.
- Activity 2 - EVLOS/VLOS – Operations in urban areas: In urban areas, the LOS C2 link will have to ensure secure and safe operations. RPAS operations will have to take into account aspects like masking and interference from other sources. This activity will identify these obstacles and provide solutions to ensure safe and secure RPAS operations.
- Activity 3 - EVLOS – Human Factors: The EVLOS operations require robust teamwork between the pilot and observer. It is essential that in this activity that both

the pilot and the observer share the same situational awareness to ensure the safe execution of EVLOS operations. It will emphasize human factor issues related to the interaction of the crew regarding communications, responsibility and non-standard events. This research activity investigates skill and information requirements for the pilot and the observer on individual and joint task requirements.

- Activity 4 – Instrument Flight Rules (IFR)/Visual Flight Rules (VFR) – Visual detectability solutions: This activity concentrates on the detectability of RPAS. In order to safely integrate RPAS, airspace users need to comply with the rules of the air. In order to do this, the air vehicle needs to be visible to airspace users and the Air Traffic Controller (ATC). If the air vehicle is too small, it might not be detectable by other airspace users and thereby create potentially hazardous situations. It also addresses the detectability from a surveillance perspective.
- Activity 5 – IFR/VFR – Sense and Avoid (S&A): It addresses all aspects like collision avoidance to ground and obstacle avoidance, surface operations and other hazards for IFR and VFR flights.
- Activity 6 – Beyond Visual Line of Sight (BVLOS) or BLOS – S&A: Operating RPAS in very low-level conditions, below 400 feet requires a new look at aviation as manned air vehicle do not tend to operate at these altitudes.
- Activity 7 – IFR/VFR – Communications C2 data link: This activity addresses the data link requirements for safe RPAS operations.
- Activity 8 – BVLOS – Communications C2 data link: This activity emphasizes the additional requirements for secure and safe data link at very low levels BVLOS.
- Activity 9 - IFR/VFR – Airspace Access and Airport Operations: RPAS, which will operate under VFR or IFR, will have to integrate into an environment dominated by manned aviation. RPAS must comply with the regulations. This activity addresses significant airspace and airport integration issues such as flight planning, minimum performance requirements for IFR flights, surface operations and many other ATM requirements to ensure RPAS integration.
- Activity 10 - BVLOS – Airspace Access and Airport Operations: This activity emphasizes the unique aspects of BVLOS operations.

- Activity 11 - IFR/VFR – Contingency: Contingency procedures must be developed in case of data link loss. In order to accommodate these conditions, suitable procedures should be established.
- Activity 12 - IFR/VFR and BVLOS – Human Factors: With the emergence of RPAS, this type of operations brings along new human factors aspects that need to be addressed. These are not only from the RPAS perspective but also from the perspective of other airspace users and all other ATM actors like ATC. BVLOS and VFR/IFR flight operations mean that no human may have direct visual contact with the air vehicle or visual overview of the situation. RPAS for these operations, therefore requires additional onboard sensors and automation equipment for flight safety and mission performance. One goal of this research activity is to explore the design requirements for interfaces that enable the pilot to manage these additional sensors and control partially autonomous functions with an acceptable cognitive workload. Another aim of this research activity is to investigate whether the pilot and ATC can create a shared situational awareness about flight status and RPAS behaviour during IFR flight.
- Activity 13 – Security: The safe execution of RPAS operations also depends heavily on the security of RPAS and its environment. This activity addresses all aspects of security that affect RPAS transactions and the ATM environment.
- Activity 14 - Demonstrations of best practices: In light of the development of technical and operational documentation, learning best practices from the operators, service providers and national authorities is of paramount importance when developing rules, procedures and proposals for industry standards. These efforts avoid duplication of work and capital and support early maturity of developments. Bringing these efforts into the R&D activities in parallel enhances collaboration between RPAS manufacturers, operators, and regulatory authorities.

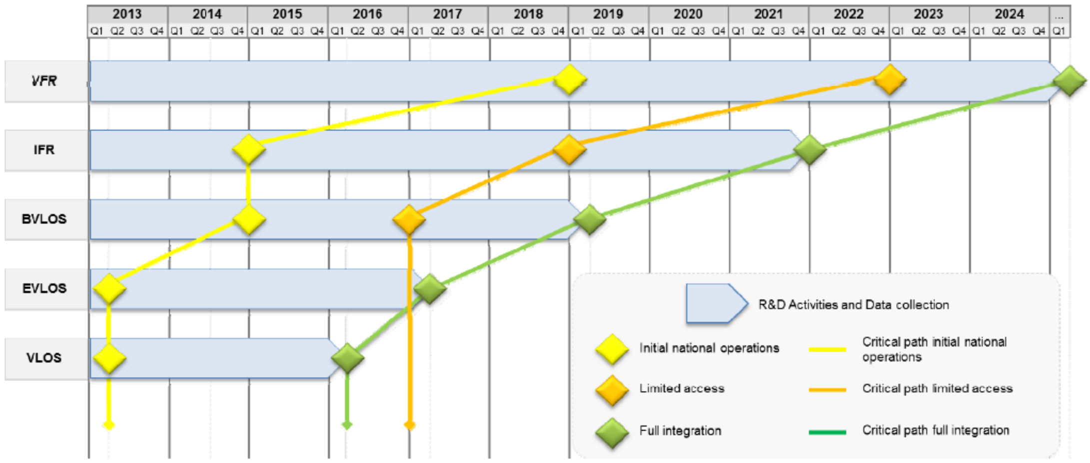

Figure 54 R&D Roadmap Timeline (European RPAS Steering Group, 2013)

The most substantial aspect of the technology roadmaps prepared by the US DoD is that technology roadmap is prepared regularly every few years. It makes it possible to make updates according to these developments and to make paradigm changes when necessary. One of the successful aspects of the technology roadmaps prepared by US DoD is the definition of challenges and way ahead. Besides, technology areas are examined in detail, and critical technologies are defined.

The issue that stands out in the document prepared by the European Commission is that a detailed action plan has been defined. It is noteworthy that they include monitoring and coordination functions.

The successful aspects of the roadmap prepared by the European RPAS Steering Group that was set-up by the European Commission that the technological gaps, key technologies, enablers, R&D activities to be conducted, key milestones and risk assessment have been prepared in detail.

SSM - Turkey Unmanned Aircraft Systems Roadmap (2011-2030) is delivered a detailed technology roadmap that focuses on military use in terms of platform and mission types. The infrastructure of domestic industrial enterprises, close to one hundred subsystems/technology-based design and production capability; the needs of domestic training and testing infrastructure are evaluated. It is presented domestic developed/under development subsystems such as flight control computer, take-off/landing systems, and related UAV projects. In the development process of UAV Systems, needs analysis, interoperability, network-enabled capability, collaboration, logistics, airworthiness requirements, and various studies are evaluated. Within the scope of the technology projections and needs for the areas to be prioritized in the upcoming period, short/medium/long term targets for necessary subsystems have been put into consideration by considering the military use areas of the UAV System (SSM, 2011).

CHAPTER 5

MATURITY MODEL

5.1 Maturity Models

The concepts of maturity model are emphasised briefly, and maturity model samples are presented in this section.

Maturity models represent a stage-based evaluation of a structure in a subject. Maturity models are expected to disclose current and desirable maturity levels and to include respective improvement measures. The maturity models can be used for the following purposes:

Descriptive: The maturity model can be used as a diagnostic tool (Maier, Moultrie, & Clarkson, 2009 as cited in Pöppelbuß & Röglinger, 2011). A maturity model serves a descriptive role for assessment of the current capabilities of the structure under investigation with respect to determined criteria (Becker, Knackstedt, & Pöppelbuß, 2009 as cited in Pöppelbuß & Röglinger, 2011).

Prescriptive: A maturity model serves a prescriptive role to indicate how to identify desirable maturity levels and provides guidelines on improvement measures (Becker, Knackstedt, & Pöppelbuß, 2009 as cited in Pöppelbuß, & Röglinger, 2011). “Specific and detailed courses of action are suggested” (Maier, Moultrie, & Clarkson, 2009 as cited in Pöppelbuß; & Röglinger, 2011).

Comparative: A maturity model serves a comparative role to allow for internal or external benchmarking. Given sufficient data from assessment entities, the maturity levels of similar units and organisations can be compared (de Bruin, Rosemann, Freeze, & Kulkarni, 2005; Maier, Moultrie, & Clarkson, 2009 as cited in Pöppelbuß, & Röglinger, 2011).

Differences in the relevant maturity models of the same or similar application areas should be specified to enable comparison of maturity models. The design process of a maturity model has to be documented and communicated in a way understandable for the target group. It should include to what extent a maturity model has been subject to empirical validation by means of interviews with domain experts, focus groups, surveys, or case studies. Maturity model critical design principles are summarised below:

- Basic design principles
  - Application domain and prerequisites of applicability,
  - Purpose of use,
  - Maturity and dimensions of maturity,
  - Maturity levels and maturation paths,
  - Available levels of granularity of maturation,
  - Underpinning theoretical foundations with respect to evolution and change.
- Design principles for the descriptive purpose of use
  - Intersubjectively verifiable criteria for each maturity level and level of granularity,
  - Target group-oriented assessment methodology.
- Design principles for the prescriptive purpose of use
  - Improvement measures for each maturity level and level of granularity,
  - Decision calculus for selecting improvement measures,
  - Target group-oriented decision methodology (Pöppelbuß & Röglinger, 2011).

5.2 Maturity Model Examples

Many maturity models in the literature were investigated, different approaches and development steps were examined, and some of them are presented in this section.

Lee & Kwak (2012) developed an open government maturity model for social media-based public engagement based on five case studies with US Healthcare

Administration agencies. These case studies include interviews with government executives, managers, and contractors from different fields. Also, data were collected and analysed from government memorandums, strategic plans, reports, white papers, and websites, blogs, and government social media accounts. The grounded theory approach was used to analyse the case data. Interviews were carried out to evaluate the validity and usefulness of the proposed model in a focus group discussion.

The proposed Open Government Maturity model has five levels in this order Level 1 - Initial conditions, Level 2 - Data transparency, Level 3 - Open participation, Level 4 - Open collaboration, Level 5 - Ubiquitous engagement.

Level 1 focuses on information broadcasting. Level 2 focuses on transparency of government processes and performance and data quality. Level 3 focuses on public feedback, conversation, voting, and ideation, interactive communications, and crowdsourcing. Level 4 focuses on interagency collaboration, open collaboration with the public, and co-creating value-added services. Level 5 focuses on increased transparency, participation, and collaboration, ubiquitous and continuous public engagement, and integrated public engagement.

Adelakun (2004) presented a model for analysing IT outsourcing maturity in organisations. The draft model has been developed based on a literature review. The first model was then discussed with five practitioners: Expert interviews were used to validate the theoretical model. The interviews focused on the experience of the interviewers in the outsourcing industry. Based on the discussions, changes were made to the model. The final model was tested by using it to analyse the maturity level of ACB stores, a case study conducted.

Five stages of IT outsourcing maturity is below:

1. Stage one of the maturity model (Insourcing/Bystander): Outsourcing between 1-5 % of IT.
2. Stage two of the maturity model (Forming/Experimenting): Outsourcing between 10-20 % of IT activities.

3. Stage three of the maturity model (Storming/Strategic decision point): Organisation leaders share conflicting ideas about outsourcing and pursue different strategies to provide IT services.
4. Stage four of the maturity model (Norming/Proactive cost focus): Beginning to form norms and actively focusing and proactively using outsourcing for cost-saving, including offshore. Outsourcing 20-40 % of IT activities.
5. Stage five of the maturity model (Performing/Strategic focus): Not just focusing on cost.

Beset (2007) aimed to develop a model to assess The Project Management Maturity Level of an Architectural Design Office (Arch-PMM) in his PhD thesis. By increasing the levels of ARCH-PMM, architectural design office creates an opportunity to focus on its concerns for the high-quality architectural design process. A semi-structured survey is conducted with selected architectural design offices in order to determine whether Arch-PMM assessment methodology is working correctly. A five levelled PM Maturity Model was developed to assess architectural design offices' current PM Maturity level. Maturity levels are evaluated via a semi-structured survey. Seventy-one members of the Association of Turkish Independent Architects participated in the semi-structured survey to validate the model. Both maturity levels and demographical data are analysed.

Maturity levels of ARCH-PMM are summarised below:

1. Level 1: Initial: Ad-Hoc designs, solutions, and processes. Architect heard about project management.
2. Level 2: Planned: Project management is supported by office managers. There is no systematic process. The success of project management depends on architects' experience. Project management is project-oriented. Every process is independently handled. Managers pay attention to higher scale projects.
3. Level 3: Organisational standardization: Standardization of the processes for the architectural design office. Stakeholders of the process act as one project team. Each project is evaluated and managed in the light of other projects. Processes should be adapted according to the project.

4. Level 4: Managed: Projects are managed in the light of plans. Office managers use the metrics for the project decisions. Project development teams work very efficiently. Standardization integrates to all project development team members. Office managers brilliantly understand their roles.
5. Level 5: Continuous improvement: Processes used for the improvement of project management activities. All the staff of the architectural design office focuses on improvement. All collected metrics are used for future decisions.

Antunes, Carreira, & da Silva (2014) proposed an Energy Management Maturity Model that can be used to guide organisations in their energy management implementation. The proposed maturity model is inspired by the Plan-Do-Check-Act cycle approach for continual improvement and covers well-understood fundamental energy management activities common across energy management texts. The completeness of the proposed model is then evaluated by establishing an ontology mapping against energy management standard ISO 50001. The study was started with a literature review. The energy management activities derived from the literature can be organized into five maturity levels following the Plan-Do-Check-Act cycle framework.

Maturity levels and activities:

1. Initial stage: No defined activities.
2. Planning stage: Energy review, benchmark current performance, identify improvement opportunities, ensure management commitment, establish energy management roles, establish energy policy, set objectives and target, establish energy performance indicators, create action plan, check regulatory compliance.
3. Implementation stage: Investment, procurement, training, communication, documentation.
4. Monitoring stage: Metering, monitoring and analysis, program audit.
5. Improvement stage: Management review.

Identified challenges about maturity levels:

1. Initial: Not Available.

2. Planning: Getting top management approval and commitment, establishing relevant performance indicators, defining feasible and obtainable goals.
3. Implementation: Staff support of energy policies, raising awareness of energy improvement, resources competition by other departments.
4. Monitoring: Ensuring systems can support data collection and analysis for established indicators, performing unbiased internal audits.
5. Improvement: Providing necessary data to establish further improvement actions.

The mapping between the proposed maturity model and ISO 50001 aims at validating if the proposed model supports ISO standard activities. To evaluate the mapping between the proposed model and ISO 50001, regarding completeness and clarity, they performed an analysis according to Wand-Weber ontology method.

Geyer & Krumay (2015) developed a social media maturity model as a tool for introducing and assessing organisational social media activities using the grounded theory approach. Different data sources such as academic literature, guidelines, case studies, beneficial sources were exploited for data collecting procedures. The collected data were analysed using a software tool (Atlas.ti). The developed social media maturity model consists of six dimensions: Operational social media management, human resource management, social listening and monitoring, social media integration, social media strategy, and guidelines for responsible behaviour.

5.3 Technology Readiness Level (TRL)

TRL is a systems engineering tool that is intended to perform maturity evaluation of a particular technology. It is originated from NASA, and the metric was developed by Stan Sadin (Sadin, Povinelli, & Rosen, 1989). Mankins (1995) defined TRLs as follows "TRLs are a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology". TRL was primarily developed to ensure a "mutual agreement between research personnel, research management, and mission flight program managers" at NASA (Sadin, Povinelli, & Rosen, 1989). It was ensured to be able to differentiate technology maturity in an independent discipline way. The original definition of TRL was a scale from one that defining basic ideas and concepts to seven, which include a system prototype demonstration in a space environment (Sadin, Povinelli, & Rosen, 1989). The method was later appended to include up to nine levels (Mankins, 1995).

Table 21 *NASA TRL Scale* (Mankins, 1995)

NASA TRL	Definition
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of-concept
4	Component and/or breadboard validation in laboratory environment
5	Component and/or breadboard validation in relevant environment
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
7	System prototype demonstration in a space environment
8	Actual system completed and - flight-qualified through test and demonstration (ground or space)
9	Actual system - flight-proven through successful mission operations

In 1999, the DoD adopted the use of TRL scale during its acquisition phase to aid in the decisions made during technology development (DoD, 2000; Sauser, Ramirez-Marquez, Magnaye, & Tan, 2006).

The maturity and readiness of a certain technology can be evaluated using TRL. This subject is explained as an example by adapting it from Savioni & Tronchin (2014).

TRL 1 Basic principles observed and reported: Lowest level of technology readiness. Scientific research begins to translate into R&D.
UAV field: Continous monitoring of scientific knowledge base. Scientific findings are reviewed and assessed for potential new technologies such as swarm intelligence, sensor fusion, GPS-denied solutions.
Actors: Scientist, researcher, R&D expert.

Scenario: Observation can be done by actors acting in the scientific area and reported in the literature, congress, blogs, and thesis.

TRL 2 Technology concept and/or application formulated: Invention begins. Practical applications can be invented when the basic principles are followed. Practices are based on assumptions, and there may be no evidence to support the assumptions.
UAV field: Scientific paper studies can generate research ideas, hypotheses, experimental designs, and application potential. It is focused on practical applications based on basic principles observed. Therefore, it is used simulation or other virtual tools to test hypotheses. A new algorithm could offer a promising solution for swarm intelligence.
Actors: Scientist, researcher, R&D expert, marketing – finance experts, intellectual property experts, regulators.
Scenario: Technology concepts are transferred to product, service, application hypothesis. It is considered finance, market, intellectual property issues. Focus groups are used to test the product concept.

TRL 3 Analytical and experimental critical function and/or characteristic proof of concept: Active R&D is initiated. This level includes analytical studies and laboratory studies to validate analytical predictions of separate elements of the technology physically.
UAV field: It is begun research, data collection, and analysis in order to test the hypothesis. It is explored alternative concepts, identify and evaluate critical technologies and components, and begin characterization of the candidate. Simulation results of the newly developed algorithm for swarm intelligence are obtained.
Actors: R&D, production.
Scenario: Key points of new technology are examined to demonstrate the solution is feasible in terms of technical and financial.

TRL 4 Component/subsystem validation in laboratory environment: Basic technological components are integrated to establish that they will work together. This level is relatively low fidelity compared to the eventual system.

UAV field: Integration of critical technologies is a promising development. A software system for swarm intelligence gave the expected results in the simulation environment and was validated.
Actors: R&D
Scenario: Prototype is developed to its full performance potential, but still in a laboratory environment.

TRL 5 System/subsystem/component validation in relevant environment: Breadboard technology's reliability increases significantly. Key technological components are integrated with reasonably realistic supporting elements so they can be tested in the simulation environment.
UAV field: Continue practical development system/subsystem/component such as a new software system, payload, or communication module.
Actors: R&D, external consultants, key costumers.
Scenario: For example, the new software system developed for swarm intelligence is validated in a controlled relevant environment with UAVs.

TRL 6 System/subsystem model or prototype demonstration in relevant environment: Representative model or prototype system is tested in a relevant environment. It is representing a significant step up in demonstrated readiness of technology.
UAV field: System/subsystem prototype such as software system for swarm intelligence, payload, or communication module is tested in controlled relevant environment.
Actors: R&D, external consultants, key customers, industrialisation, manufacturing.
Scenario: Scale-up process begins. Definitive feedback from users is required to outline the final product specifications.

TRL 7 System prototype demonstration in operational environment: Prototype near, or at, planned operational system. Represents a significant step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment.

UAV field: System prototype such as software system, payload, or non-cooperative collision avoidance system is demonstrated in operational environment for quality control, manufacturing process.
Actors: R&D, industrialisation, manufacturing, quality control, finance experts.
Scenario: Internal validation, quality control process and release procedures are finalised. Financial management of the future product is considered.

TRL 8 Actual system completed and mission qualified through test and demonstration in operational environment: The technology has proven to work in its final form and under the expected conditions. In almost all cases, this TRL represents the end of actual system development.
UAV field: Finalize manufacturing process. An actual system such as software system, payload, or non-cooperative collision avoidance system is completed and qualified.
Actors: R&D, industrialisation, manufacturing, quality control, marketing, regulators.
Scenario: External validation is performed at reference centres according to a predefined protocol.

TRL 9 Actual system mission proven through successful mission operations: Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation.
UAV field: Actual system such as software system, payload, or non-cooperative collision avoidance system successfully performs missions under real conditions.
Actors: R&D, manufacturing, quality control, marketing, media.
Scenario: End of the product development process and the start of distribution activities through sale force or distributors. Acquisition of further inputs from the market (salesforce, operators, customers) useful for future product/process improvements is started.

CHAPTER 6

RESEARCH METHODOLOGY AND TECHNIQUES

The research is designed in a mixed model by using quantitative and qualitative methods. Mixed method research is defined as the researcher's integration of qualitative and quantitative methods, approaches and concepts within a study or subsequent studies (Tashakkori & Teddlie, 1998). With the mixed method, the limitations that take place in quantitative and qualitative research alone are balanced (Creswell, 2008). Based on the stable features of qualitative and quantitative methods in the researches modelled with a mixed-method, the quality of the studies increases (Creswell, 2008; Johnson & Christensen, 2008). Mixed method researches are not considered as a simple combination of qualitative and quantitative methods, but rather as comprehensive integration studies where their strengths are supported by each other (Fırat, Kabakçı Yurdakul, & Ersoy, 2014). According to Creswell (2008), in mixed-method researches, the research problem is better understood by using qualitative and quantitative research methods together than in using individual methods.

Turkish UAV industry's problems, needs, and required actions for the future are investigated by conducting interviews.

Although a comprehensive literature study has been made for technology prediction, critical/prior technology areas were tried to be identified in interviews with industry participants, and technology statements were examined quantitatively with Delphi technique. In the second round of Delphi technique, participants were asked questions to collect qualitative data.

In the study of developing the maturity model, interviews were conducted with experts to discover what maturity model would be more useful and beneficial. In the application of the maturity model, six experts answered through interview.

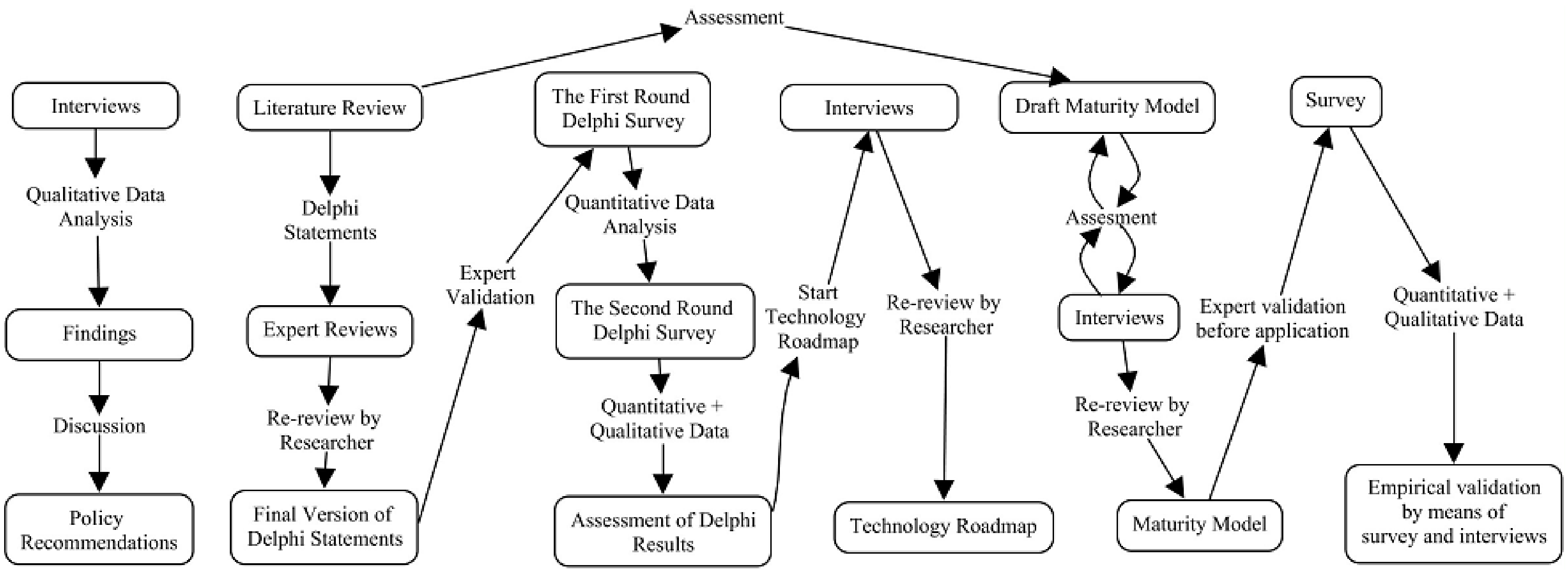

Figure 55 Research Process

Table 22
Research Methodology Application

Methodology Application Parts	Activities in the Methodology
Investigation of the UAV Industry	Interviews Analysis
Technology Roadmap	The First Round Delphi Survey The Second Round Delphi Survey Roadmapping through Interviews
Maturity Model	Interviews Survey Analysis

Data sources of the research are:

- Representatives from UAV companies,
- Academicians from universities.

6.1 Interviews

Qualitative research is often described as inductive. Induction describes the process of constructing and validating theory using data analysis. Qualitative research designs are characterised by flexibility and limited structure. This approach is to let analysis and findings emerge from the data over the time of the study (Kelly, 2016).

According to Patton (2002), interview; "The type of research that consists of open-ended questions and is used to obtain the respondents' experiences, thoughts, knowledge, and feelings about the subject."

The interview, which is also used frequently in organisational studies, includes individuals; it is an important research method that is used to obtain information about their experiences, attitudes, opinions, complaints, feelings, and beliefs (Yıldırım & Şimşek, 2011). The interview seems to be one of the most appropriate methods in this regard to conduct screening research in a field such as a strategy development using the knowledge of experts and experienced people.

According to Bir (1999), the interview is a purposeful conversation. It usually takes place between two people. One aimed to get information from another. In qualitative research, the interview can be used in two ways. Either it is the dominant technique in collecting data, or it is used with participant observation, document analysis or other techniques. In all these cases, it aims to collect descriptive data based on the researcher's own words. With this information, the researcher develops an opinion about how people interpret phenomena.

The interviewer should know the questions to be asked and should be impartial during the interview (Newman, 2010). The main features of the interview are:

- Often the interviewer asks, and the respondent responds.
- Only reveals the responding feelings and ideas.
- The interviewer is not judgemental, and it is impartial.
- The interviewer tries to get direct answers to certain questions.
- Allows answering almost all information. The interviewer does not correct the factual mistakes of the respondent.
- Always friendly throughout the interview, but it tries to maintain a serious and objective tone,
- It should not overwhelm answering questions and give correct, thoughtful answers (Newman, 2010).

Interview types are as below.
Unstructured Interview: There are no predefined questions. Questions are created in the form of a conversation on certain topics and by recording this conversation.

Structured Interview: It aims to get the same kind of information from different people. This interview approach covers a list of questions or topics to be examined during the interview.
Semi-structured Interview: This approach consists of a series of carefully written and ranked questions. These questions are asked in turn to each interviewee. This approach can increase interviewer subjectivity. This type of interview allows an investigation to be repeated by others (Yıldırım & Şimşek, 2011).

In this study, the semi-structured interview approach was adopted. In the interviews made through face-to-face or video conferencing, the detailing was made according to the answers received. Some participants did not have the opportunity to meet face to face or via video conferencing, and a written response was received. It remained in the form of answers to specified questions.

Strengths of the interview method:

- It is flexible; researchers can ask additional questions to get more in-depth answers.
- Since it is applied orally and face to face, the response rate is high.
- Non-verbal behaviours and situations can also be included in the research.
- The researcher can change the factors in the environment that may affect the questionnaire.
- The order of the questions can be changed as desired or as required.
- Instant reactions and fluctuations can be recorded.
- The data source can be confirmed as it is one-to-one.
- When the answers received are evaluated as completeness, they are complete compared to other survey types. The researcher can complete the survey without leaving any missing parts.
- In-depth information is possible (Yıldırım & Şimşek, 2011).

Weaknesses of the interview method:

- It is a long-time consuming method. It takes time to conduct interviews after an appointment with individuals. However, recording interviews also requires time.
- It may occur a possible bias. Although the researcher tries to be objective, the subjectively given answers may be received.
- The use of registered or written information is limited.
- There may not be enough time during the interview. Interviews may be kept short.
- There is no question standard. This situation may cause difficulties in comparing the data of the interview questionnaire.
- Determining the location and addresses of the individuals, setting the place and time for the interview is difficult (Yıldırım & Şimşek, 2011).

The primary purpose of content analysis is to reach concepts and relationships that can explain the collected data. Data interpreted in the descriptive analysis are processed in-depth, and concepts and themes that are not noticeable in descriptive analysis can be discovered in this analysis. The collected data is conceptualised first and then arranged reasonably according to the emerging concepts. Themes describing the data are determined accordingly. Briefly, data is defined in content analysis. The facts that may be hidden in the defined data are tried to be revealed. Data similar to each other are brought together within the framework of certain concepts and themes. Harmonised data is interpreted in a way that the reader can understand (Yıldırım & Şimşek, 2011).

According to Yıldırım & Şimşek (2011), some of the concepts used in the content analysis are as follows.

Inductive analysis: It is the concept of revealing the underlying concepts of data and the relations between these concepts by coding. (Strauss & Corbin, 1990 as cited in Yıldırım & Şimşek, 2011) defines this process as creating theory. Unknown cases are explained first by content analysis, and some propositions are reached. This process is called the theory-building process.

Coding: It is the process of naming meaningful sections in the data. The coding process requires dividing, analysing, comparing, conceptualising, and associating the obtained data (Yıldırım & Şimşek, 2011).

Concept: The meaning given to the sections and events in the data. It constitutes the basic analysis unit in content analysis (Yıldırım & Şimşek, 2011).

Category (theme): The concepts obtained in the content analysis are classified under a certain theme. The relations of the concepts are revealed. The relations uncovered are explained by a higher-level theme. It is more general than the concepts obtained in category or theme content analysis (Yıldırım & Şimşek, 2011).

6.2 The Delphi Method

Quantitative research is usually associated with surveys. Survey analysis is used most frequently to collect information from a large sample of individuals. The sample is selected to be representative of whole populations. Measurement is essential in quantitative research because it is an important way of demonstrating the relationships between concepts (Kelly, 2016).

Delphi is a group utilisation technique that seeks to obtain consensus on the opinions of experts through a series of structured surveys in a multistage process (Grisham, 2009; Hasson & Keeney, 2011). The size of the Delphi panels can vary widely, and there is a disagreement about the appropriate panel size. Gordon (1994) emphasized that most panels contain from 15 to 35 experts in the Delphi studies. The Delphi panellists should meet four requirements: knowledge and experience with the research subject, participation willingness, allocation enough time in the Delphi survey, effective communication skills (Skulmoski, Hartman, & Krahn, 2007; Grisham, 2009). The Delphi technique can be used for qualitative research to explore and identify the nature and fundamental elements of phenomena (Habibi, Sarafrazi, & Izadyar, 2014). Outliers may be explained in responses to explore tacit knowledge to create rich evidence in the Delphi technique (Somerville, 2008).

6.3 Reliability and Validity of the Research

This research is a study designed in which the mixed method, where qualitative and quantitative methods are used. One of the features of data analysis in mixed method research is the necessity to present the methods followed to check both the validity of quantitative data and the accuracy of qualitative findings. Tashakkori & Teddlie (1998) argue that validation procedures should be used for both qualitative and quantitative stages of study in mixed-method researches.

In the first stage of the research, interviews were conducted with the actors from the industry to investigate the problems and needs of the Turkish UAV industry and required actions for the future. Then a Delphi study aimed at determining the foresighted technologies were carried out, prepared by making use of the interviews made with the experts who received a roadmap for a selected technology field, and the final output of the research. A maturity model is developed and applied in order to evaluate the UAV industry using qualitative and quantitative methods. The reliability and validity of the research conducted within the scope of this thesis are tried to be determined in this section.

Approaches to validity and reliability in scientific research become complicated when it is examined for qualitative research. There are many criticisms in the literature about the reliability and validity of qualitative methods. One of the most trenchant criticisms of qualitative research is that there are no commonly used definitions, methods, and tests on reliability. While qualitative research works on the existence and meaning of a case, quantitative research focuses on the quantitative features of the case. In qualitative research, validity is concerned with the fact that the researcher investigates the phenomenon that is investigated as unbiased as possible, namely the accuracy of the research results (Yıldırım & Şimşek, 2011).

According to Yıldırım & Şimşek (2011), the researcher can use some additional methods (e.g. triangulation, participant confirmation, expert confirmation) to validate the data that is obtained and the results achieved. Validity is divided into two as external validity and internal validity:

- External validity refers to the transferability of the results obtained in the research to similar groups or environments. In other words, external reliability is whether the results of the research can be obtained in the same way in similar settings.
- Internal validity is related to the adequacy of the process, followed in reaching the research results in revealing the studied reality. That is, internal reliability is about whether other researchers will achieve the same results using the same data.

For reliability and validity of this research process:

1. The interview questions, which focuses on the industry’s problems, needs were reviewed by two experts.

2. Before proceeding to the qualitative data collection phase, pilot interviews were conducted with two experts.
3. Some interviews were conducted face to face, and some were done by video conferencing method; written responses were received from some participants via e-mail. In face-to-face interviews, data was recorded by the note-taking method, and then these notes were sent to the participants for confirmation and correction. The two participants made corrections on the answers and sent them back. Video conferencing interviews were recorded with the approval of the participant, and transcripted over the recordings play again.
4. The analysis of qualitative data was validated by expert opinions.
5. It was ensured triangulation by means of expert validation.
6. Data collection tools, data collection process, and analysis stages are explained.

Assumptions for data sources and data collection process in this research:

- It is assumed that knowledge and sources are correct in the literature review.
- It is assumed that sample fittingly represents the population.
- It is assumed that participants have enough knowledge and experience.
- It is assumed that the answers in interviews and surveys are correct and objective.

Delphi technique was also applied within the scope of the study. It is challenging to evaluate that the Delphi method is scientifically valid and reliable (Aydın, 1999). Different methods can be used to determine the reliability and validity of Delphi studies. Fink, Kosecoff, Chassin, & Brook (1991) emphasizes that evaluating the findings will help to develop an information structure about the validity of consensus studies. It also states that several features are essential to ensure the reliability of Delphi findings. Fink, Kosecoff, Chassin, & Brook (1991) explicitly complete the rules that indicate the suitability of the chosen problem, expert panel selection, data collection methods, consensus levels, and implementation stages to the method, which are effective in the researcher's decision to categorize the data and make inferences. Murphy, Black, Lamping, McKee, Sanderson, Askham, & Marteau (1998) highlight multiple ways to evaluate the findings of a Delphi study. These ways are: first comparing the findings with the results of a controlled sample, the second way is the validity comparing to the findings of data from other sources, thirdly, the internal evaluation application by performing the consistency test of the outputs from the group. Finally, it is expressed as measuring the surface validity by examining the usefulness in the context of correctness and application.

Validity is directly related to the selection of the expert, as the content is created by using expert opinions in Delphi studies (Fish & Busby, 2005). According to Patton (1987), purposive sampling enables to study the situations that are thought to have rich knowledge. It is important to define the qualifications that panel members should have clearly and to select the members under these qualifications in order to ensure validity (Clayton, 1997). In this context, the criterion sampling method, which is one of the purposive sampling methods, was used in the study.

According to this criterion; it was targeted employees in institutions and organisations working on UAV technologies, academics studying on UAV technologies.

The link of the Delphi form prepared on the Google Forms platform was sent to the experts who comply with the criteria, and it was asked them to forward Delphi form link their networks in order to expand the participation.

In the second round of Delphi study, the participants were asked, “Can you explain the reasons for the maturity level you chose? Can you remark your suggestions for the development of the related technology?” In addition to collecting qualitative data, an attempt was made to provide control for research reliability.

One of the essential criteria used in ensuring reliability and validity in the research is “triangulation” (Yıldırım & Şimşek, 2011). In this study, triangulation was provided by collecting data from different individuals and environments with different methods. The data obtained from the participants in the study were validated by two experts, and triangulation was ensured.

In order to make an application of the maturity model, a survey was prepared again using the Google Forms platform, the survey link was sent to experts from academia and industry and asked to send it to their appropriate links to increase participation. Some participants filled out the online form, and some participants stated that they could interview with the video conferencing method. The answers of the participants interviewed by video conferencing were inserted by the researcher through the form. Survey answers were analysed using IBM SPSS Statistics 22, and Cronbach's Alpha coefficient was calculated.

Cronbach's Alpha coefficient is a weighted standard variation average, which is found by proportioning the total of the variances of the k items in the scale to the general variance. The Cronbach's Alpha coefficient obtained for all items indicates the total reliability of that survey, and the general acceptance is that this value is 0.70 and greater. Different classifications are included in the literature for the interpretation of Cronbach's Alpha coefficient.

Table 23
Explanation of Cronbach's Alpha Coefficient (George & Mallery, 2003 as cited in Kılıç, 2016)

Reliability Coefficient (Cronbach's Alpha)	Comment
$\alpha \geq 0.9$	Excellent
$0.7 \leq \alpha < 0.9$	Good
$0.6 \leq \alpha < 0.7$	Acceptable
$0.5 \leq \alpha < 0.6$	Weak
$\alpha < 0.5$	Unacceptable

Table 24
Interpretation of Cronbach's Alpha Coefficient (Özdamar, 2002 as cited in Kılıç, 2016)

Reliability Coefficient (Cronbach's Alpha)	Comment
$0.81 < \alpha < 1.00$	High reliable
$0.61 < \alpha <0.80$	Medium reliable
$0.41 < \alpha <0.60$	Low reliable
$0.00 < \alpha < 0.40$	Not reliable

The answers given to the maturity model survey were analysed, and reliability was evaluated with respect to Cronbach’s Alpha coefficient. What is done to ensure the validity of the maturity model; how a maturity model would be more useful and beneficial was discussed with two field experts. The maturity model was validated by four experts, and then the survey was applied. The maturity model was validated by six experts who were interviewed via video conference during the application of the maturity model.

CHAPTER 7

RESEARCH PROCESS AND FINDINGS

7.1 Investigation of Turkish UAV Industry

In order to investigate the industry's problems, needs, and required actions for the future, qualitative data was collected from representatives of enterprises engaged in the UAV industry by means of interviews. The interview questions, as seen in Appendix A, were prepared to collect qualitative data to explore problems, needs, positive/negative affecting factors of the Turkish UAV industry, to determine prior technologies and requirements, to investigate collaboration and information sharing issues, to define required actions to be a pioneer in the world from actors in the UAV industry. The questions posed to the actors such as Founder, Co-founder, General Manager, and General Director to collect qualitative data.

Table 25
Qualitative Data Collecting Chart for Investigation of UAV Industry

Position	Method	Location	Duration
Co-founder	Face to face interview	Ankara	4 h 45 m
Founder (inactive)	E-mail written reply	E-mail	9 questions
Department Manager	Face to face interview	Ankara	3 h 45 m - 1 h 45 m
General Coordinator	E-mail written reply	E-mail	9 questions
Project Coordinator	Face to face interview	Ankara	1 h 45 m
General Manager	Face to face interview	Ankara	1 h 30 m
Founder	Face to face interview	Ankara	2 h 15 m
General Coordinator	Face to face interview	Ankara	1 h 30 m
Technical Manager	Face to face interview	Ankara	1 h 10 m
General Manager	Face to face interview	Ankara	50 m
Production Director	Face to face interview	Ankara	1 h 15 m
General Manager	Face to face interview	Ankara	40 m
Founder	Face to face interview	Ankara	1 h
Founder	Face to face interview	Ankara	35 m
Engineering Director	E-mail written reply	E-mail	9 questions
Founder	Face to face interview	Ankara	1 h

Thirteen participants were interviewed face to face, and three participants sent written answers via e-mail. It is collected 16 pages and 5,433 words qualitative data via face to face interviews by taking notes or e-mail responses from 16 responses.

There are several software programs in the market for content analysis, such as MAXQDA, NVivo, and Atlas.ti. However, the whole qualitative data analysis was conducted with Microsoft Excel 2013 office program. The Excel sheet was used as a database for qualitative content to ease the analysis of data collected from different interviewees.

Data Coding: In the first phase of the analysis process, the qualitative data was inserted to excel cells by questions, and participants. Answers given to each question reviewed and repeatedly filtered in the same way and tried to reach the codes representing the landscape. Code is the label to tag concepts, ideas explicit or implicit in the text. Similar thoughts of the different participant were tagged with the same codes.

Question	Participant-1	Participant-2	Participant-3	…	Participant-16
Question-1	Answer	Answer	Answer	…	Answer
Question-2	Answer	Answer	Answer	…	Answer
Question-3	Answer	Answer	Answer	…	Answer
…	…	…	…	…	…
Question-9	Answer	Answer	Answer	…	Answer

Figure 56 Excel Qualitative Data Table

Reliability of codes is provided with the agreement of two coders (Campbell, Quincy, Osserman, & Pedersen, 2013). Firstly, the codes were extracted by the researcher and reviewed by an expert. Re-review and agreement were performed by the researcher. Coding was conducted until reaching the agreement in two iterations.

Table 26
Codes from Qualitative Data

Codes	Definition
Finance	Firms are in poor financial conditions, and incentives are inadequate.
External dependence	There is an external dependency on technology, components, and materials.
State	Cumbersome state bureaucracy is a substantial obstacle. There is a lack of coordination.
Collaborations	Collaboration is very weak.
Technologies	There are technologies need to be developed.
Competition	Competition is feeble.
Applications	The existing applications are predominantly for defence.
Human resources	There is a need for qualified human resources.
TDZs/Technoparks	TDZs/Technoparks are malfunctioning and insufficient.

Sample evidence for the codes is presented below.

Finance

> *Another important issue is the budget allocated to R&D. Although this share has increased recently, research budgets are still insufficient compared to other competing countries.* Participant-4
> *There is a capital and financing problem in the sector. We need funding and incentives. The gradual system can be applied for incentives. When developing technology, it can be in the form of a stage, next stage, next stage, until it reaches a certain level. When we develop a concept, we apply for incentives for implementation, we are rejected and cannot start at all. Incentives can be implemented by setting intermediate targets. Almost all of the small companies like R&D have financial problems.* Participant-8
> *We have financial problems. The incentive mechanism is insufficient. We need to fund R&D projects; we use our salary in R&D projects.* Participant-11
> *Financing is required. Long-term basic science research should be done in this regard to financial requirements.* Participant-14

External Dependence

> *Almost all electronic components, sensors, image acquisition components, engines, and many more, we are external dependence.* Participant-2
> *There is no production of critical equipment in Turkey. Getting and boxing OEM cards does not make the product domestic.* Participant-3
> *Roadmaps should be developed and applied in order to acquire the capabilities to produce critical technological components domestically. These roadmaps should be prepared considering the aspects we have been missing so far and considering the future.* Participant-6

Critical components purchased from abroad are the most significant weaknesses of the sector. Participant-9

State

The state should organize its agencies. Participant-3

I can enumerate cumbersome bureaucracy and unfair competition conditions as problems. I think that in order to be a pioneer in technology, organisations like TÜBİTAK should focus on technology development rather than product development, and I think that the issue of technologies to be developed should be determined together with UAV firms. Participant-7

Permission from the SHGM takes too long. Participant-10

We need regulation. The state should undertake the task of coordinating information sharing and collaboration. Participant-13

We need the disposal of heavy bureaucracy. State should buy more products from firms like us. Participant-15

Collaborations

Collaboration with subsystem manufacturers is increasing day by day, but information and strategy sharing need further development. Participant-7

Collaboration and information sharing are very weak; there are problems. The state authority or technoparks do not seem to have a function of mediation in this regard. Participant-8

Information sharing and collaboration is not enough. A regulatory agency can distribute sub-projects by dividing to companies. It can be started with a low budget, short-termed projects. Participant-16

Technologies

Materials (Semiconductors, Composites and Alloys), Turbine Engine Technology, Sensor Technologies, Radar Systems. Participant-4

Material, sensor, battery, engine, software. Participant-6

I think competence is important in payload technologies. A payload to be developed should be used for many different purposes. It should be able to be structured according to a task. We have a lack of payload capability in UAVs. The payload is what makes UAV meaningful. Participant-8

Competition

A more competitive market should be formed. …lack of competition… competition in domestic supply should be increased. Participant-5

First of all, I can say that there is very little competition. We can bid for the tender, but we have no chance in a tender with the participation of state companies. I can't sell my product so. First, competition should be ensured. Participant-6

Applications

Defence is a priority now. It is early for civil applications. It should be paved the way for civil applications. Participant-11

TDZs/Technoparks

The misapplications are made by the TDZs administrations. It is wrong to include foundation companies in TDZs. For example, a company that makes accounting software may take place in TDZs. TDZs really needs to include *companies that conduct R&D really. R&D and innovation performance indexes should be conducted in TDZs. Enterprise governance is weak.* Participant-3

Human resources

The most important issue for the development of UAV technologies is the training of personnel that can be employed in this field. In this context, it is important to pay particular attention to the basic sciences (mathematics, physics and chemistry) and to establish the infrastructure that will allow the training of technician staff along with the engineering personnel together with the universities… Participant-4

7.2 A Technology Roadmap for Turkish UAV Industry

Popper, Keenan, Miles, Butter, & Sainz (2007) examined 755 technology foresight cases all around the world, and they determined that most widely used method are literature review in the first with 437 times and the expert panel is at the second with 324 times.

Technology sentences are created for the Delphi survey conducting a comprehensive literature review and evaluating them in terms of technological gaps, challenges, and future trends for foresighted UAV technologies. References selected for Delphi expressions from the literature review are presented in Table 27. References examined for more than one Delphi statement are shown across one Delphi statement.

Table 27
Samples from Examined Literature

Delphi Statement	References
D1	Howard (2013); Nehme, Crandall, & Cummings; Emelyanov, Makarov, Panov, & Yakovlev (2015); Tosunoğlu (2013); Fahlstrom & Gleason (2012)
D2	Drury, Riek, & Rackliffe (2006); Gupta, Gonge, & Jawandiya (2013); McCauley & Matsangas (2004); Nolan (2013); Peschel, Duncan, & Murphy (2012); Uhrmann & Schulte (2011); Altın (2017)
D3	Brittain & Wei (2019); Devasia & Lee (2016); Lutz, Frederick, Walsh, Wasson, & Fenlason (2017); Mihetec, Steiner, & Odic (2013); Schatten (2015); Radmanesh (2016); NASA (2014); Gerdes, Temme, & Schultz (2016); Flener & Pearson (2018)
D4	Harrison (2013); Palacios, Quesada, Sanahuja, Salazar, & Carrillo (2017); Hiemenz (2016); Goh, Agarwala, Goh, Dikshit, Sing, & Yeong (2017); Leitao, Barbosa, & Trentesaux (2011); Ferroa, Grassia, Seclib, & Maggiorea, (2015); Lee, Lapira, Yang, & Kao (2013); Kusiak (2018)
D5	Samso & Atkinson (2015); Azeem (2012); Burdziakowski (2017); Chao, Cao, & Chen (2010); De Garmo (2004); Desilles, Zidani, & Crück (2012); Lim, Park, Lee, & Kim (2012); FAA (2009); Rhudy, Gu, Gross, & Napolitano (2011); Baomar & Bentley; Vassilyev, Kelina, Kudinov, & Pashchenko (2016); Mahjri, Dhraief, & Belghith (2015); Sebbane (2016); Chee & Zhong (2012); Durmaz (2015); Bregu (2015); Albaker & Rahim (2010)
D6	Austin (2010); Beard, Lee, Quigley, Thakoor, & Zornetzer (2005); Burdziakowski (2017); Alsalam, Morton, Campbell, & Gonzalez (2017); Cesetti, Frontoni, Mancini, & Zingaretti (2010); Chao, Cao, & Chen (2010); Kim, Ong, Nettleton, & Sukkarieh (2004); Padhy, Verma, Ahmad, Choudhury, & Sa (2018); Gökçe, Üçoluk, Şahin, & Kalkan (2015); How, Bethke, Frank, Dale, & Vian (2008); Cadena et al. (2016); Jung & Ariyur (2017); Kumar & Michael (2012); Lepej, Santamaria-Navarro, & Sola (2017); Mancini, Caponetti, Monteriu, Frontoni, Zingaretti, & Longhi (2007); Nonami, Kendoul, Suzuki, Wang, & Nakazawa (2010); Sanchez-Lopez, Pestana, Puente, & Campoy (2016); Sebbane, (2018); Nawrat & Kus (Eds.) (2013); Sebbane (2014); Lu, Xue, Xia, & Zhang (2018); US DoD (2009); Ernest, Carroll, Schumacher, Clark, Cohen, & Lee (2016); Choi, Geeves, Alsalam, & Gonzalez (2016); Scott (2016)
D7	Daniel & Christian (2011); Gupta, Jain, & Vaszkun (2015); Hosseini, Jamal, Matolak, Haque, & Magesacher (2019); Iyer (2016); Li, Zhou, & Lamont (2013); Lin et al. (2018); Matolak & Sun (2015); Okcu (2016); Rodday (2015); Rosati, Traynard, Kruzelecki, & Rimoldi (2013); Şahingöz (2014); Sineglazov & Daskal (2017); Sliusar; Alzenad, Shakir, Yanikomeroglu, & Alouini (2016); Carrasco-Casado,Vergaz, & Sanchez-Pena (2011); Uysal & Nouri (2014); Namuduri, Chaumette, Kim, Sterbenz (2018); US DoD (2014); Yanmaz, Yahyanejad, Rinner, Hellwagner, & Bettstetter (2017); Chen et al. (2017); Mammadov (2013); Kaushal, & Kaddoum, (2016); Kaushal & Kaddoum (2017); Elgala, Mesleh & Haas (2011); Huo, Dong, Lu, Xu, & Yuen (2018); Chandhar, Danev, & Larsson (2016); Khan, Qureshi, & Khanzada (2019); Zeng, Zhang, & Lim (2016); Wang, Wang, Gong, Zou, Jiang, & Xu (2018)

Table 27 *(continued)*

Delphi Statement	References
D8	Davaslioglu, Coskun, & Ayanoglu (2015); Kakar & Marojevic; Ali & Leung (2009); Hellaoui, Bekkouche, Bagaa, & Taleb (2018)
D9	Dong, Ota, Lin, Tang, Du, & Zhual (2014); Erdelj & Natalizio (2016); Hu, Bai, Yang, Zheng, Bian, & Song (2018); Luo, Asemota, Nightingale, & Grecos (2015); Mahmoud & Mohamed (2014); Castenado (2013)
D10	Takenaka, Carrasco-Casado, Fujiwara, Kitamura, Sasaki, & Toyoshima (2017); Teunissen & Montenbruck (Eds.) (2017); Grewal, Andrews, & Bartone (2020); Hosseini, Jamal, Matolak, Haque, & Magesacher (2019)
D11	Adao, Hruska, Padua, Bessa, Peres, Morais, & Sousa (2017); Beard, Lee, Quigley, Thakoor, & Zornetzer (2005); Johnston, Longhi & Marrocco (2017); Porecki, Thomas, Warburton, Wheatley, & Metzger (2013); Tommaselli & Torress (2016); Meijer (Ed.) (2008); Meijer, Pertijs, & Makinwa (Eds.) (2014); Patterson & Brescia (2008); Kasturi, Milanovic, Atwood, & Yang (2016); Amon, Riegl, Rieger, & Pfennigbauer (2015)
D12	Feil (2012); Gu, Leet, Alon, & Singh (2012); Hartmann & Giles (2016); Holzer & Moses (2015); Kim, Wampler, Goppert, Hwang, & Aldridge (2012); RAND Corporation (2013); Spezio (2002); Poisel (2013); STM ThinkTech (2019); Saranya, Pavithira, Premsai, Lavanya, & Govindarajan (2016); De Martino (2018)
D13	Lerner (2013); Chin & Sern; Lionis (2016); Olson (2012); Karaağaç (2016); CRS (2019); Burton & Soare (2019)
D14	d'Oliviera, de Melo, & Devezas, (2016); Ünlüsoy (2014); Wool (2008)
D15	Austin (2010); US DoD (2010); Capata, Marino, & Sciubba (2013)
D16	Krawczyk, Mazur, Sasin, & Stoklasa (2014); Logan, Chu, Motter, Carter, Ol, & Zeune (2017); Malaver, Alexander, Gonzalez, Motta, & Villa (2015); Romeo, Cestino, Borello, & Pacino (2012); Belmonte, Luetto, Staulo, Rizzi, & Baricco (2017); NASA (2017)
D17	Göktoğan & Sukkarieh (2005); Pena, Caamano, Varela, Orjalesi, & Deibe (2016); Ma, Gausemeier, Fan, & Grafe (Eds.) (2011)
D18	McLaughlin (2013); Mohamed, Al-Jaroodi, Jawhar, & Lazarova-Molnar (2013); Pastor, Barrado, Royo, Rubio, & Santamaria (2009); US DoD (2018); Motlagh, Bagaa, & Taleb (2017); Jawhar, Mohamed, Al-Jaroodi, Agrawal, & Zhang (2017)
D19	Varadharajan, St-Onge, Svogor, & Beltrame (2017); Fernandez (2010); Fields (2012); Miller & Goodrich (2006); Han, Xu, Di, & Chen (2012); Li, Guo, & Wang (2015); Özpala, Efe, & Sever (2017); Shin & Segui-Gasco (2014); Smith, Hunjet, Aleti, & Barca (2018); Valavanis & Vachtsevanos (Eds.) (2015); Spezzano (Ed.) (2019); Skobelev, Budaev, Brankovsky, & Voschuk (2018); Bingler & Mohseni (2017)
D20	Kasapoğlu & Kırdemir (2019); Fraser (2015); Solodov, Hanaei, Williams, & Goddard (2017); Gözkaydıran (2019); CSA (2014); Wallace & Loffi (2015); Rassler (2016)

The first version of Delphi statements developed by the researcher is presented below.

D1: Intelligent systems have been developed for UAV and payload monitoring and control.

D2: Such as EEG signals/speech recognition that will increase human-machine collaboration based control systems have been developed.

D3: Reliable dynamic airspace management systems, which are self-configuring, optimizing, predicting congestion, enabling low-altitude applications to be carried out safely, resistant to adverse weather conditions and cyber attacks, have been developed and put into use.

D4: UAV prototype, system and application simulation and test platforms are used.

D5: High-reliable anti-collision systems which are resistant to adverse conditions, can distinguish between obstacles have been developed.

D6: High-reliable flight control systems resistant to adverse conditions have been developed.

D7: Intelligent systems have been developed to plan real-time routes during the flight.

D8: Hybrid laser/RF communications systems have been developed that provide reliable, very high bandwidth, UAV-UAV, UAV-Satellite, UAV-Ground data links, resistant to physical obstacles, atmospheric turbulence, scattering, and attenuation.

D9: Ultra-Violet communications systems have been developed, which are resistant to fading and multiple scattering, reliable, very high bandwidth.

D10: Frequency spectrum constraints have been solved technologically.

D11: Cybersecurity technologies that detect and take action against all kinds of cyber attacks against UAVs have been acquired.

D12: Advanced radar, sonar, LiDAR (Light Detection and Ranging), remote sensing and computer vision technologies have been developed.

D13: Such as chemical/biological/radioactive/nuclear, acoustic, meteorological, mine, forensic investigation, EO/IR advanced sensor technologies have been developed for situations.

D14: Payloads (e.g. optoelectronics, robotics, micro-electromechanical) that have low energy consumption and can be configured according to the task have been developed.

D15: Directed-energy weapon systems are in use.

D16: Advanced Electronic Warfare and Information Warfare systems have been developed.

D17: Material technologies that self-growing/shrinking, self-healing, and are resistant to impact and explosion have been possessed.

D18: Intelligent production systems which can use all materials like biomaterials, based on augmented modelling, optimisation and simulation, contain advanced production techniques like nanoscale fabrication, provide rapid prototyping, are data-oriented, predictive and self-organizing.

D19: Hybrid energy systems are used effectively in UAVs.

D20: Hybrid propulsion systems with very high efficiency and sound reduction have been developed.

D21: Lightweight electric batteries with a very long durability period have been developed and put into use.

D22: High-performance Artificial Intelligence technologies have been developed for UAV applications.

D23: Virtual, augmented and mixed reality technologies are used for UAV applications.

D24: UAVs are enabled to work with different types of platforms.

D25: Scalable swarming was ensured.

D26: Full autonomous systems were developed and put into use.

D27: Anti-UAV systems are used to detect, classify, identify, monitor and disposal threats that may come through UAVs.

D28: UAV taxi applications have been developed and accepted.

Delphi statements were developed as a result of six experts' opinion and reviews of the researcher. The final version of Delphi statements was validated by two experts. The final version of Delphi statements is below.

D1: Intelligent systems have been developed to monitor and control for Unmanned Aerial Vehicle (UAV) and payloads.

D2: Such as brain signals, speech recognition based control systems that will increase the Human-Machine Collaboration have been developed.

D3: Autonomous Air Traffic Management system, which ensures airspace integration has been developed.

D4: Data-driven, predictive intelligent manufacturing, maintenance systems, and test platforms based on autonomous modelling and simulation have been deployed for UAV and applications.

D5: Intelligent flight control systems that are resistant to adverse conditions have been developed.

D6: Intelligent systems have been developed for real-time route planning in all conditions (e.g. GPS denied environments, indoor navigation) during flight.

D7: All weather-resistant IP-based communications systems which provide robust data links with a high data transfer rate (>100 GB/s) have been possessed.

D8: Frequency spectrum constraints have been solved technologically.

D9: Intelligent decision support system which ensures to extract useful knowledge from UAV/other types of platforms/sensor network intense communications data and to react immediately in operation environment has been developed.

D10: Satellite system which ensures intense communications and the high-precision positioning of UAVs with robust, secure, and fast (>100 GB/s) data links have been deployed.

D11: Such as smart sensor, micro-electro-mechanical systems (MEMS), robotics payloads which energy-efficient, lightweight, and configurable according to mission have been developed.

D12: Advanced Electronic Warfare and Information Warfare systems which are providing absolute superiority in warfare environment have been developed.

D13: Next-generation Artificial Intelligence-enabled weapons and technologies have been obtained.

D14: Self-growing, morphing, self-healing, and impact/explosive-resistant light material technologies have been developed.

D15: Hybrid propulsion systems with very low thermal/acoustic/electromagnetic footprint which were optimized in terms of Size-Weight-Power-Cost (SWaP-C) have been developed.

D16: Battery with very long endurance (>200 h) providing very high energy density (>100 KWh/kg) has been developed.

D17: Virtual, augmented, and mixed reality technologies are being used effectively to plan, conduct, review for UAV missions, and crew/tactical training.

D18: Interoperability of UAVs with different types of platforms (e.g. UGV/UMV, manned systems, wearable computers) has been ensured.

D19: Fully autonomous scalable swarming has been ensured.

D20: Anti-UAV system has been developed for detection, identification, classification, monitoring, and disposal of all threats through UAVs.

The following questions were answered by the participants for each Delphi statement.
a: Expertise
(Expert, Familiar, No knowledge)
b: Importance for UAV and its applications
(1: Not Important; 2: Low; 3: Medium; 4: High; 5: Very High)
c: Impact on development and competitiveness of Turkey
(1: Not Important; 2: Low; 3: Medium; 4: High; 5: Very High)
d: Importance for national technologies in terms of triggering further research
(1: Not Important; 2: Low; 3: Medium; 4: High; 5: Very High)
e: Maturity Level of Technology in Turkey
(1: TRL 1 - 2; 2: TRL 3 - 4; 3: TRL 5 - 6 ; 4: TRL 7 - 8; 5: TRL 9)

f: Realisation time frame

(2020-2024, 2025-2029, 2030-2035, After 2035, Never)

The Delphi survey was prepared on Google Forms platform and carried out in two rounds. The first round Delphi form sample screenshots are presented in Appendix B. The first round Delphi form link was sent to experts who are a previously prepared list who are engaged in UAV technologies and expected to respond in ten days. Also, the participants asked to forward to their connections, who were able to answer the survey. The expected number of responses did not come within ten days, and reminder mail was sent to the participants. In the first round, it was obtained the first answer on 12.02.2020, the last answer on 12.03.2020 and then the survey was closed. Responses were received from 31 respondents. One of the respondents' answers are incomplete for the majority of Delphi statements, and the answers of this participant's responses were deleted because of no reply to the reminder mail for partial-answered questions in the survey period. Delphi Survey answers were collected according to their e-mail addresses on Google forms in translated forms of an electronic table in comma-separated values (CSV) format, and then this file was easily converted Excel table. Thirty responses of the first-round were analysed, and results of the first round are presented in Appendix E with charts.

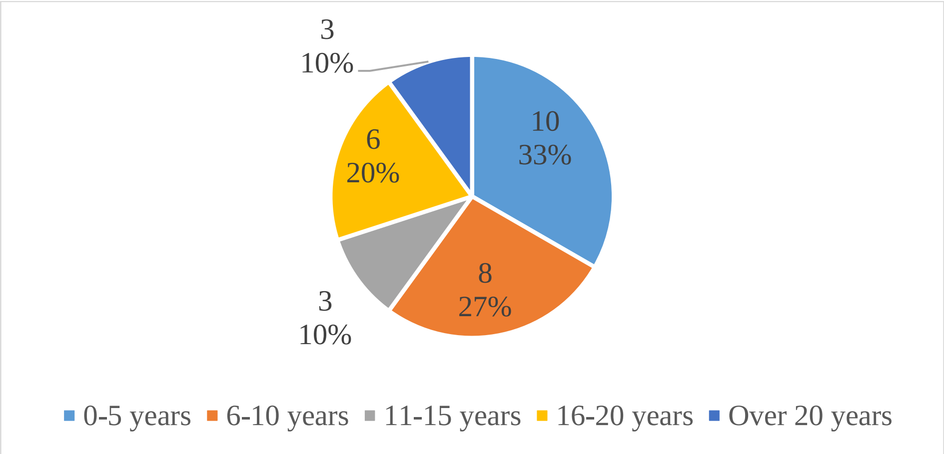

Figure 57 Experience of Respondents on UAV Technologies in First Round

Figure 58 was obtained by taking the median of total responses given to the criteria of C1, C2 and C3 to each Delphi statement. In calculations, the answers of experts and familiars were taken equal weight.

C1: Importance for UAV and its applications,

C2: Impact on development and competitiveness of Turkey,

C3: Importance for national technologies in terms of triggering further research.

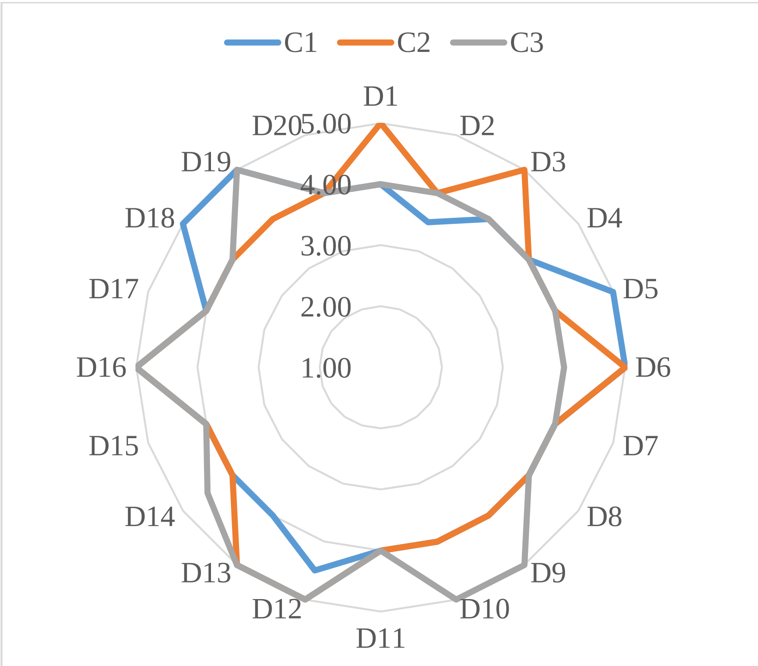

Figure 58 Distribution of Delphi Statements according to Criteria

Total results of the first round and individual answers were added onto second round Delphi for every statement. Different links that include individual answers to each participant were sent, and it was provided them to review and change their first answers for controlled feedback in the second round. In the second round, it was obtained the first answer on 27.03.2020, the last answer on 14.04.2020 and then the second round form access was closed. The second round Delphi form sample screenshots are presented in Appendix C.

In the second round of Delphi study, 24 answers were received, and two of 24 participants gave the same answers without changing their answers in the first round.

Twenty-two participants made a total of 418 response changes in the second round. One participant changed the 52 answers in the second round and became the participant who the most changed opinion. The second round responses were analysed by the same methods as the first round. Results of the second round are presented in Appendix F with charts.

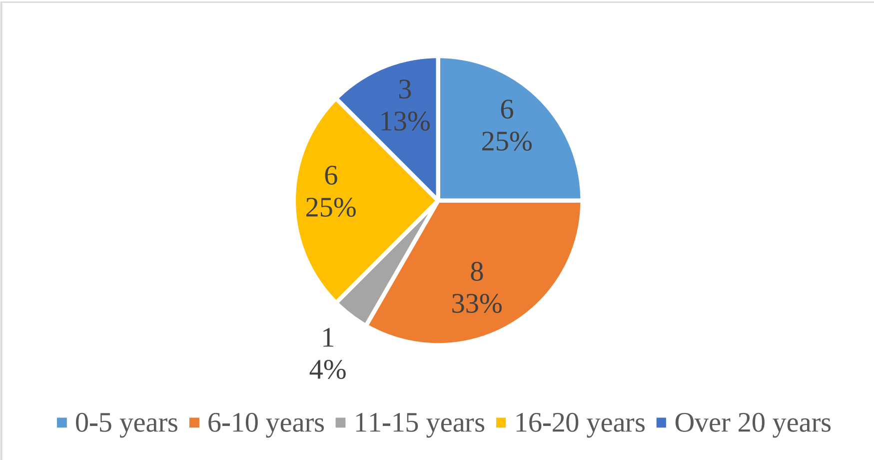

Figure 59 Experience of Respondents on UAV Technologies in Second Round

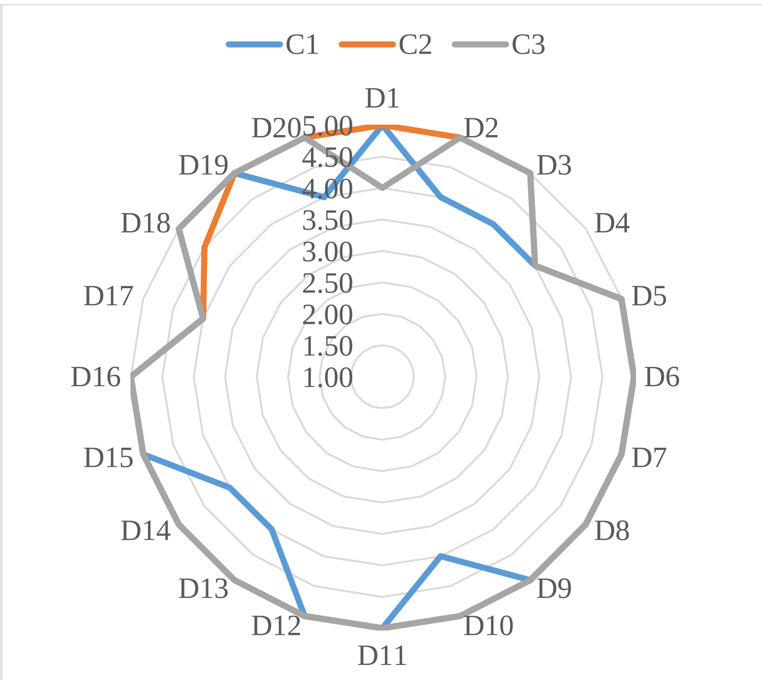

Figure 60 Evaluation of Delphi Statements according to Criteria in the Second Round

Results with the median value of the second round Delphi survey, according to C1, C2, and C3 criteria are shown in Figure 60. D4, D5, D6, D7, D8, D9, D11, D12, D15, D16, D17, and D19 statements are overlapped in the evaluation of C1, C2, and C3 criteria.

Median: When an array is created by ordering all values in a series from small to large or large to small, it is the value that divides the series into two parts with equal frequency. Median is the middle value takes 50% of responses to the right and 50% to the left. Median value shows group decision in this research.
First Quarter (Q1): It is the point that takes 25% of the answers to the left and 75% to the right.
Third Quarter (Q3): It is the point that takes 25% of the responses to the right and 75% to the left.
Interquartile Range (Q3-Q1): It is the difference between the third quarter and the first quarter. As the width decreases, consensus increases.
The data analysis method and level of compromise used in Delphi studies may vary depending on the subject, purpose, research process and the results of the research (Powell, 2003). Consensus level refers to the percentage of responses received within the specified ranges. It is asked that the level of consensus depends on the research topic (Keeney, Hasson, & McKenna, 2006). Central tendency and distribution criteria such as arithmetic mean, mode, median, standard deviation, the interquartile range (IQR) can be used as consensus criteria in Delphi studies. Median and interquartile range values are used more in Delphi studies because of the possibility that marginal responses that are given can unrealistically affect the results of the study (Cochran, 1983; Gordon, 1994; Mullen, 2003). In this context, the criteria for the definition of consensus for the evaluation of the second round Delphi survey are:
Median ≥ 4.0 (for C1, C2, and C3), IQR ≤ 1.0 (for all criteria).

For consensus, it was asked the Median value should be at least the “High” level, and the IQR should be at most one answer interval (e.g. 4.0-5.0) in this research. It is taken only IQR as consensus criterion for Maturity and TimeFrame. Median is appropriate for the questions in which the importance of Delphi statements is questioned. For the second round, the answers given by the participants were analysed with IBM SPSS Statistics 22, and measures of central tendency tables were obtained.

Table 28
Measures of Central Tendency for D1

		C1	C2	C3	Maturity	TimeFrame
N	Valid	24	24	24	24	24
	Missing	0	0	0	0	0
Mean		4.6250	4.6667	4.3333	3.2500	1.2083
Median		5.0000	5.0000	4.0000	3.5000	1.0000
Mode		5.00	5.00	4.00	4.00	1.00
Std. Deviation		.64690	.56466	.56466	1.18872	.41485
Variance		.418	.319	.319	1.413	.172
Percentiles	25	4.0000	4.0000	4.0000	2.0000	1.0000
	50	5.0000	5.0000	4.0000	3.5000	1.0000
	75	5.0000	5.0000	5.0000	4.0000	1.0000

The group decisions for D1 statement are Very High for C1 and C2, High for C3, and the realisation time frame is 2020-2024. Maturity of the statement in Turkey is TRL 7-8 levels, but IQR = 2.0 the group consensus was not ensured.

Table 29
Measures of Central Tendency for D2

		C1	C2	C3	Maturity	TimeFrame
N	Valid	19	19	19	19	19
	Missing	0	0	0	0	0
Mean		3.6316	4.5789	4.6316	1.2632	2.5263
Median		4.0000	5.0000	5.0000	1.0000	2.0000
Mode		3.00	5.00	5.00	1.00	2.00
Std. Deviation		.83070	.60698	.59726	.56195	.84119
Variance		.690	.368	.357	.316	.708
Percentiles	25	3.0000	4.0000	4.0000	1.0000	2.0000
	50	4.0000	5.0000	5.0000	1.0000	2.0000
	75	4.0000	5.0000	5.0000	1.0000	3.0000

The group decisions for D2 statement are High for C1, Very High in terms of C2 and C3. The maturity is TRL 1-2 levels and realisation time frame 2025-2029. It is IQR = 1.0 for C1, C2, C3, and IQR = 0.0 for TimeFrame and Maturity. The group consensus was provided for all questions in this statement.

Table 30
Measures of Central Tendency for D3

		C1	C2	C3	Maturity	TimeFrame
N	Valid	16	16	16	16	16
	Missing	0	0	0	0	0
Mean		4.2500	4.6875	4.5000	2.1250	1.7500
Median		4.0000	5.0000	5.0000	2.0000	2.0000
Mode		4.00	5.00	5.00	2.00	2.00
Std. Deviation		.68313	.60208	.73030	.80623	.68313
Variance		.467	.363	.533	.650	.467
Percentiles	25	4.0000	4.2500	4.0000	1.2500	1.0000
	50	4.0000	5.0000	5.0000	2.0000	2.0000
	75	5.0000	5.0000	5.0000	3.0000	2.0000

Group decisions for D3 are High for C1, Very High in terms of C2 and C3, and the realisation time frame is 2025-2029. Maturity is TRL 3-4 levels in line with the median 2.0, but IQR = 1.75, so group consensus was not be ensured for maturity.

Table 31
Measures of Central Tendency for D4

		C1	C2	C3	Maturity	TimeFrame
N	Valid	21	21	21	21	21
	Missing	0	0	0	0	0
Mean		3.9524	3.9524	4.0000	2.6190	1.4762
Median		4.0000	4.0000	4.0000	3.0000	1.0000
Mode		4.00	4.00	4.00	2.00	1.00
Std. Deviation		.58959	.49761	.54772	.86465	.74960
Variance		.348	.248	.300	.748	.562
Percentiles	25	4.0000	4.0000	4.0000	2.0000	1.0000
	50	4.0000	4.0000	4.0000	3.0000	1.0000
	75	4.0000	4.0000	4.0000	3.0000	2.0000

Group decisions in D4 are High for C1, C2, and C3. The maturity is TRL 5-6 levels, and realisation time frame is 2020-2024. IQR = 0.0 for C1, C2, and C3, so group consensus is excellent. IQR = 1.0 for Maturity and TimeFrame and group consensus was achieved.

Table 32
Measures of Central Tendency for D5

		C1	C2	C3	Maturity	TimeFrame
N	Valid	20	20	20	20	20
	Missing	0	0	0	0	0
Mean		4.8500	4.5500	4.5500	2.6500	1.5500
Median		5.0000	5.0000	5.0000	3.0000	1.5000
Mode		5.00	5.00	5.00	3.00	1.00
Std. Deviation		.36635	.60481	.60481	1.08942	.60481
Variance		.134	.366	.366	1.187	.366
Percentiles	25	5.0000	4.0000	4.0000	2.0000	1.0000
	50	5.0000	5.0000	5.0000	3.0000	1.5000
	75	5.0000	5.0000	5.0000	3.0000	2.0000

D5 group decisions are Very High for C1, C2, and C3. Maturity is TRL 5-6 levels, and realisation time frame is 2020-2024. IQR = 0.0 for C1 and IQR = 1.0 for other questions, so group consensus was achieved for all questions.

Table 33
Measures of Central Tendency for D6

		C1	C2	C3	Maturity	TimeFrame
N	Valid	22	22	22	22	22
	Missing	0	0	0	0	0
Mean		4.9545	4.7727	4.5909	2.8636	1.2727
Median		5.0000	5.0000	5.0000	2.0000	1.0000
Mode		5.00	5.00	5.00	2.00	1.00
Std. Deviation		.21320	.52841	.66613	1.24577	.45584
Variance		.045	.279	.444	1.552	.208
Percentiles	25	5.0000	5.0000	4.0000	2.0000	1.0000
	50	5.0000	5.0000	5.0000	2.0000	1.0000
	75	5.0000	5.0000	5.0000	4.0000	2.0000

Group decisions for D6 are Very High in terms of C1, C2, and C3, and the realisation time frame is 2020-2024. Maturity of the statement is TRL 3-4 levels in line with Median 2.0 but IQR = 2.0, so the group consensus was not achieved for maturity.

Table 34
Measures of Central Tendency for D7

		C1	C2	C3	Maturity	TimeFrame
N	Valid	15	15	15	15	15
	Missing	0	0	0	0	0
Mean		4.6667	4.6667	4.6000	1.7333	1.8667
Median		5.0000	5.0000	5.0000	1.0000	2.0000
Mode		5.00	5.00	5.00	1.00	2.00
Std. Deviation		.48795	.61721	.50709	.96115	.63994
Variance		.238	.381	.257	.924	.410
Percentiles	25	4.0000	4.0000	4.0000	1.0000	1.0000
	50	5.0000	5.0000	5.0000	1.0000	2.0000
	75	5.0000	5.0000	5.0000	2.0000	2.0000

D7 group decisions are Very High for C1, C2, and C3 aspect, the maturity level of the statement in Turkey is TRL 1-2 levels, the realisation time frame is 2025-2029. It is seen that IQR = 1.0 for all questions, so group decision was ensured.

Table 35
Measures of Central Tendency for D8

		C1	C2	C3	Maturity	TimeFrame
N	Valid	13	13	13	13	13
	Missing	0	0	0	0	0
Mean		4.7692	4.6923	4.6923	2.1538	1.5385
Median		5.0000	5.0000	5.0000	2.0000	1.0000
Mode		5.00	5.00	5.00	2.00	1.00
Std. Deviation		.43853	.63043	.63043	.89872	.66023
Variance		.192	.397	.397	.808	.436
Percentiles	25	4.5000	4.5000	4.5000	1.5000	1.0000
	50	5.0000	5.0000	5.0000	2.0000	1.0000
	75	5.0000	5.0000	5.0000	3.0000	2.0000

Group decisions for D8 are Very High for C1, C2, and C3, and the realisation time frame is 2020-2024. Maturity of the statement in Turkey is TRL 3-4 levels, but it is seen IQR = 1.50, so group consensus was not supported for maturity.

Table 36
Measures of Central Tendency for D9

		C1	C2	C3	Maturity	TimeFrame
N	Valid	22	22	21	22	22
	Missing	0	0	1	0	0
Mean		4.5000	4.6364	4.7143	2.3182	1.5909
Median		5.0000	5.0000	5.0000	2.0000	2.0000
Mode		5.00	5.00	5.00	2.00	2.00
Std. Deviation		.59761	.58109	.64365	.83873	.59033
Variance		.357	.338	.414	.703	.348
Percentiles	25	4.0000	4.0000	5.0000	2.0000	1.0000
	50	5.0000	5.0000	5.0000	2.0000	2.0000
	75	5.0000	5.0000	5.0000	3.0000	2.0000

Group decisions are Very High for C1, C2, and C3. Maturity is TRL 3-4 levels and realisation time frame 2025-2029. IQR = 1.0 for C1, C2, C3, Maturity, and TimeFrame. The group consensus was provided for all questions for D9 statement.

Table 37
Measures of Central Tendency for D10

		C1	C2	C3	Maturity	TimeFrame
N	Valid	15	16	15	15	16
	Missing	1	0	1	1	0
Mean		4.4000	4.7500	4.7333	1.6000	2.5000
Median		4.0000	5.0000	5.0000	1.0000	2.5000
Mode		4.00[a]	5.00	5.00	1.00	2.00
Std. Deviation		.63246	.57735	.59362	1.12122	.51640
Variance		.400	.333	.352	1.257	.267
Percentiles	25	4.0000	5.0000	5.0000	1.0000	2.0000
	50	4.0000	5.0000	5.0000	1.0000	2.5000
	75	5.0000	5.0000	5.0000	2.0000	3.0000

Group decisions for D10 are High for C1, Very High in terms of C2 and C3. Maturity is TRL 1-2 levels, and time frame is 2030-2025. For D10 statement, the group consensus was achieved in all questions.

Table 38
Measures of Central Tendency for D11

		C1	C2	C3	Maturity	TimeFrame
N	Valid	17	17	16	17	17
	Missing	0	0	1	0	0
Mean		4.7059	4.7647	4.6875	2.2941	1.8235
Median		5.0000	5.0000	5.0000	2.0000	2.0000
Mode		5.00	5.00	5.00	3.00	1.00
Std. Deviation		.46967	.43724	.47871	.77174	.88284
Variance		.221	.191	.229	.596	.779
Percentiles	25	4.0000	4.5000	4.0000	2.0000	1.0000
	50	5.0000	5.0000	5.0000	2.0000	2.0000
	75	5.0000	5.0000	5.0000	3.0000	2.0000

The group decisions are Very High for C1, C2, and C3. Maturity of the statement in Turkey TRL 3-4 levels and realisation time frame is 2025-2029. The group consensus was provided for all questions in the D11 statement.

Table 39
Measures of Central Tendency for D12

		C1	C2	C3	Maturity	TimeFrame
N	Valid	14	14	14	14	14
	Missing	0	0	0	0	0
Mean		4.5714	4.7143	4.7143	3.0714	1.6429
Median		5.0000	5.0000	5.0000	3.0000	2.0000
Mode		5.00	5.00	5.00	2.00	2.00
Std. Deviation		.51355	.61125	.61125	1.07161	.63332
Variance		.264	.374	.374	1.148	.401
Percentiles	25	4.0000	4.7500	4.7500	2.0000	1.0000
	50	5.0000	5.0000	5.0000	3.0000	2.0000
	75	5.0000	5.0000	5.0000	4.0000	2.0000

The group decisions are Very High in terms of C1, C2, and C3, and 2025-2029 for the realisation time frame. Maturity is TRL 5-6 levels according to Median value of 3.0, but it is seen IQR = 2.0 for the maturity of the statement.

Table 40
Measures of Central Tendency for D13

		C1	C2	C3	Maturity	TimeFrame
N	Valid	21	20	21	21	21
	Missing	0	1	0	0	0
Mean		4.1905	4.5500	4.7143	1.7619	2.2857
Median		4.0000	5.0000	5.0000	1.0000	2.0000
Mode		5.00	5.00	5.00	1.00	2.00
Std. Deviation		.98077	.68633	.56061	.94365	.95618
Variance		.962	.471	.314	.890	.914
Percentiles	25	4.0000	4.0000	4.5000	1.0000	1.5000
	50	4.0000	5.0000	5.0000	1.0000	2.0000
	75	5.0000	5.0000	5.0000	2.5000	3.0000

Group decisions for D13 are High for C1 and Very High for C2 and C3. Maturity of the statement in Turkey is TRL 1-2 levels and realisation time frame 2025-2029 but IQR = 1.50 for answers of these two questions. The group consensus was not ensured for Maturity and TimeFrame.

Table 41
Measures of Central Tendency for D14

		C1	C2	C3	Maturity	TimeFrame
N	Valid	16	16	16	16	16
	Missing	0	0	0	0	0
Mean		3.8750	4.5625	4.7500	1.5000	2.8125
Median		4.0000	5.0000	5.0000	1.0000	2.5000
Mode		4.00	5.00	5.00	1.00	2.00
Std. Deviation		.71880	.62915	.44721	.63246	.91059
Variance		.517	.396	.200	.400	.829
Percentiles	25	3.0000	4.0000	4.2500	1.0000	2.0000
	50	4.0000	5.0000	5.0000	1.0000	2.5000
	75	4.0000	5.0000	5.0000	2.0000	4.0000

Group decisions for D14 are High for C1, Very High in terms of C2 and C3, and maturity TRL 1-2 levels. IQR = 1.0 for C1, C2, and Maturity and IQR = 0.75 for C3. The group consensus was not ensured for the realisation time frame of the statement because of IQR = 2.0.

Table 42
Measures of Central Tendency for D15

		C1	C2	C3	Maturity	TimeFrame
N	Valid	13	13	13	13	13
	Missing	0	0	0	0	0
Mean		4.5385	4.6923	4.7692	1.6923	2.4615
Median		5.0000	5.0000	5.0000	1.0000	3.0000
Mode		5.00	5.00	5.00	1.00	3.00
Std. Deviation		.66023	.48038	.43853	1.03155	.66023
Variance		.436	.231	.192	1.064	.436
Percentiles	25	4.0000	4.0000	4.5000	1.0000	2.0000
	50	5.0000	5.0000	5.0000	1.0000	3.0000
	75	5.0000	5.0000	5.0000	2.5000	3.0000

The group decisions for D15 statement are Very High for C1, C2, and C3, and the realisation time frame 2030-2035. IQR = 1.0 for C1, C2, and TimeFrame and IQR = 0.50 for C3, so group consensus is achieved for these questions.

Table 43
Measures of Central Tendency for D16

		C1	C2	C3	Maturity	TimeFrame
N	Valid	16	16	16	16	16
	Missing	0	0	0	0	0
Mean		4.9375	4.8750	4.8750	1.1250	3.0625
Median		5.0000	5.0000	5.0000	1.0000	3.0000
Mode		5.00	5.00	5.00	1.00	4.00
Std. Deviation		.25000	.34157	.34157	.34157	.85391
Variance		.063	.117	.117	.117	.729
Percentiles	25	5.0000	5.0000	5.0000	1.0000	2.0000
	50	5.0000	5.0000	5.0000	1.0000	3.0000
	75	5.0000	5.0000	5.0000	1.0000	4.0000

Group decisions for D16 are Very High in terms of C1, C2, and C3. Maturity of the statement in Turkey is TRL 1-2 levels and IQR = 0.0, so group consensus is excellent. It can be said 2030-2035 for the time frame of the statement, but it seems that IQR = 2.0 for this question, so group consensus was not achieved.

Table 44
Measures of Central Tendency for D17

		C1	C2	C3	Maturity	TimeFrame
N	Valid	17	17	17	17	16
	Missing	0	0	0	0	1
Mean		3.8235	3.8235	3.9412	2.3529	1.5625
Median		4.0000	4.0000	4.0000	3.0000	1.0000
Mode		4.00	4.00	4.00	3.00	1.00
Std. Deviation		.72761	.72761	.74755	.93148	.81394
Variance		.529	.529	.559	.868	.663
Percentiles	25	3.0000	3.0000	3.0000	1.5000	1.0000
	50	4.0000	4.0000	4.0000	3.0000	1.0000
	75	4.0000	4.0000	4.5000	3.0000	2.0000

Group decisions for D17 are High in terms of C1, C2, and C3, the maturity TRL 5-6 levels, realisation time frame 2020-2024. For C1, C2, and TimeFrame, IQR = 1.0, so group consensus is achieved. IQR = 1.50 for C3 and maturity, so group consensus was not achieved in these questions.

Table 45
Measures of Central Tendency for D18

		C1	C2	C3	Maturity	TimeFrame
N	Valid	16	16	16	16	16
	Missing	0	0	0	0	0
Mean		4.5000	4.3125	4.3750	2.4375	1.6250
Median		5.0000	4.5000	5.0000	2.0000	1.5000
Mode		5.00	5.00	5.00	2.00	1.00
Std. Deviation		.81650	.79320	.80623	1.26326	.71880
Variance		.667	.629	.650	1.596	.517
Percentiles	25	4.0000	4.0000	4.0000	1.2500	1.0000
	50	5.0000	4.5000	5.0000	2.0000	1.5000
	75	5.0000	5.0000	5.0000	3.7500	2.0000

Group decisions for D18 are Very High in terms of C1, C2, and C3. It is possible to say the maturity is TRL 3-4 levels but IQR = 2.50 for the answers to these questions. IQR = 1.0 for C1, C2, C3, and Time Frame, so group consensus was ensured.

Table 46
Measures of Central Tendency for D19

		C1	C2	C3	Maturity	TimeFrame
N	Valid	19	19	19	19	19
	Missing	0	0	0	0	0
Mean		4.7368	4.6842	4.5789	2.6316	1.4737
Median		5.0000	5.0000	5.0000	3.0000	1.0000
Mode		5.00	5.00	5.00	3.00	1.00
Std. Deviation		.45241	.47757	.69248	.89508	.69669
Variance		.205	.228	.480	.801	.485
Percentiles	25	4.0000	4.0000	4.0000	2.0000	1.0000
	50	5.0000	5.0000	5.0000	3.0000	1.0000
	75	5.0000	5.0000	5.0000	3.0000	2.0000

Group decisions for D19 are Very High C1, C2, and C3. The maturity TRL 5-6 levels and realisation time frame 2020-2024. It is seen that IQR = 1.0 in all questions in this statement. These results indicate that group consensus for all questions in this Delphi statement.

Table 47
Measures of Central Tendency for D20

		C1	C2	C3	Maturity	TimeFrame
N	Valid	17	17	17	17	17
	Missing	0	0	0	0	0
Mean		4.2941	4.5294	4.5882	2.6471	1.3529
Median		4.0000	5.0000	5.0000	3.0000	1.0000
Mode		5.00	5.00	5.00	3.00	1.00
Std. Deviation		.84887	.71743	.61835	.78591	.49259
Variance		.721	.515	.382	.618	.243
Percentiles	25	4.0000	4.0000	4.0000	2.0000	1.0000
	50	4.0000	5.0000	5.0000	3.0000	1.0000
	75	5.0000	5.0000	5.0000	3.0000	2.0000

Group decisions for D20 are High C1 aspect and Very High in terms of C2 and C3. The maturity of the statement in Turkey TRL 5-6 levels and realisation time frame 2020-2024. It is seen that IQR = 1.0 in all questions in this statement. This situation indicates that group consensus for all questions in this Delphi statement, as it meets the set consensus criteria.

Group consensus is provided for C1, C2, and C3, which are the criteria taken into account in determining the technological goals, in all Delphi statements. It is not achieved group consensus for the maturity level of the statement in Turkey in D1, D3, D6, D8, D12, D13, D15, D17, and D18. It is not ensured group consensus for the realisation time frame in D14 and D16. It was not performed additional application for consensus in Delphi statements, which was not ensured consensus for maturity and realisation time frame. It is evaluated the Delphi study with four participants after two round application. It was determined that there are differences in interpretation about maturity level and time of realisation, and this situation was reflected in four participants' answers. C1, C2, and C3 are used to determine technological goals.

In the second round of Delphi study, for the qualitative data to the participants, "Can you explain the reasons for the maturity level you chose? Can you remark your suggestions for the development of the related technology?" was asked. The aim of this question is to take the rationale for maturity level evaluations and suggestion for improvement measures. Examples from the experts' answers are presented.

D1

> *I do not know an intelligent system for UAV and payloads monitoring, health management and control in Turkey. We have similar technologies in different areas. Also, it can be developed for UAVs, and it would be very beneficial.*

D2

> *There are studies at article and thesis level. I think UAVs are important for task flexibility and sustainability in the future. With such a system, UAV control can also be a solution in terms of cybersecurity. This technology can be used in different areas like biomedical. For this technology, universities should be worked hard, and R&D activities should be funded in the long run.*
> *I am aware of some of the studies done at METU-TSK MODSIMMER. There are some trials in the lab environment, and it is not applied to UAV products. The importance level of the issue can arise from mid-level when UCAV, which will fight air-air in the future, is advanced.*

D3

> *There are radar and image processing technologies required for non-cooperative sensing systems and are being tested by various groups in the laboratory environment. For further development, relevant standardization studies should be followed closely, and tenders should be opened by SSB for production.*
> *The number of companies working in this country is very low. The most advanced company in this field is ESEN, where I am currently working. We have a product called T2CAS. This product is the basis for the technology mentioned here, but it is a technology that requires a more complicated, larger, hybrid application. That is why I give 3-4.*

D4

> *Studies on intelligent production and maintenance systems continue. For example, we have preventive maintenance goals through big data analysis. Test platforms are still used; for example, almost all tests are performed automatically in the system integration laboratory.*

D5

> *In systems that react actively and make decisions by self-perception, a competence demonstration has been made in the simulation environment.*

D6

> *I want to say 5-6, but this is only true for certain subdomains. Some projects are field-tested within the scope of development, but they do not deserve 5-6. However, the number of companies working on this issue is high, and user demand is high.*

D7

> *There is no study. When it comes to 100 Gb/s, for example, laser datalinks come to my mind. I have not seen any mention of this data rate in Turkey.*

D8

Our companies are developing products to control multiple UAV and ammunition via the same band by modulation such as TDMA.

D9

Companies have started some work on sensor fusion that will provide input to such decision support systems. There are also some studies on making a decision support system using artificial intelligence.

D10

Communications satellite links have been developed, but data rates have not yet provided 100 Mb/s. I know that positioning is not working yet on the satellite system.

D11

Some study is ongoing on MEMS-based navigation systems and fibre-based strain gauges.

D12

There are many products from different companies that are currently being tested on the field.

D13

The use of Artificial Intelligence studies, which will mark the coming decades and shape our lives, by integrating them with weapon systems will also have great importance on the survivability of countries. For this reason, it is of great importance that the AI studies carried out individually within the universities are carried out in collaboration with the defence industry.

D14

I think structures that can change shape (such as morphing wings) are an important issue in terms of aviation in particular, in terms of UAVs and defence industry and country industry. There were studies initiated for this purpose within METU Aerospace Engineering. These studies should be continued towards the end product in terms of material development.

D15

I estimate that some preliminary studies have been carried out in this direction in the automotive industry. For aviation, our companies have taken this issue to roadmaps.

D16

Within the scope of current battery technology, there are no serious localisation studies. The thermal battery competence achieved in missile technologies has not been achieved in the new generation of rechargeable lightweight batteries. There are companies that engage in the battery, but they are at the beginning of the way in developing technology in battery chemistry.

D17

There are studies on AR and VR in other areas, but they are not yet used in UAV missions.

D18

UAVs have interoperability studies, but the scope in the statement is very comprehensive, so I choose this level of maturity.

D19

The swarm of UAV attempts, which are also reflected in the press, unfortunately, are not the ones that are coordinated by communicating between them, but only multiple flights in open loop. It has just begun to work on swarm algorithms and communications.

D20

İHA Savar was developed for small commercial UAVs. However, it cannot be said that this capability includes UAV and cruise missiles in all category.

It is possible to say that answers support the Delphi research'reliability.

D5, D6, and D19 statements were handled together, and it was decided to prepare a technology roadmap on "Intelligent Flight Management of UAV Swarms that are resistant to adverse conditions".

- Related technology areas,
- Assessment of the current status of related technologies in Turkey,
- Affecting factors of related technologies,
- Developing stages,
- Stakeholders.

Related technology areas were drafted by the researcher and presented to expert opinion. Expert interviews were conducted to develop the technology roadmap. Interviews were made by video conferencing method, except for one written response that was received from one expert. Excerpts from the interviews are presented below.

Interviewee-1

Related technologies

Every individual in the swarm should have a set of capability in terms of individual autonomy. It should know where it is; it should have information about the objects around; it is environmental awareness. If I am here, what should I do if I have them around, this is situational awareness, task sharing, it should have environmental awareness if it can fulfil tasks, even if it is left alone. If UAVs are not detached from the swarm, UAVs should be able to do a job that they cannot do alone.

When there is a change in their environment, UAVs should be able to decide how to perceive it, what to do, and be able to create consensus for sharing tasks.
Environmental awareness, reasoning ability, and situational awareness as an individual are the ultimate goals of the swarm.
These technologies in its infancy in Turkey, this is actually partially in such a world, the world we are not far behind in this respect. Swarm intelligence is a newly launched concept in the world.
It is necessary to talk about the maturity level in the swarm. There is consensus in the academic community to make it decentralised control paradigm. While communication is limited to make it decentralised, there is a tendency to evolve into a structure that individuals can do within themselves, to carry out the swarm task when individuals come together.
Communications within the swarm, communications between individuals, it should be done. It cannot be done with wireless networks such as standard WiFi, Bluetooth.
There is a need for the protocols to support dynamic swarm structures such as the swarm coming together and dispersing. Protocols suitable for swarm behaviour need to be developed ZigBee relatively supports these structures. Also, another protocol can be developed.
Task sharing is very critical. If it consists of generic individuals, if there is a base configuration, all of them can do each other's task, but if there are more than one type of individuals in the swarm, if there are individuals with different configurations, one cannot do the work of the other, then certain individuals can be assigned to a task, developing rules sets for who will be assigned to the task. This issue is related to swarm intelligence. Rule sets are included in the concept of swarm intelligence.
The number of academicians working on swarm intelligence is few. The number of academicians working on the UAV swarm is very, very few.
There is a technology field called sensor fusion, construct information from each individual on all global data by making sensor fusion. The data accumulated among individuals should be shared.
Very robust sensor fusion must be done. Sensor fusion is necessary both within the individual and within the data shared by individuals.
It is necessary to have a module to prevent collision within the swarm. Collision-avoidance needs to know the location of other individuals, collision estimation and motion estimation do not have mature studies about where other individuals are going, issues that need to be solved.
It seems that the maturity of the controller is important in atmospheric effects, the formation protection of the swarm.
External factors like wind, aerodynamic design are important for robustness.

Affecting factors

Proficiency in engineering education affects.
It is nice to do simulations, but when you go on the field and experiment, many UAVs are required. They have an economic aspect in supplying them, there is a financial barrier, and this can affect negatively.

Development stages

2020-2024

Maturing of individual autonomy.

2025-2029

Maturing of swarm autonomy.
Starting human interaction with the swarm, paving the way for the management of a swarm of 100 UAVs.

2030-2035

Advancing studies in the previous two to five years.
It may be that different types of individuals constructs swarm.

Stakeholders

SHGM should be a stakeholder; regulation is required for a fully autonomous swarm.
SMEs, TDZs, STB, universities, SSB.
There must be investors; technologies with low TRL must be investors to start mass production. SMEs and universities need to come together.

Interviewee-2

Situation awareness.
Reaction detection.
One of the two air vehicles must perceive the manoeuvre according to the move of the other. UAVs very close move to each other during operations.
Integrated data link is required.
Ground control station.
Onboard processor.
Autopilot software needs to be developed to process different data.
Sense and avoid systems.

Development stages

2020-2024

Integrated data link.
Sense and avoid systems.

2025-2029

Increasing on-board processor capacity.

2030-2035

Autopilot software.
Raising the level of autonomy.
Integrated data processing.

Stakeholders

TUBİTAK, SSB, Companies, STM.

Interviewee-3

The following technology fields have been added by following the related technology statements prepared by the researcher.

Formation flight, everyone knows the other's position. Point-to-point laser communication is important. Communications within swarm is short-term difficult, limited information transfer.
GCS can be made, load balancing in multi air vehicle control.
Image processing is also within the subject of autonomy.
Distributed sensor and weapon network is not on the agenda of any company. Everything does not have to be on the air vehicle. Coordination, they need to cooperate, the platformer who will make this scenario.
GNSS denied environments, working on CRPA antenna technology, …CRPA antenna to make it durable on the agenda of everyone, navigating with terrain following, DFR image processing, so as not to need GNSS. There is a surface-navigation. Navigation by making estimates from these radio navigation stations in order to be able to continue with a certain precision by using DME stations.
Swarm intelligence, there is a lack of coordination for studies. There are some intentions, but the maturity level is low.
Sensor fusion. There is no sensor fusion at the image intelligence level. Electronic Warfare sensor fusion is better in Turkey.
Onboard processor. We came to the limits of the processor. It may be a project should be opened for this. The flight computer can be made, but the processor is a critical issue, taken from abroad.
Collision avoidance. Cooperative and non-cooperative. We assume that there is a transponder on the opposite side. Tactical collision avoidance is supposed to be on air vehicle of a certain weight. Non-cooperative collision avoidance systems are in the R&D phase in the world, no level of complexity.
Continuity of R&D activities should be ensured. There is a lack of funding. Sustained R&D funding is a need.

Interviewee-4

Swarm intelligence.
Resistance to environmental conditions.
A scenario-based study should be done. There is a required infrastructure in Turkey.
Certification and ethical regulation studies may be done about the swarm.
It is difficult to state the development steps as it is a very dynamic process, but we will complete studies within five years. We see swarm application in our lives within five years. By following the studies in the world, we must carry out the studies with our means by being informed about the country. Studies at universities are theoretical but far from practice. The studies in the industry are practical and also far from the theory. Therefore, the University and Industry sides should work together.
Competitions that set goals can be organised.

Stakeholders

Universities, SSB, Companies.

Interviewee-5

The written reply is received via mail in line with the draft document sent from the participant. Excerpts from the answers are presented below.

The current situation of technology areas in Turkey.

Advanced ground control system:

All kind of GCS from mobile phone to large command and control centre can be developed in Turkey.

Individual and swarm autonomy:

Individual autonomy can be performed depend on a supervisor operator (e.g. ANKA, TB2, Karayel, Aksungur, Akıncı, Serçe).

It is known that studies on swarm autonomy are carried out. Swarm autonomy can be performed at Level-5 or later, according to the NIST definition of individual autonomy.

Distributed sensor and weapon networks:

In the event that reconnaissance-surveillance UAVs are seen as sensors, it can be argued that there is partly existing technology with the use of multi-UAV.

Terrestrial distributed sensors were developed as a prototype in 2016-2017, and their trials were made for homeland security.

Navigation sensor and vision-based navigation algorithms that operate in GNSS denied environments:

Various capabilities are gained with different approaches in this regard. It is known that using new generation technologies; studies are conducted to enable smaller systems to make GNSS-independent navigation with visual or different sensors. Various R&D projects supported by SSB was started in 2020.

Communications within swarm; Flying Ad Hoc networks:

Various studies are carried out on the capability of the flying network. It is a technology that will increase the task capabilities of the swarms and has a multiplier effect on the increase of swarm intelligence.

Robust and secure Ground-to-Air data link, transmission modes:

New solutions are being developed in this field in Turkey.

Swarm intelligence:

Active studies on swarm intelligence are carried out.

Sensor fusion:

There are sensor fusion capabilities in Turkey.

High-performance onboard processor:

Despite the lack of chip and operating system on flight computers, a required capability is available at the card and above level in Turkey. It is studied on the operating system.

Collision avoidance/sense and avoid:

Collision avoidance, sense and avoid systems are critical and can be designed by combining different technological solutions. Different and innovative solutions are required to prevent collisions for swarm systems.

Human-machine collaborations, supervisory control of swarms from command post:

It is a remarkable technology title that manned-unmanned systems act as a team. In this case, technological infrastructure studies should be carried out for assigning basic tasks with simple interfaces and for the concept where the task is performed through the swarm.

Developing stages

2020-2024

The first examples of distributed swarms can be seen and used in real operations.

2025-2029

The capabilities of distributed and working swarms can be improved, and TRL 9 can be achieved.
a) Reconnaissance, surveillance
b) Strike and destruction
c) Electronic Warfare.

2030-2035

Robot troops can start serving in the TSK and world armies.

Interviewee-6

By discussing the focus of onboard processors, other technologies and suggestions were briefly discussed in the remaining time. Quotations from the interview are presented below.

Processor development efforts in Turkey started late. The requirement to produce chips was not noticed. It is procured from abroad, but it is not cheap, efficient, and it is also possible to put something hidden inside.
In the defence industry, these chips must be produced domestically for security reasons.
It is also important to be a UAV. It may not be necessary to make a locally produced processor for a quadrotor. It is necessary to make a locally produced processor for platforms like Anka, Bayraktar.
It should be produced for reasons of safety and efficiency out in Turkey. It is also expensive when purchased from outside. Production facilities are required in Turkey. There is no facility in Turkey. More importantly, it must be researchers to produce these semiconductors.

There is a lack of knowledge and experience. Turkey is not a strategic approach to this issue. Unaware, it is thought that instead of spending millions, I get 30-40 dollars.
When it is taken from outside, the producer can put something inside, and it is difficult to understand.
It is unthinkable that processor production is not made, an organisation like TAI should establish the team directly and start doing these studies. It is purchased separately for each platform, the team can be installed, and a processor can be produced for each platform.
Current applications do not require much onboard computing power, but the need will increase when you consider the applications of the swarm and the high-autonomous task based on artificial intelligence in the future.
Some processors should be designed more originally according to the platform.
There will be no need to connect from ground to air in the future, he will give instructions in advance, and he will do it like this, and it will depend on Artificial Intelligence.
It needs companies that develop imaging-related hardware.
It will be the development of Artificial Intelligence, make navigation in the denied environment. Give it your duty, forget it, something that will happen with Artificial Intelligence.
GPU accelerator and visualizer hardware may be required.

Interviewee-7

Technology areas you determined are covered extensively. I have no suggestions on these.
There is no area where we can say we are very good among these technologies. It is necessary to work on 20-30 years.
There are some super algorithms, but you need a processor to run it.
Flying Ad Hoc Network can be developed between 10-20 years.
Sensor fusion is very important. Speed data is coming; image data is received, images are received from ground and air vehicles, how will they be combined. This has not been resolved in the world; it is advantageous to solve this.
You filtered the data received, it is necessary to make a decision, how to make a coordinated decision, how they will work together, Artificial Intelligence methods, if there is a heterogeneous structure. Turkey should invest in this issue. These issues are based on Artificial Intelligence at a significant level.
Maturity of theoretical and scientific studies on Artificial Intelligence is required. It comes in years to reach the level of maturity.
Full autonomy will be difficult in the short-term and the long-term. There are scientific studies, but TRL is low.
It is not possible to see real-life problems in universities. University-Industry collaboration should be strong and long-term.
The companies' let us do by ourself everything approach is wrong. Start-ups should be used effectively.

Affecting factors

Serious long-term plans should be made, and people should be trained by providing long-term training.
Problems are tried to solve it with short-term investment. When it cannot be solved, it is procured from abroad.
Long-term development studies should be carried out by preparing the requirements in detail.

Developing stages

2020-2024

Processor, communication, sensor fusion.
It is forcing the state of the art that passes existing systems. Academic goals, commercial goals.
It can be conducted border surveillance semi-autonomously by developing a scenario.

2025-2029

It is developing and implementing a scenario to do a task without central control.

2025-2029

Let us do a task with GPS-denied and very high agility. 3D scanning the environment and swarm application with vision-based navigation.
Commercial goals can be set. The country cannot develop after you cannot sell.

Interviewee-8

Technology areas that you prepared are very detailed. The following issues can be addressed. What level of learning within the scope of swarm intelligence, who is doing the mission planning, who will do the target assignment should be detailed? There will be false targets; it will learn over time, intelligence is required in this regard.
Multiple processors are required, if image processing will be onboard, GPU is required, embedded processing should be very good.
There should be consensus algorithms. If a joint decision is to be made, algorithms are necessary to reach a joint decision.
Communications within swarm, hybrid technology should be used. How will UAVs move, how it will get closer and farther.
It can be Zig Bee in a short distance, satellite or GSM in the remote distance. More than one communication technology can be hybrid.
Air-to-Air communications are required for the swarm. It should support sensor fusion to work in multiple modes.
Sensor fusion, what are the most used sensors, can be achieved by providing the fusion of the most used sensors in the short term and then adding them to the module by module.
The development steps you have prepared seems rational. Required times; GNSS-denied 15 years. Individual autonomy fully 15 years, two levels every five years. Swarm intelligence 15 years.

Prepared Technology Roadmap is presented below.

Related Technology Areas (TAs):

1) High-performance onboard processor.
2) Robust and secure Ground-to-Air/Air-to-Air data link, transmission modes.
3) The advanced GCS.
4) Sensor fusion.
5) Navigation sensor and vison based navigation algorithms that operate in GNSS-denied environments.
6) Collision avoidance/sense and avoid.
7) Individual autonomy.
8) Communications within swarm for decentralised control, Flying Ad-Hoc Network.
9) Distributed sensor and autonomous weapon networks.
10) Swarm intelligence.
11) Human-machine/swarm collaboration, supervisory control of swarms.

TA1: In the swarm paradigm, the onboard processor requirement will increase compared to the current situation. It is necessary to develop high capacity energy-efficient processors to meet the requirements. Graphics Processing Unit is required for onboard image processing. Especially for defence applications, it is necessary to produce onboard processors domestically. There is a lack of processor development capability in Turkey.

TA2: Ground-to-air data links are currently used in the central control paradigm. Even if the decentralised control paradigm is adopted, ground-to-air data links will be needed. However, air-to-air data links will also be required for communication with a UAV or a manned air vehicle outside the swarm. Progress has been made in this technology area.

TA3: Ground control stations suitable for the swarm paradigm should be developed and adaptations should be made in line with developing technologies. Although the decentralised control paradigm provides independence from the ground control station, a ground control station will be needed. Various kind of control stations can be produced in Turkey.

TA4: Sensor fusion should be able to be done very successfully in swarm applications. Very successful sensor fusion is required in order to combine the information obtained from a member of the swarm. There is no capability for image sensor fusion. EW sensor fusion is better in Turkey.

TA5: Necessary technologies, such as sensors and algorithms, should be developed to ensure intelligent, independent and adaptive navigation in denied environments. There is no capability for this technology area in Turkey.

TA6: As the autonomy level increases, the risk of collisions increases in swarm applications. Sense and avoid systems should be developed in a dynamic structure. There different technological solutions in Turkey. Advanced non-cooperative collision avoidance technologies should be developed.

TA7: When a UAV is separated from the swarm, it must have situational and environmental awareness and continue its missions. The individual autonomy level of a UAV affects the autonomy level of the swarm. For this reason, the individual autonomy level of UAVs should be increased.

TA8: In the decentralised control paradigm, communications within the swarm, in other words, the communications of the individuals that make up the swarm, is very important. Data within the swarm is shared through within swarm communications technology. It is difficult to talk about only one technology that is valid for all situations in swarm communications. The types of UAVs that make up the swarm (such as rotary-wing, fixed-wing as well as their sizes), how close these UAVs will come to each other, how far they will move from each other, are important for choosing the technology to be used. It is appropriate to develop hybrid communications systems containing more than one technology according to the requirements.

TA9: In the future trend, interoperability with distributed sensors or autonomous weapons should be ensured in swarm applications. The interaction between sensor networks and swarms for monitoring critical infrastructures is an example for civil applications. The interoperability of next-generation autonomous weapons with a swarm is a defence requirement that needs to be prepared. It is a future trend subject, and no study can be observed.

TA10: Issues such as making common decisions within the swarm, sharing tasks, performing tasks, and coordination of swarm members are within swarm intelligence. The more advanced the swarm intelligence, the higher performance swarms can be created. Bio-inspired computation algorithms such as Particle Swarm Optimization, Artificial Bee Colony, Ant Colony Optimization, Fruit Fly Optimization, Bat Algorithm and their applications should be studied. Also, behaviours in nature (e.g. stigmergy) should be modelled for swarm applications. There are studies in Turkey, but the maturity level is low.

TA11: In the future trend, it is important to provide supervisory control of one or more swarms with human-machine interfaces. This technology will provide flexibility and agility in performing tasks. It is a future trend subject, and no study can be observed.

Affecting Factors

1) Operations of UAVs in civil airspace is currently limited to Visual Line of Sight (VLOS as defined in SHT-İHA) in the current regulations (SHT-İHA). This restriction should be removed with new regulations extending the operations to Beyond Visual Line of Sight (BLOS as defined in SHT-İHA), to make full utilisation of UAV capabilities (including autonomous flight). The technologies that will be developed should be supported by regulations. Regulations should not be an obstacle to the use of technologies to be developed.

2) It should be ensured guidance and strategic planning defining workshare between SMEs/start-ups in terms of duplicate efforts and financial risks.

3) Integration and collaboration between the defence and aerospace companies should be ensured at the required level. Integration is required for system-level development.

4) It is necessary to develop high-performance algorithms, especially in swarm intelligence and sensor fusion. The engineers who will carry out the development of such high-performance algorithms must receive outstanding mathematical modelling education at the university. At the same time, it is necessary to conduct basic researches in universities in this field exceptionally well. While academic studies generally focus on one aspect of the problems, it is used as an approach that accepts the other aspects (e.g. communication issues, adverse conditions) as ideal. With University-Industry collaboration, holistic studies should be carried out that address all aspects of problems in line with real requirements.

5) Hardware components to support the high-performance algorithms mentioned in the previous article should also be developed and sustained. In other words, processors, which algorithms can run successfully and communications systems to support data transfer, should be developed.

6) The technology areas investigated are technologies that have low maturity and require long-term R&D studies. Therefore, investors and financial supports should be provided for long-term R&D studies.

In Figure 61, the starting and progress plans of technology areas are presented. Since there are requirements that will arise in the future trend of TA9 and TA11, it is not necessary to start these studies immediately in terms of resource efficiency. Work in other technology areas can be started in parallel. When studies in a technology area are completed, it will be appropriate to direct resources to ongoing technology areas. Among the technology areas examined in this technology roadmap, the most challenging issues requiring long-term study are considered as TA4, TA5, TA7, and TA10.

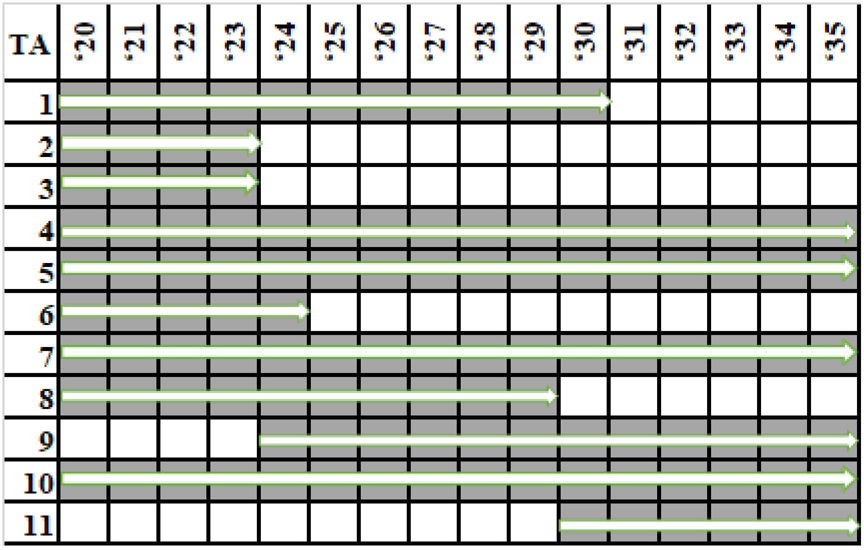

Figure 61 Progressing Stages

Stakeholders

STB, SHGM, TÜBİTAK, SSB, Defence/Aerospace industry companies, SMEs/Start-ups, TDZs/Technoparks, and Universities.

7.3 UAV Industry Maturity Model

An attempt was made to develop a maturity model that proposes descriptive and prescriptive roles for the Turkish UAV industry. Maturity scope assesses on R&D capability and technology usage. The maturity model was established and validated by means of expert review. Maturity dimensions and criteria for maturity levels in each dimension were drafted by the researcher through evaluating the literature review conducted to determine the technology goals for the Turkish UAV industry. Interviews were iteratively conducted with the two experts on how a maturity model would be more beneficial and useful. After these interviews, the maturity model was created by reviewing by the researcher. The dimensions seen in Figure 62 were defined by the researcher.

Air Vehicle Technologies Developing technologies that will prolong the economic life of UAVs and ensure that operations are performed with high efficiency and reliability	**Payload Technologies** Ability to develop and use payload systems that enable a wide range of complex and challenging UAV missions to be performed with high reliability in all conditions	**Secure Communications Technologies** Developing technologies that enable UAVs to communicate reliably and securely with other platforms on the ground, in the air and space at all times
Interoperability Ensuring interoperability and data fusion at platform and payload level of UAVs with other systems such as Unmanned Marine/Ground Vehicles, manned vehicles, portable or wearable devices	**Autonomy** Capability to develop and use technologies that enable UAVs to perform their tasks with minimum supervision or completely independently, with high reliability and efficiency	**Human-Machine Collaboration** Ability to develop and use technologies that enable Human-Machine collaboration to perform operations with high flexibility, agility and safety

Figure 62 Dimensions of Maturity

The maturity model was validated by four experts before application. It was surveyed for a sample application to evaluate the Turkish UAV industry and validation the maturity model through reliability analysis and participants' improvement measures opinions.

Air Vehicle Technologies

1. Not Competent: Low efficient air vehicle technologies are used.

2. Low Competent: Improvement solutions are researched for platform technologies**.**

3. Moderately Competent: R&D studies are increasingly carried out in aerodynamics, propulsion, construction/material, flight control and battery technologies.

4. Competent: Improvement results in locally produced air vehicle technologies started to be observed.

5. Highly Competent: Advanced technologies have been developed that optimize the size and weight of air vehicle, increase reliability and reduce costs per-mission.

Payload Technologies

1. Not Competent: Payload systems are mostly supplied COTS via imports, and domestic production subsystems are limited in capability.

2. Low Competent: Programs have been initiated to develop payload systems, and R&D studies are carried out.

3. Moderately Competent: Domestic production payload systems have started to be used in real operations.

4. Competent: Efforts to increase the local content, maturity, and diversity of locally produced payload systems are ongoing.

5. Highly Competent: All kinds of payload systems that can be used with high reliability in every task can be produced locally, including critical subsystems.

Secure Communications Technologies

1. Not Competent: Communications systems have a low data transmission speed and are easily affected by adverse conditions.

2. Low Competent: Improvement studies in communications technologies have started, and required policies, procedures and techniques are being developed.

3. Moderately Competent: More efficient, robust, and secure data links have been developed.

4. Competent: Data transfer rate is increased, vulnerability assessment, cyber-attack resilience, redundancy and anti-jamming efforts are performed. Studies for local production in modem/waveform and other critical components are ongoing.

5. Highly Competent: Communications technologies that ensure high data transmission rate, spectrum efficiency, cyber resilience, better all-weather capacity, robust electronic protection have been developed. Development/production for indigenous modem/waveforms and other critical components are completed.

Interoperability

1. Not Competent: Some studies such as open architectures, data fusion, and modularity are carried out for interoperability.

2. Low Competent: Inter-machine communications and common data warehouses have been developed.

3. Moderately Competent: Data collection and data fusion between machines are done with high reliability.

4. Competent: Systems can perform air vehicle control/mission planning and data fusion at the payload level.

5. Highly Competent: Teams consisting of different types of platforms can carry out a mission from beginning to end by task-sharing between each other with high reliability and flexibility.

Autonomy

1. Not Competent: UAVs are remotely controlled.

2. Low Competent: R&D studies on autonomy were started, and some techniques were developed. Accordingly, UAVs can implement the mission plan themselves and switch to another predefined flight plan in urgent situations.

3. Moderately Competent: In semi-autonomous level, group coordination or less remote control ensure task execution. For example, UAVs have situational awareness and can decide whether they can continue their tasks by perceiving failure situations.

4. Competent: UAVs and munition with high autonomy can be developed. These systems have capabilities such as real-time decision making, route planning, location determination, and navigation in denied (GPS-denied) environments. There is progress in swarm intelligence studies.

5. Highly Competent: Fully autonomous swarms can perform operations with high safety and efficiency without human control/supervision from start to finish.

Human-Machine Collaboration

1. Not Competent: No Human-Machine interaction.

2. Low Competent: Machine control and data collection is done with simple Human-Machine interfaces.

3. Moderately Competent: Control and task management of single-vehicle is conducted with advanced interfaces.
4. Competent: Multiple machine control and task management are done through Human-Machine interaction.
5. Highly Competent: Human intent can be inferred by machines; fully Human-Machine collaboration has been achieved. The payload information obtained from many machines is processed autonomously and agile, responsive, and adaptive collaboration is ensured.

After determining criteria for maturity levels above, the technologies and supporting activities that need to be developed to progress at these levels are described below. These technologies provide improvement measures for the maturation of Turkish UAV industry.

Air Vehicle Technologies

Intelligent health management algorithms, Collision avoidance, Composites, Self-morphing and self-healing materials, Smart material technologies, Optical materials, Carbon-based materials, Stealth technologies, Morphing structures, Battery advancements, Fuel cells, High energy density materials, Turbine engines, Ramjet/Scramjet engines, Wireless power transmission, Intelligent power management, Hybrid propulsion technologies, Energy harvesting technologies.

Payloads Technologies

Sensor electronics, Acoustic sensors, Autonomous small sensors, Light Detection and Ranging (LiDAR), Tactical laser radars, Robotics, EO sensors, Directed energy, Hyperspectral imaging, Laser researches, Multispectral imaging, IR sensors, Robotics, AI-enabled weapons, Signal researches, Imagery sensors, Self-healing sensors, THz sensors, SAR advancements, Deception techniques, RF Localisation and Guidance, NRBC sensors, Jamming techniques, ESM/ELINT, COMINT/DF, Target acquisition, SIGINT, RF sensors, Wireless sensor array networks, Smart MEMS technology.

Secure Communications Technologies

Communications electronics, Advanced multiple access techniques, Advanced multiplexing techniques, Cyber resilience and robustness, Smart and lightweight antennas, Cellular networks, Flying Ad Hoc networks, Optical Local Area Networks (LANs), Increased network and spectrum capacity, Satellite system.

Interoperability

Common/open architectures, Common languages, Common data repositories, Information and data fusion techniques, Data mining techniques, Modularity, Inter-machine collaboration, Integrated end-to-end data delivery, Sensor fusion, Autonomous data strategy adaptation.

Autonomy

Artificial intelligence, Autonomous modelling and simulation, Bio-inspired computation, Computer vision technologies, High-performance computing technologies, Machine learning, GPS-denied solutions, Multi-agent-systems, Hyper-heuristics, Vision-based navigation, Swarm intelligence, Simultaneous Localization and Mapping (SLAM).

Human-Machine Collaboration

Augmented/Virtual Reality technologies, Biotechnology, EEG signal processing, Human-machine interfaces, Speech and natural language processing, Wearable computers.

Enabling capabilities

Research infrastructure, Knowledge management, Project management, Systems engineering.

Research Infrastructure

Universities - Interfaces (e.g. Innovation Transfer Centres, Incubation Centres, Network-Structures, University-Industry Collaboration Platforms, Technology Transfer Offices) - Firms.

Universities have huge research potential with laboratories, and Research-Application Centres and firms have R&D and design centres. Value chains such as TDZ (specialization), Knowledge bases, Communication platforms.

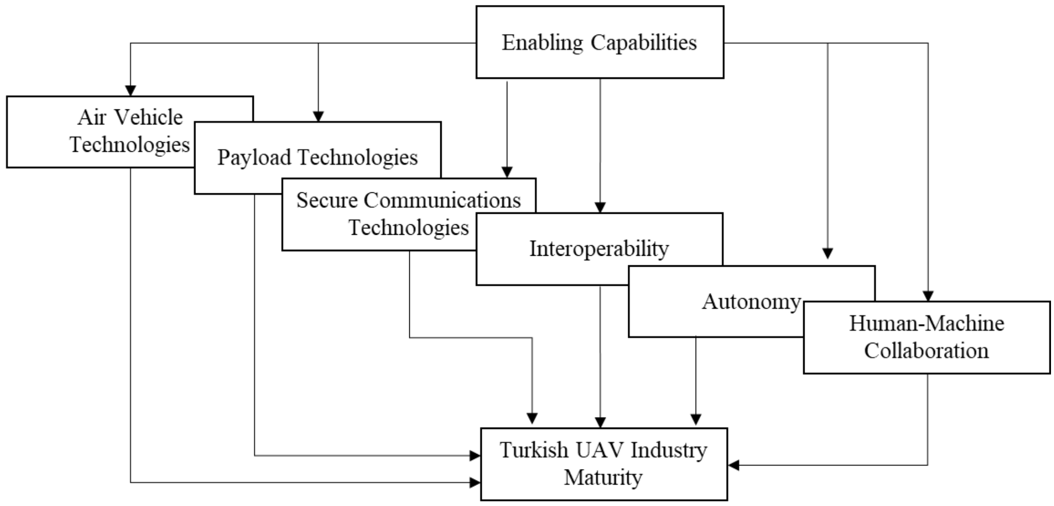

Figure 63 Chart of Maturity Model

After the maturity model is constructed, a survey containing defined criteria was applied to evaluate the maturity level of the Turkish UAV industry.

The survey link was sent to the participants from the academy and industry. It is asked to forward the survey link to their appropriate connections. The first answer was received on 05.06.2020. Interviews are conducted with six experts through video conferencing, and the answers of the participants were then inserted in the survey form by the researcher afterwards. The last answer was received on 16.07.2020, and the survey was closed to access on 21.07.2020. Maturity model survey screenshots are presented in Appendix D.

In video conferencing; experts were also asked about the validity of the model. The maturity model was validated by all of six experts. Reliability value is an indicator of the degree of giving the same problem in repeated applications of a measurement tool. Cronbach’s Alpha coefficient was calculated based on the answers given for the survey. It is possible to say that the research is reliable, according to Cronbach's Alpha coefficient in Table 48.

Table 48
Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.905	.904	6

Table 49
Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
AirVehc. Tech.	12.2400	16.107	.848	.802	.870
Payload Tech.	12.8400	16.973	.813	.731	.876
Comm. Tech.	12.6400	18.407	.679	.601	.896
Interoperability	13.4800	19.427	.549	.478	.913
Autonomy	12.9200	17.993	.714	.589	.891
HMC	12.6800	17.560	.836	.703	.874

Table 50
Measures of Central Tendency for Maturity

		AirVehicle Tech.	Payload Tech.	Comm. Tech.	Interop.	Autonomy	HMC
N	Valid	25.00	25.00	25.00	25.00	25.00	25.00
	Missing	0.00	0.00	0.00	0.00	0.00	0.00
Mean		3.12	2.52	2.72	1.88	2.44	2.68
Median		3.00	2.00	3.00	2.00	2.00	3.00
Mode		3.00	2.00	3.00	1.00	2.00	3.00
Std. Deviation		1.13	1.05	0.98	0.97	1.00	0.95
Variance		1.28	1.09	0.96	0.94	1.01	0.89

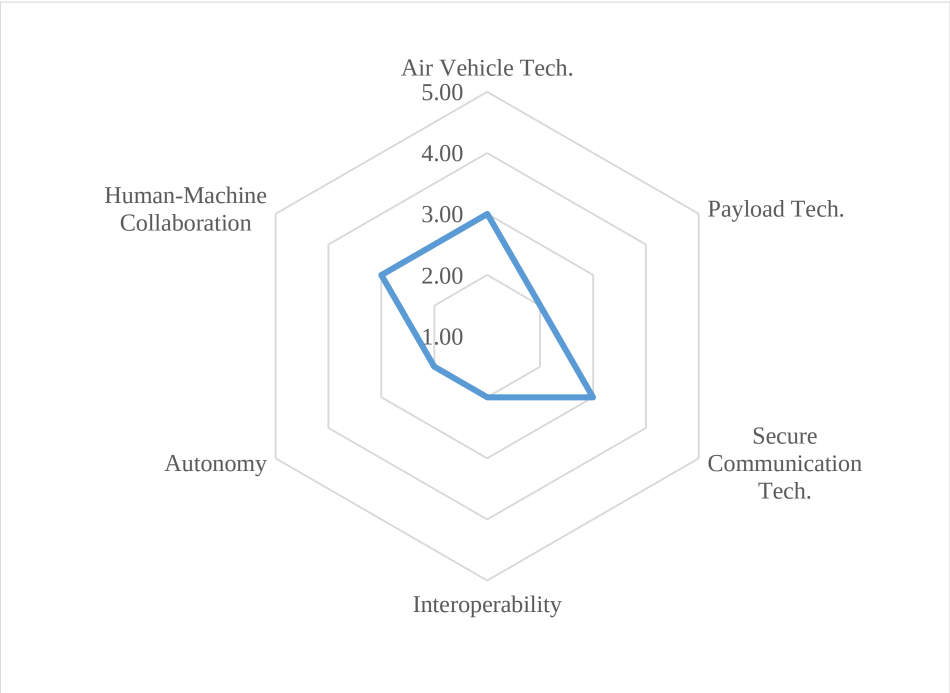

Figure 64 Maturity Levels of UAV Technologies

According to answers, the maturity of Air Vehicle Technologies Moderately Competent, the maturity of Payload Technologies Low Competent, the maturity of Secure Communications Technologies Moderately Competent, the maturity of Interoperability Low Competent, the maturity of Autonomy Low Competent, and maturity of Human-Machine Collaboration Moderately Competent.

Participants were asked for suggestions for development in technology. Quotations from the answers are presented.

Air Vehicle Technologies

> *To give more opportunities to domestic products and solutions in the civil and military fields. To maintain domestic competition by providing an environment where cost-effective new players, which provide innovative solutions, can also emerge.*
> *Establishing accessible test areas, developing accessible analysis tools, developing engine technologies, investing in light and durable material technologies required for air vehicles, developing open information-sharing environments.*
> *To increase the number of resources for basic research and technology development in the field. To support and increase university-industry collaborations at a high level. It should be provided with a high level of support*

for the development with high standards of the essential components/modules (such as engines, sensors, avionics, communications modules, positioning modules, propellers) of UAVs with domestic resources.
There is an improvement on the control side. Aerodynamics, engines, batteries should be studied. There are no studies for optimisation on the structural side. Pressures about calendars. Improvements related to algorithms. UAVs are mostly lost with the electrical system, the propulsion system, EW attacks. Studies for these should be done.
It should be cared to produce and supply everything locally, including subcomponents. It should be supported to use and develop domestic products in terms of capital and motivation instead of procuring foreign product by saying that there is a better one at the foreigner. This responsibility is not only for the state but also of the domestic firms that the state procures...
Both the numerical and experimental tools used in the air vehicle design process and the analysis and simulation methods have not yet reached an inclusive maturity level. In particular, there is a view far from the desired point in the design improvement and development of existing systems by collecting flight test data and making use of it.

Payload Technologies

Competent research groups (academia and industry) and end-users (civil and military) are required to prepare technology roadmaps and prioritization led by relevant Ministries and affiliated institutions. This study can be done separately civil and military, or together. Investments for the sub-technology areas required to develop each payload system need to be addressed within the framework of training human resources, establishing relevant infrastructures and R&D support mechanisms.
It should be supported to develop payload systems based on application and UAV constraints. University-industry collaboration should be realised at a high level.
The environmental conditions of payload systems should be expanded, lightened and cost-effectively presented to end-users. Entrepreneurship should be supported by giving to make domestic studies of sub-systems and components that are critical for the payloads developed by large companies to small companies in technoparks.
Slow advances are being made on the first generations in payload technologies. Our national design and development capability needs to be increased to a much higher level. Some of our existing designs are still quite heavy and high volume. There is a long way to go, especially with regard to miniaturisation.

Secure Communications Technologies

It should be accelerated efforts to develop national waveform and modem resistant to jamming, which uses spectrum more efficiently.
I think that as capacity Turkey has human resources capacity which can come to a better level of communications technology and this capacity should be used with projects and new products. Competent research groups (academia and industry) and end-users (civil and military) should prepare technology roadmaps and prioritization led by relevant Ministries and affiliated institutions.

It should be supported the development of secure, low power consumption, highly encrypted communications technologies on an algorithm and hardware basis. Communications technologies should not be seen under the monopoly of certain organisations, but support should be provided within a broader framework. University-industry collaboration should be given importance as in other answers.

Our competence is low level. Almost all of the communications devices are brought from abroad. Studies should be done to develop our systems.

It should be absorbed by current developments and developed performance efficient solutions, especially in mini/micro-level systems. I think that we are one step behind in the sector regarding miniature systems.

It is crucial that communications protocols which supporting swarm applications can be originally developed.

Interoperability

It should be developed national interoperability standards and provided the industry develops products that comply with these standards in new products.

It should be supported studies on heterogeneous systems, cooperative systems, distributed planning, distributed learning, distributed task sharing, distributed compromise, distributed optimisation algorithms, common protocols, common data definitions, system/component skills-based algorithms. University-industry collaboration should be ensured.

Systems engineering is of great importance for interoperability. In this field, the sector should start studies on both the systematization and systems engineer training.

I think we are just at the beginning of interoperability. In this regard, the number of experts in the defence industry is few, and they deal with everyday urgent problems. Studies in the academic world are without targets. It is beneficial to carry out goal-oriented studies by organizing academicians under technoparks under the leadership of SSB and TÜBİTAK under specific roof programs.

In different environments (sea/land), and areas with different end-users (data users), maximum participation of technology developers should be ensured in simulations and exercises. Steps should be taken to see the problems or results (successful-unsuccessful) on-site and ensure that the requests are met at the maximum level.

Autonomy

It should be increased investment in image processing technologies.

Although autonomous algorithms have been developed in engine or link losses, they are in the form of autonomous implementation of a particular route. Autonomous decision-making mechanisms need to be activated in case of multiple malfunctions.

Fault detection (diagnostic) and fault prediction (prognostic) studies; Automatic route and/or landing planning works should be accelerated under threat, weather, malfunction conditions etc.

R&D and product development activities should be increased in areas such as Artificial Intelligence, communications technologies, orientation-control, positioning, preventing jammers.

Intelligent systems and Artificial Intelligence (planning, learning, task scheduling, environmental perception, situational awareness (context awareness), reconciliation, optimization and their distributed applications) and their applications on autonomous systems, especially UAV, should be supported. University-industry collaboration should be ensured.

I think that they have powerful research abilities in the academic world in this regard, but they are also motivated to pursue a career and broadcast on subjects that are targeted or determined only by academic environments in the outside world. In line with the definition of needs of the defence industry companies, it is beneficial to carry out goal-oriented activities by organizing academicians under technoparks, under the leadership of SSB and TÜBİTAK under specific roof programs.

Image processing based navigation technologies should be studied. This issue also is deficient in the world.

Technologies should be developed in order to navigate GPS independent autonomously. Fully autonomous swarm studies in accordance with the distributed control paradigm should be done.

Human-Machine Collaboration

Studies on different methods for human-machine interaction should be increased - computer interface/special interfaces (such as joysticks, gloves)/touch, interaction with sound, sign and similar structures, interaction with human monitoring and predicting goals, human-swarm interaction studies should be supported. University-industry collaboration should be provided.

Ground Control Stations allow control of multiple air vehicle. However, data from different payloads of different air vehicle cannot be processed simultaneously. Image processing algorithms should be developed and should reach the level that can make the decisions that the payload operator can make.

Basic research should be done at universities. It is a very long term, and high R&D required subject, so it should be studied in universities at the beginning.

Biotechnology and wearable computers should be studied.

Human-machine interfaces should be developed to reduce the operator's load and ensure reliable execution of tasks in environments with high uncertainty.

The answers for improvement measures confirm those in the designed maturity model.

CHAPTER 8

DISCUSSION AND CONCLUSION

8.1 Main Issues

This research aims to examine the Turkish UAV industry by developing a new perspective and to make recommendations. In this direction, the aims of this dissertation are as follows.

One aim of this thesis is to investigate the Turkish UAV industry's problems and needs and required actions for the future. For this purpose, the actors from the industry were asked the questions seen in Appendix A, and evidence was collected by face-to-face interviews or written answers through e-mail. As a result of examining the collected evidence, the first issues were related to finance and external dependency. In line with the findings, this study makes policy recommendations for the development of the Turkish UAV industry.

Another aim of the thesis is to determine technology goals for the Turkish UAV industry and to prepare a technology roadmap in a selected area. The goals set in the technology areas determined after the comprehensive literature review conducted were finalized with expert interviews, and due to the suitability of the resources and method, the Delphi technique was examined in two rounds. D5, D6 and D19 statements investigated in Delphi statement were handled together, and it was decided to prepare a technology roadmap on "Intelligent flight management of UAV swarms that are resistant to adverse conditions". Technology areas for roadmap were determined, and evaluated, affecting factors, development stages, stakeholders were investigated through expert interviews. In this section, policy recommendations are made for the technology areas investigated in the technology roadmap.

Another aim of this study is to develop a maturity model to evaluate the competencies of the Turkish UAV industry. There is no similar maturity model developed before for the UAV industry.

The draft model was developed by the researcher for the maturity model. Afterwards, two experts from academia and industry were interviewed to evaluate how a maturity model would be more useful and beneficial. In line with expert interviews, the maturity model was created. Maturity is based on the dimensions of “Air Vehicle Technologies”, “Payload Technologies”, “Secure Communications Technologies”, “Interoperability”, “Autonomy”, and “Human-Machine Collaboration”. Criteria for maturity levels are determined for each dimension. Which technologies should be invested and what activities should be done for development are presented. This maturity model presents descriptive and prescriptive roles. According to the determined criteria by the descriptive role, competencies are evaluated as well as improvement measures are presented with the prescriptive role. It is aimed to evaluate the current situation of the Turkish UAV industry and to test the reliability and validity of the developed maturity model by making a sample application of the maturity model. The answers were analysed, and Cronbach’s Alpha coefficient was calculated as 0.905. This value is an indicator that the maturity model is at a sufficient reliability level. In the application of the maturity model, six experts were interviewed through video conferencing, and in these interviews, the experts were asked to evaluate the validity of the model, and the maturity model was validated by six experts.

Measures of central tendency were calculated based on the answers received in the application of the maturity model. Median values were used to determine maturity levels because the median is a more appropriate measure for ordinal data. Maturity levels of dimensions were determined as for Air Vehicle Technologies “Moderately Competent” with 3.0, for Payload Technologies “Low Competent” with 2.0, for Secure Communications Technologies “Moderately Competent” with 3.0, for Interoperability “Low Competent” with 2.0, for Autonomy “Low Competent” with 2.0 and Human-Machine Collaboration “Moderately Competent” with 3.0.

Interoperability, Payload technologies, and Autonomy appear to be far behind in maturity, respectively. It is recommended to work on issues such as sensor fusion, distributed algorithms, common protocols, and common data definitions for interoperability. It is necessary to study in this field by evaluating that the different types of payloads of UAVs developed by different companies are not interoperable. It is determined that the locally produced payloads are low in size and power consumption, and most payloads are brought from abroad. On autonomy, GPS-independent vision-based navigation, autonomous decision-making capability in multiple malfunctions, situational and environmental awareness, and swarm intelligence are immature studies.

Competencies in Air Vehicle Technologies, Secure Communications Technologies and Human-Machine Collaboration are at a higher level. In the field of Air Vehicle Technologies, propulsion, battery, light and durable material, aerodynamic, multidisciplinary analysis, simulation and optimisation tools, test platforms are missing issues. In the field of Secure Communications Technologies, there is a need to develop domestic communications systems and robustness solutions that use the spectrum efficiently, resistant to jamming, highly encrypted, power consumption and size optimized. The requirements, such as advanced Human-Machine Interfaces (e.g. joystick, glove, voice, signal), biotechnology, wearable computers, are prior in the subject of Human-Machine Collaboration.

Participation in the research could not be achieved at the expected level. It was expected that technology developing companies, civil and military state institutions, universities, suppliers and customer domain participated in the study. At the stage where the problems and needs of the Turkish UAV industry were investigated, interviews were held with representatives of technology developing companies. The research for the technology roadmap and maturity model was mainly carried out with participants from the academic environment. Ensuring the participation of all stakeholders in a broader basis could support a more detailed description of the problems and the introduction of different alternatives to solutions. The unwillingness of stakeholders to participate in the study was a negative factor.

In future studies, studies can be conducted on issues such as regulations for the Turkish UAV industry, factors affecting technology adoption, and incentive mechanisms. It can be studied to develop roadmaps in different technology areas related to the UAV industry. It can be studied on weighting the dimensions of the proposed maturity model. In the focus of UAV technologies, the necessary features of the university-industry relations mechanism and research infrastructure can be studied.

The rotary-wing UAVs have high manoeuvrability and the ability to hovering in the air. Since they take off and land vertically, they do not need a runway; they can take off and land from any environment. These capabilities significantly increase the flexibility of use of rotary-wing UAVs. The rotary-wing UAVs are more deployable and cost-efficient. They have ease of use and good camera control possibility and can operate in confined areas. These features make rotary-wing UAVs advantageous for many applications. Aerial inspection, photography, robotic tasks, specific area monitoring and many more applications are suitable for rotary-wing UAVs.

8.2 Policy Implications

In this study, the Turkish UAV industry was investigated examined, and outputs that will contribute to the development of the Turkish UAV industry are proposed. Since the policy is a set of decisions and related activities to implement them, this section reveals policy recommendations on decisions that support the research outcomes and what steps should be taken to implement these decisions.

The qualitative data collected are analysed, and inferences are made for the Turkish UAV industry and principles were proposed for these inferences in Table 51.

Table 51
Principles for Turkish UAV Industry

Findings	Consideration
The existing applications are predominantly for defence.	Regulations should be made to promote civil applications. Public procurement can be ensured for civil applications. Airspace planning and airworthiness issues should be dealt with by the relevant authorities.
Competition is feeble.	Consortiums for projects should be coordinated. Possible tools; R&D partner index, evaluation of company scorecards for participation in consortiums. Planning, coordination, monitoring processes to boost competition. A monitoring organization is required to monitor procurement activities.
There is an external dependency on technology, components, and materials.	It should be domestically developed foresighted technologies. Manufacturing industry should be revitalized, and essential materials, components and consumables should be locally manufactured, and effective supply chains should be established for rapid development. It should be ensured university-industry collaboration for R&D projects on foresighted technologies.
TDZs are malfunctioning and insufficient.	Training and collaboration activities should be increased. Participation in academic studies should be ensured. Researches should be performed for the problems and needs of the industry. Companies should be evaluated according to R&D and innovation indicators. Technology companies that contributing R&D and innovation should be located in TDZs.
Firms are in poor financial conditions, and incentives are inadequate.	New incentive models should be developed. It should be increased funding programs specified R&D projects on foresighted technologies. It should be provided for training and support services (e.g. financial, marketing, commercialisation) by state organisations. It can be provided long term supports for technology developing SMEs. TDZ office rents should be decreased.
Collaboration is very weak.	Project collaborations can be ensured. Intellectual property applications should be improved. A performance monitoring mechanism should be established to ensure fairness between firms, for example, the best R&D partner index. Consortiums can be established for exports. Scorecards can be used to evaluate participation in these consortiums. University-Industry collaboration should be ensured in terms of R&D.
There is a need for qualified human resources.	The curriculum of universities should be set depending on the requirements of R&D on foresighted technologies and industry input.
Some technologies need to be developed.	Technology roadmaps should be prepared with the contribution of all stakeholders. The monitoring process should be conducted.

Table 51 *(continued)*

Findings	Consideration
Cumbersome state bureaucracy is a substantial obstacle.	Document works should be decreased, and the business process should be improved. Regulations should be improved for high efficiency.
Coordination within the industry is needed.	The state should be an efficient coordinator and regulator. Decisions on foresighted technologies should be made immediately.

Recommended policies are presented.

1. UAV applications should be promoted: It should be ensured the use of UAVs in new areas, especially civil applications. Public procurement can be implemented for this purpose. Regulations that will pave the way for civil applications should be made. Applications such as traffic monitoring, public security, fire fighting, precision agriculture, environmental monitoring, disaster relief, natural resources monitoring areas will have a positive impact on the growth of the Turkish UAV industry.
2. Competition should be increased: The survival of companies operating in the UAV industry largely depends on their involvement in defence projects. How many companies can be included in the industry, and if these companies can present their innovative solutions, the Turkish UAV industry will be positively affected by this ecosystem. An ecosystem that will support the emergence of new players developing innovative solutions by providing domestic competition should be created, and its continuity should be ensured.
3. The domestic UAV Technologies development strategy in Turkey should be modelled clearly: Domesticalisation studies of the components purchased from abroad should be done. Strategies should be clearly defined for eliminating external dependency and development of domestic UAV technologies, and the waste of resources should be avoided by following these strategies by all actors, and the level of success should be increased. Strategies such as technologies to be developed need to be met, development approaches, the supply chain should be developed.

Table 52
Policy Implications for Turkish UAV Industry

Policy Recommendations	Policy Instruments
UAV applications should be promoted	• Regulations for civil applications • Public procurement
Competition should be increased	• Project consortiums • R&D and Innovation indexes • A state agency for coordination and monitoring
The domestic UAV technologies development strategy in Turkey should be modelled clearly	• Think-tank groups • Technology foresight • TRL tools • Providing incentives for domestic technology developers • Long term University-Industry collaboration • Revitalizing manufacturing industry for domestic supply chain
TDZs/Technoparks should be made more effective	• R&D and Innovation indexes • To participate in academic studies
Firms should be financially strengthened	• Increased funding programs for R&D projects on foresighted technologies • New incentive models • Training and support services (e.g. financial, marketing) by state organisations • Long-term supports for technology developing SMEs/start-ups
Collaborations should be boosted	• Project consortiums • R&D partner index • Intellectual property applications • University-Industry collaboration
Human resources should be qualified	• Curriculums based on foresighted technologies • University-Industry collaborations
Certain technologies should be developed	• Technology roadmaps • Delphi studies
State bureaucracy should be mitigated	• Process improvement

4. TDZs/Technoparks should be made more effective: TDZs/Technoparks should engage in activities to support SMEs/Start-ups and take steps. They should trigger firms to develop innovative solutions.

5. Firms should be financially strengthened: Firms should be financially strengthened to ensure longevity. Also, training and support services should be provided.
6. Collaborations should be boosted: Collaborations should be ensured among the actors operating in the industry. These collaborations will be beneficial in terms of resource efficiency, information sharing, clarification of requirements, system-level integration of developed technologies, the participation of new actors in the industry, and enhancement of innovative solutions.
7. Human resources should be qualified: Qualified human resources should be trained to develop technologies at the required level. Human resources should be trained in the required positions to exploit the technologies.
8. Certain technologies should be developed: Technologies should be developed to meet these requirements by clearly determining the requirements in the civil and military fields.
9. State bureaucracy should be mitigated: Legal processes such as regulations, permissions seem to be a negative factor for the industry. Necessary measures should be taken to overcome the obstacles brought by bureaucracy.

Recommended policy instruments to enable and facilitate the implementation of the policies:

- Regulations for civil applications: Regulations that will pave the way for civil applications should be made and implemented. The potential in civil applications is at a level that will have a positive impact on the growth of the Turkish UAV industry. Regulations are needed in areas such as airspace usage, flight availability, BLOS flights, insurance.
- Public procurement: State can purchase for civil applications. The issues of the ministries that can be solved with UAVs should be analysed in detail and technologies should be developed and implemented in line with the defined needs. After a certain level of talent acquisition, it can also be directed to the overseas market.
- Project consortiums: Large projects can be realised with project consortiums. The projects can be divided into sub-projects to be made by the companies in the consortium. Thus, more actors can join the industry and ensure its continuity. This

ecosystem will support the production of more innovative solutions with increased competitiveness.

- A state agency for coordination and monitoring: A state agency is required for the planning, creation and monitoring of project consortiums. This agency can provide the creation of technology talent inventory and reduce bureaucracy and make quick decisions.
- Think-tank groups: Constructing and exploiting think-tank groups to determine challenges and opportunities, and to understand and plan the future for technological development.
- Technology foresight: In order to avoid waste of resources and time, which technologies should be worked on, what needs should be satisfied, and technology foresight studies should be conducted with panels attended by all stakeholders.
- TRL tools: TRL tools can be used to evaluate the maturity levels of technologies.
- Providing incentives for domestic technology developers: Incentives should be provided to those who develop technology domestically. These incentives should be provided by considering resource efficiency.
- Long-term University-Industry collaboration: Universities have an extensive research infrastructure with academicians, undergraduate and graduate students, and laboratories. However, academic studies are far from meeting the needs of the industry. Long-term needs should be determined, and university and industry should work in collaboration in the long-term. Graduate students should also work on these projects and prepare their thesis.
- Revitalizing manufacturing industry for domestic supply chain: Manufacturing industry should be revitalized, and the essential components needed by the industry should be produced with domestic resources. This approach will provide a fast supply chain and reduce external dependency. It will trigger the production of higher quality with the participation of more actors in the industry.
- R&D and Innovation indexes: Firms' performance should be measured in terms of R&D and innovation.
- To participate in academic studies: It is observed that companies are reluctant to participate in academic studies. TDZs/Technoparks administrations should use

participation in academic studies as a policy instrument. Thus, it will be possible to reflect the needs of the industry to academic studies and to develop solutions.

- Technology roadmaps: Preparing technology roadmaps on foresighted technologies for technological development.
- Delphi studies: Use of Delphi technique to investigate technology areas.
- Increased funding programs for R&D projects on foresighted technologies: R&D projects to be realised in the foreseen technology fields should be funded.
- New incentive models: Problems encountered in projects should be examined, and new incentive models should be developed to solve the problems encountered.
- Training and support services (e.g. financial, marketing) by state organisations: Platforms and events should be organised to provide support and training services to SMEs and Start-ups in particular and market their products.
- Long-term supports for technology developing SMEs/Start-ups: Long-term supports should be provided to technology developing companies. These can be in the form of incentives and purchase-guaranteed product development.
- R&D partner index: Metrics can be used to measure how well a firm is suitable for R&D project together.
- Intellectual property applications: Intellectual property applications should be developed accordingly while promoting project partnerships.
- Curriculums based on foresighted technologies: University curriculums can be tailored to meet the needs of predicted technologies.
- Process improvement: Process improvement techniques can be used to remove bureaucracy from being an obstacle.

Recommended actions in the "Intelligent flight management of UAV swarms that are resistant to adverse conditions" technology roadmap are presented in Table 53.

It is necessary to develop high-performance algorithms, especially in swarm intelligence and sensor fusion. The required curriculum should be prepared at the university for achieving these challenges.

Hardware components (e.g. processor, communications systems) should be developed to support the execution of high-performance algorithms.

SMEs/Start-ups should be supported for agile development of high-performance algorithms and software components. Large-scale companies may be cumbersome due to their nature, so the development of software components in these large companies may not be an appropriate solution. SMEs/Start-ups can do agile development. By assigning starts-up, they can work on specific solutions. It would be appropriate for large companies to ensure the integration of components.

Solution suggestions should be collected from the companies by defining the requirements. These proposals can be used for assignments.

In order to ensure the use of the developed technologies, the problems of the Ministries that can be solved with UAV swarms should be revealed, and their areas should be defined by the application. Developing technologies that meet defined needs will be a more successful method. This way can prevent waste of resources and time.

Regulations that will open the way for the use of UAV swarms and the technologies to be developed and the problems must be proactively solved. It should be prepared regulatory roadmap. Regulations should be made to pave the way for technologies to be developed and to ensure their use.

Invited projects should be carried out to meet the national software and hardware components requirements for UAV swarms.

Coordination should be ensured among all stakeholders. Adaptation to changing needs should be ensured with planning, monitoring and updating activities, and task distribution and integration among stakeholders should be ensured.

Competitions aiming to encourage companies should be launched. These competitions will enable more actors to participate in the industry and trigger the emergence of innovative solutions to the identified problems.

Defence/Aerospace Companies should focus on system-level products and subcontract other components. Collaboration should be ensured by integrating stakeholders in projects. Integration of subcomponents with high performance at the system level should be ensured.

SMEs/Start-ups should focus on critical technologies/required subsystems. They should develop fast solutions by using agile development approaches.

TDZs/Technoparks should ensure communication and collaboration between SMEs/Start-ups. Knowledge and experience sharing and collaboration will prevent waste of resources and time by working on the problems that encountered and solved before and ensure that the requirements are clearly defined. Also, subsystems that can be integrated with high-level success can be developed.

University curriculums should be arranged and revised according to industrial and technological requirements. It is necessary to develop high-performance algorithms, especially in swarm intelligence and sensor fusion. When there are different types of UAVs in the swarm, the difficulty in task-sharing increases within the swarm. Also, this difficulty increases gradually in case of different type of platform swarms. On the sensor fusion issue, the fusion of different types of sensor data is challenging, considering the time delay situation. The fusion of images sent by UAVs in the swarm is another problematic example. These examples can be increased. It is necessary to provide an excellent education in universities in order to develop the mentioned high-performance algorithms. University curriculums need to be organized and revised to satisfy these requirements.

Table 53
Recommended Actions to be Realised for Development

Recommended Actions	Responsible Stakeholder
• Financial supports should be provided to companies that invest in R&D in terms of UAV swarming software and hardware components. • Request for proposals should be started issuing for UAV swarming applications. • Planning, coordination, monitoring process should be conducted for civil UAV swarming needs for Ministries. • SMEs/Start-ups should be supported for agile development on UAV swarming.	STB SSB
• It should be prepared regulatory roadmap on UAV swarming and started implementation.	SHGM
• Invited R&D projects should be performed for the needs of national software and hardware components on UAV swarming. • It should be carried out coordination and orientation by monitoring the progress of the studies and changing requirements.	TÜBİTAK SSB
• It should be launched competitions that encourage companies.	SSB
• It should be focused on products, subcontracted others and integrated stakeholders actively in the projects.	Defence/Aer. Companies
• It should be focused on critical technologies and required subsystems.	SMEs/Start-ups
• TDZs/Technoparks should ensure communication and collaboration between SMEs/Start-ups.	TDZ/ Technoparks
• Curriculums should be reviewed and aligned according to industrial and technological requirements. • Academy and industry should be coordinated, and studies should be carried out within the scope of University-Industry collaboration in the field of UAV swarms.	Universities TÜBİTAK SSB
• The progress of the roadmap should be monitored, policy updates should be made according to the results of the situation assessments, and the necessary steps should be taken.	All stakeholders

Academy and industry should be coordinated. Research potential at universities should be implemented in a way that meets the needs of the industry. It can be said that the studies in universities are carried out in the focus of publishing, in line with the trends in academy, far from the needs of the industry. It is seen that the studies in the industry are carried out with entirely convenient and commercial concerns, far from a scientific base. Long-term university-industry collaboration should be ensured. Long-term projects should be created; undergraduate and graduate students should work in these projects. This collaboration will also support the employment mechanism. Graduate students should work on the problems of industry in theses. It will enable the development of domestic technologies by solving real problems using these scientific approaches.

The progress in the technology roadmap should be evaluated with the panels that will be held periodically with the participation of stakeholders, and policy updates should be made according to the results of the situation assessments, and necessary steps should be taken.

A maturity model was developed, and an application was conducted to evaluate the Turkish UAV industry. The results of the application and which technologies should be studied are presented in the previous sections. In this section, as policy implications, it is discussed what approaches are adopted to increase the maturity level of the competencies of the Turkish UAV industry in Table 54.

Air Vehicle Technologies: Critical air vehicles technologies should be developed through long-term university-industry collaboration. Research and Application centres should be established on critical technologies in universities. R&D and design centres should be established in TDZs/Technoparks and firms.

Payload Technologies: Works groups should be employed to define the concept of operations, and requirements should be determined. Required technologies should be developed through long-term university-industry collaboration. Research and Application centres should be established on critical technologies in universities. R&D and design centres should be established in TDZs/Technoparks and firms.

Secure Communications Technologies: Research and Application centres should be established to develop critical communications technologies through long-term university-industry collaboration in universities. R&D and design centres should be established in TDZs/Technoparks and firms.

Table 54
Policy Implications for Maturation of Turkish UAV Industry

Dimension	Policy Recommendations
Air Vehicle Technologies	• Critical technologies such as intelligent health management, collision avoidance, smart material technologies, stealth technologies, battery, propulsion technologies should be developed through long-term University-Industry collaboration. • R&D and design centres should be established in TDZ/Technoparks and firms. • Research and Application centres should be established in universities.
Payload Technologies	• Research and Application centres should be established at universities, and joint studies should be conducted with industry. • Concept of operations definitions should be made with all-stakeholder, and requirements should be clearly defined. Technologies suitable for the needs should be developed.
Secure Communications Technologies	• It should be ensured that communications system components are produced domestically. • It should be developed robust and secure communications technologies that use spectrum efficiently.
Interoperability	• National interoperability standards should be developed to cover different types of platforms and subsystems. • It should be ensured that the technologies to be developed in line with interoperability standards should be guided, and integration studies were coordinated. • Techniques such as heterogeneous systems, collaborative systems, distributed planning, distributed learning, distributed task sharing, distributed optimization, common protocols, common data repositories, modularity, sensor fusion, and autonomous data strategy adaptation should work with long-term University-Industry collaboration.
Autonomy	• Critical technologies such as artificial intelligence, computer vision, bio-inspired computation, hyper-heuristics, multi-agent systems, vision-based navigation, swarm intelligence should be developed through long-term University-Industry collaborations. • University curriculums should be set to support critical technologies.
Human-Machine Collaboration	• A multidisciplinary research centre should be established where studies will be conducted on subjects such as computational neuroscience, behavioural biology, data science, speech and natural language processing, Augmented/Virtual Reality, advanced human-machine interfaces. Joint studies should be conducted with the Research and application centres at universities. Studies on other dimensions can also be carried out in the proposed multidisciplinary research centre.

Interoperability: Workgroups should be employed to develop national interoperability standards. A state agency should coordinate and monitor technology development activities suited to standards. Critical technologies defined before should be developed through long-term university-industry collaboration.

Autonomy: Critical technologies defined before should be developed through long-term university-industry collaboration. Research and application centres should be established for these critical technologies in universities. R&D and design centres should be established in TDZs/Technoparks and firms. Necessary education should be provided in universities that are suitable for critical technologies.

Human-Machine Collaboration: Multidisciplinary research centres should be developed for human-machine collaboration and other UAV technologies. Critical technologies should be developed through long-term university-industry collaboration.

Research infrastructure is the basis to increase the maturity level of the Turkish UAV industry. It is not possible to carry out the necessary studies on the foresighted technologies without establishing a strong research infrastructure. Within the scope of research infrastructure, universities, interfaces, and firms should be considered. Universities offer great potential with laboratories, Research and Application Centres. In this direction, importance should be attached to Research and Application Centres on UAV technologies in universities. The R&D and design centres of the companies are essential for the development of the Turkish UAV industry. For this reason, companies should be promoted to establish R&D and design centres, they should be supported financially, and their efficiency should be ensured. Interfaces such as innovation transfer centres, incubation centres, network-structures, university-industry collaboration platforms, technology transfer offices should be effectively exploited to develop domestic UAV technologies.

Value chain such as TDZ (specialization), knowledge bases, communication platforms should be enriched for collaborations.

Enabling capabilities that affect the maturity level of the Turkish UAV industry are project management, information management and systems engineering activities. It is not possible to examine in detail in this research, since each of these topics is comprehensive study subjects. For this reason, these issues are briefly mentioned and the implementation necessities of these activities are emphasized.

Project Management: With the advancement of technologies and increasing requirements, it became a necessity to use project management techniques in the development of increasingly complex systems, multi-disciplinary knowledge, targeted properties, costs and time. Project management includes dimensions such as time management, scope management, cost management, quality management, human resources management, communication management, procurement management, risk management and integration management.

Using project management techniques in R&D and product development projects in the UAV industry will increase the level of success in UAV technologies.

Knowledge Management: It has become crucial to protect the knowledge possessed in the rapidly changing world, to reproduce it by sharing, and to reflect it on the product.

Knowledge capital is divided into two:
Open knowledge: It is the information that has been disclosed, recorded, and shared.
Tacit knowledge: Understanding, experience, techniques are embedded in business processes. Transformation of tacit knowledge into open knowledge is of great importance. Knowledge management systems are used for knowledge creation, storage, and sharing.

In the interviews with the actors in the Turkish UAV industry, it has been determined that collaboration and information sharing is almost nonexistent. Establishing a knowledge management framework in the Turkish UAV industry is essential in terms of providing resource efficiency by sharing knowledge, experience and understanding and increasing the level of success in technological progress.

Systems Engineering: A system is a collection of components that complement each other for a common goal, and systems engineering deals with the entire process of designing, developing, deploying, and disposal of a system.

Systems engineering techniques come to the fore in multi-stakeholder product development projects and interoperability of systems, so using systems engineering techniques will be of great benefit.
These approaches should be adopted in technology development studies in the Turkish UAV industry.

Technology management activities, collaboration management, intellectual property management, knowledge management, project management, systems engineering, strategic management activities should be carried out for institutional structuring and capacity building.

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APPENDICES

A. INTERVIEW QUESTIONS/GÖRÜŞME SORULARI

1. Hangi tür (tarım, fotogrametri, keşif/gözetim vb.) uygulamalarda kullanılan İHA'lar üzerine çalışıyorsunuz?
2. Türkiye İHA sektöründeki sorunlar ve güçlü yönler nelerdir? (Probe: Neden, açıklar mısınız?)
3. Bir bütün olarak Türkiye sanayisinin İHA teknolojilerinde diğer ülkelere kıyasla ne durumda olduğunu düşünüyorsunuz? (Probe: Neden, açıklar mısınız?)
4. Sahip olduğunuz İHA teknolojilerini geliştirmek için nelere ihtiyacınız vardır? (Ar-Ge çalışmaları için ihtiyaçları tespit etmeyi amaçlamaktadır)
5. Türkiye'de milli İHA teknolojilerinin olgunluğunu olumlu ve olumsuz etkileyen faktörler nelerdir?
6. İHA konusunda kritik/öncelikli teknoloji alanları nelerdir? (Probe: Neden, açıklar mısınız?)
7. Geliştirilecek İHA teknolojileri Türkiye'de öncelikli hangi gereksinimleri karşılamalıdır? (Probe: Neden, açıklar mısınız?)
8. Türkiye'de kamu ve özel sektör kurum/kuruluşlarının İHA teknolojilerine ilişkin çalışmalarda bilgi paylaşımı ve işbirliklerini nasıl buluyorsunuz? Bu konuda nasıl mekanizmalar geliştirilmelidir? (Probe: Neden, açıklar mısınız?)
9. Gelişmekte olan bir ülke olan Türkiye'nin İHA sektöründe gelişmiş ülkelerin sahip olduğu teknolojileri üretebilecek kapasiteye ulaşıp, bunun da önüne geçerek teknolojide öncü olabilmesi için, hangi faaliyetler gerçekleştirilmelidir? (Probe: Neden, açıklar mısınız?)

B. THE FIRST ROUND DELPHI SURVEY/BİRİNCİ TUR DELFİ ANKETİ

Türkiye'de İnsansız Hava Aracı Teknolojilerinin Yol Haritası

Bu ankette 20 ifade değerlendirilecektir. Anketi cevaplamak 15-20 dakika sürmektedir.

20 ifadenin her biri için:
-İfadedeki konuya ilişkin uzmanlık düzeyiniz, ifadede belirtilen teknolojinin İHA ve uygulamaları için önemi (öngördüğünüz), Türkiye'nin gelişimine ve rekabet gücüne etkisi (öngördüğünüz), daha fazla araştırmayı tetiklemesi potansiyeli (öngördüğünüz), Türkiye'deki olgunluk düzeyi (mevcut durum), ifadenin gerçekleşme zamanı (öngördüğünüz) soruları cevaplanacaktır.

Anketi cevaplamak için konunun uzmanı olmak şart değildir, ilgili ifadeyi yorumlayacak kadar bilgi sahibi olmak da yeterlidir.

Katkılarınız çok değerli.

Afşar Türk (e-posta: afsar.turk@metu.edu.tr)

* Required

Email address *

Your email

Eğitim Durumunuz *

- Ön Lisans
- Lisans
- Yüksek Lisans
- Doktora

İnsansız Hava Aracı Teknolojileri Üzerine Çalışma Süreniz *

- 0-5 yıl
- 6-10 yıl
- 11-15 yıl
- 16-20 yıl
- 20 yıl üzeri

Next

1: İnsansız Hava Aracı (İHA) ve faydalı yükler için izleme ve kontrol amacıyla zeki sistemler geliştirildi.

1.a: Uzmanlık *

Choose

Konunun uzmanıyım

Bilgim var

Bilgim yok (En alttaki butonu tıklayarak sonraki ifadeye geçebilirsiniz)

1.b: İHA ve uygulamaları için önemi

Choose

Önemsiz

Düşük

Orta

Yüksek

Çok Yüksek

ı Türkiye'nin gelişimine ve rekabet gücüne etkisi

ı tetiklemesi yönüyle milli teknolojiler için önemi

1.c: Teknolojiyi edinmenin Türkiye'nin gelişimine ve rekabet gücüne etkisi

Choose

1.d: Daha fazla araştırmayı tetiklemesi yönüyle milli teknolojiler için önemi

Choose

1.e: Teknolojinin Türkiye'deki olgunluk düzeyi

TRL (Teknoloji Hazırlık Düzeyi); geliştirilmekte olan bir teknolojinin olgunluk ve kullanılabilirlik düzeyini ölçmek amacıyla kullanılan bir endekstir. Bu düzeyler: TRL 1: Teknolojiye ilişkin temel ilkeler gözlendi ve raporlandı, TRL 2: Teknoloji kavramı formüle edildi, TRL 3: Teknoloji kavramı analitik ve deneysel olarak kritik işlev/özellik yönüyle kanıtlandı, TRL 4: Teknoloji laboratuvar ortamında doğrulandı, TRL 5: Teknoloji uygun çevresel ortamda doğrulandı, TRL 6: Teknoloji sistem/alt sistem modeli veya prototip ile uygun çevresel ortamda gösterildi, TRL 7: Sistem prototipi operasyonel (gerçek) ortamda gösterildi, TRL 8: Sistem tamamlandı ve performans değerlendirmesi yapıldı, TRL 9: Operasyonel ortamda kanıtlanan sistem ticarileşti olarak kısaca açıklanabilir. İlgili ifade için değerlendirdiğiniz mevcut düzeyi bu endekse göre seçebilirsiniz.

Choose

TRL 1 - 2

TRL 3 - 4

TRL 5 - 6

TRL 7 - 8

TRL 9

1.f: Teknolojinin olası gerçekleştirme zamanı

Choose

Back

Next

20: İHA'lar aracılığıyla gelebilecek tüm tehditlere karşı tespit, tanıma, sınıflama, izleme ve yok etme amaçlı olarak anti-İHA sistemi geliştirildi.

20.a: Uzmanlık *

Choose

20.b: İHA ve uygulamaları için önemi

Choose

20.c: Teknolojiyi edinmenin Türkiye'nin gelişimine ve rekabet gücüne etkisi

Choose

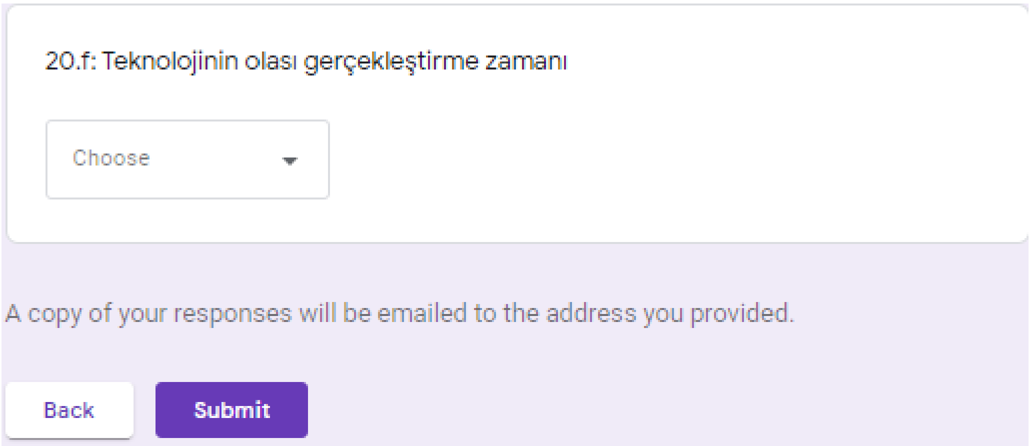
20.d: Daha fazla araştırmayı tetiklemesi yönüyle milli teknolojiler için önemi

Choose

20.e: Teknolojinin Türkiye'deki olgunluk düzeyi

TRL (Teknoloji Hazırlık Düzeyi); geliştirilmekte olan bir teknolojinin olgunluk ve kullanılabilirlik düzeyini ölçmek amacıyla kullanılan bir endekstir. Bu düzeyler: TRL 1: Teknolojiye ilişkin temel ilkeler gözlendi ve raporlandı, TRL 2: Teknoloji kavramı formüle edildi, TRL 3: Teknoloji kavramı analitik ve deneysel olarak kritik işlev/özellik yönüyle kanıtlandı, TRL 4: Teknoloji laboratuvar ortamında doğrulandı, TRL 5: Teknoloji uygun çevresel ortamda doğrulandı, TRL 6: Teknoloji sistem/alt sistem modeli veya prototip ile uygun çevresel ortamda gösterildi, TRL 7: Sistem prototipi operasyonel (gerçek) ortamda gösterildi, TRL 8: Sistem tamamlandı ve performans değerlendirmesi yapıldı, TRL 9: Operasyonel ortamda kanıtlanan sistem ticarileşti olarak kısaca açıklanabilir. İlgili ifade için değerlendirdiğiniz mevcut düzeyi bu endekse göre seçebilirsiniz.

Choose


20.f: Teknolojinin olası gerçekleştirme zamanı

Choose

A copy of your responses will be emailed to the address you provided.

Back

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C. THE SECOND ROUND DELPHI SURVEY FOR CONTROLLED FEEDBACK/KONTROLLÜ GERİ BİLDİRİM İÇİN İKİNCİ TUR DELFİ ANKETİ

Türkiye'de İnsansız Hava Aracı Teknolojilerinin Yol Haritası

* Required

Email address *

Your email

Next

1: İnsansız Hava Aracı (İHA) ve faydalı yükler için izleme ve kontrol amacıyla zeki sistemler geliştirildi.

1.a: Uzmanlık *

1.a: Uzmanlık *

Konunun uzmanıyım

Konunun uzmanıyım	12
Bilgim var	17
Bilgim yok	1

Choose

1.b: İHA ve uygulamaları için önemi

1.b: İHA ve uygulamaları için önemi

Yüksek

	Önemsiz	Düşük	Orta	Yüksek	Çok Yüksek
Konunun uzmanıyım			1	4	7
Bilgim var			1	11	5

Choose

1.c: Teknolojiyi edinmenin Türkiye'nin gelişimine ve rekabet gücüne etkisi

Yüksek

	Önemsiz	Düşük	Orta	Yüksek	Çok Yüksek
Konunun uzmanıyım			1	4	7
Bilgim var				6	11

Choose

1.d: Daha fazla araştırmayı tetiklemesi yönüyle milli teknolojiler için önemi

Yüksek

	Önemsiz	Düşük	Orta	Yüksek	Çok Yüksek
Konunun uzmanıyım				8	4
Bilgim var			2	10	5

Choose

1.e: Teknolojinin Türkiye'deki olgunluk düzeyi

TRL (Teknoloji Hazırlık Düzeyi); geliştirilmekte olan bir teknolojinin olgunluk ve kullanılabilirlik düzeyini ölçmek amacıyla kullanılan bir endekstir. Bu düzeyler: TRL 1: Teknolojiye ilişkin temel ilkeler gözlendi ve raporlandı, TRL 2: Teknoloji kavramı formüle edildi, TRL 3: Teknoloji kavramı analitik ve deneysel olarak kritik işlev/özellik yönüyle kanıtlandı, TRL 4: Teknoloji laboratuvar ortamında doğrulandı, TRL 5: Teknoloji uygun çevresel ortamda doğrulandı, TRL 6: Teknoloji sistem/alt sistem modeli veya prototip ile uygun çevresel ortamda gösterildi, TRL 7: Sistem prototipi operasyonel (gerçek) ortamda gösterildi, TRL 8: Sistem tamamlandı ve performans değerlendirmesi yapıldı, TRL 9: Operasyonel ortamda kanıtlanan sistem ticarileşti olarak kısaca açıklanabilir. İlgili ifade için değerlendirdiğiniz mevcut düzeyi bu endekse göre seçebilirsiniz.

TRL 9

	TRL 1 - 2	TRL 3 - 4	TRL 5 - 6	TRL 7 - 8	TRL 9
Konunun uzmanıyım	1	1	2	3	5
Bilgim var	8	2	8	7	2

Choose

Seçtiğiniz olgunluk düzeyinin gerekçelerini açıklar mısınız? İlgili teknolojinin geliştirilmesi için önerilerinizi belirtir misiniz?

Your answer

1.f: Teknolojinin olası gerçekleştirme zamanı

1.f: Teknolojinin olası gerçekleştirme zamanı

2020-2024

	2020 - 2024	2025 - 2029	2030 - 2035	2035 sonrası	Hiçbir zaman
Konunun uzmanıyım	10	2			
Bilgim var	14	2		1	

Choose

Back Next

20: İHA'lar aracılığıyla gelebilecek tüm tehditlere karşı tespit, tanıma, sınıflama, izleme ve yok etme amaçlı olarak anti-İHA sistemi geliştirildi.

20.a: Uzmanlık *

20.a: Uzmanlık *

Bilgim var

Konunun uzmanıyım	7
Bilgim var	14
Bilgim yok	9

Choose

20.b: İHA ve uygulamaları için önemi

20.b: İHA ve uygulamaları için önemi

Yüksek

	Önemsiz	Düşük	Orta	Yüksek	Çok Yüksek
Konunun uzmanıyım		1	1	2	3
Bilgim var			1	7	6

Choose

20.c: Teknolojiyi edinmenin Türkiye'nin gelişimine ve uluslararası rekabet gücüne etkisi

20.c: Teknolojiyi edinmenin Türkiye'nin gelişimine ve uluslararası rekabet gücüne etkisi

Yüksek

	Önemsiz	Düşük	Orta	Yüksek	Çok Yüksek
Konunun uzmanıyım			3		4
Bilgim var				8	6

Choose

20.d: Daha fazla araştırmayı tetiklemesi yönüyle milli teknolojiler için önemi

20.d: Daha fazla araştırmayı tetiklemesi yönüyle milli teknolojiler için önemi

Yüksek

	Önemsiz	Düşük	Orta	Yüksek	Çok Yüksek
Konunun uzmanıyım		1	1	1	4
Bilgim var			3	5	6

Choose

20.e: Teknolojinin Türkiye'deki olgunluk düzeyi

TRL (Teknoloji Hazırlık Düzeyi); geliştirilmekte olan bir teknolojinin olgunluk ve kullanılabilirlik düzeyini ölçmek amacıyla kullanılan bir endekstir. Bu düzeyler: TRL 1: Teknolojiye ilişkin temel ilkeler gözlendi ve raporlandı, TRL 2: Teknoloji kavramı formüle edildi, TRL 3: Teknoloji kavramı analitik ve deneysel olarak kritik işlev/özellik yönüyle kanıtlandı, TRL 4: Teknoloji laboratuvar ortamında doğrulandı, TRL 5: Teknoloji uygun çevresel ortamda doğrulandı, TRL 6: Teknoloji sistem/alt sistem modeli veya prototip ile uygun çevresel ortamda gösterildi, TRL 7: Sistem prototipi operasyonel (gerçek) ortamda gösterildi, TRL 8: Sistem tamamlandı ve performans değerlendirmesi yapıldı, TRL 9: Operasyonel ortamda kanıtlanan sistem ticarileşti olarak kısaca açıklanabilir. İlgili ifade için değerlendirdiğiniz mevcut düzeyi bu endekse göre seçebilirsiniz.

20.e: Teknolojinin Türkiye'deki olgunluk düzeyi

TRL 9

	TRL 1 - 2	TRL 3 - 4	TRL 5 - 6	TRL 7 - 8	TRL 9
Konunun uzmanıyım		1	3	2	1
Bilgim var	4	2	4	3	1

Choose

Seçtiğiniz olgunluk düzeyinin gerekçelerini açıklar mısınız? İlgili teknolojinin geliştirilmesi için önerilerinizi belirtir misiniz?

Your answer

20.f: Teknolojinin olası gerçekleştirme zamanı

20.f: Teknolojinin olası gerçekleştirme zamanı

2020-2024

	2020 - 2024	2025 - 2029	2030 - 2035	2035 sonrası	Hiçbir zaman
Konunun uzmanıyım	6	1			
Bilgim var	6	5	3		

Choose

A copy of your responses will be emailed to the address you provided.

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D. TURKISH UAV INDUSTRY MATURITY MODEL SURVEY/TÜRK İHA ENDÜSTRİSİ OLGUNLUK MODELİ ANKETİ

Türk İnsansız Hava Aracı (İHA) Endüstrisi Olgunluk Modeli

Sayın katılımcılar,

Doktora tezi çalışmam kapsamındaki bu ankette Türk İHA endüstrisi, 6 eksende belirlenen kriterler doğrultusunda değerlendirilmektedir. Kişisel veya ticari sır niteliğinde bilgi istenmemektedir.
Her bir Olgunluk Ekseninin tanımı yapıldıktan sonra, o eksendeki 5 düzeyin kriterleri tanımlanmıştır.
Açılır listede görebileceğiniz, tanımlanmış kriterlere göre değerlendirmelerinize en yakın bulduğunuz düzeyi seçiniz. Değerlendirmeler Ulusal düzeyde olup Türkiye'deki yetkinlikleri ölçmeyi amaçlamaktadır.
Her bir Olgunluk Ekseni için gelişme adımlarına ilişkin önerileriniz de sorulmaktadır.
İlerlemek için hangi adımların atılması, nelerin yapılması gerektiğine ilişkin önerilerinizi bu alanlara yazabilirsiniz.

Anket yaklaşık 5 dakikanızı alacaktır.
Katkılarınız çok değerli.

Afşar Türk
afsar.turk@metu.edu.tr

* Required

1. Hava Aracı Teknolojileri: İHA'ların ekonomik ömrünü uzatacak, görevlerin yüksek verimlilik ve güvenilirlikte gerçekleştirilmesini sağlayacak teknolojiler geliştirmek. *

- ◯ 1.Yetkin değil: Düşük verimlilikte veya eski hava aracı teknolojileri kullanılmaktadır.
- ◯ 2.Düşük düzeyde yetkin: Platform teknolojileri için iyileştirme çözümleri araştırılmaktadır.
- ◯ 3.Orta düzeyde yetkin: Artan bir şekilde aerodinamik, itki, yapı/malzeme, uçuş kontrol ve batarya teknolojilerinde Ar-Ge çalışmaları yapılmaktadır.
- ◯ 4.Yetkin: Yerli olarak üretilen hava aracı teknolojilerindeki iyileşme sonuçları gözlemlenmeye başlanmıştır.
- ◯ 5.Yüksek düzeyde yetkin: Hava araçlarının boyutunu ve ağırlığını optimize eden, güvenilirliği artıran ve görev başına maliyetleri azaltan ileri teknolojiler geliştirilmiş ve kullanıma alınmıştır.

Hava Aracı teknolojilerinde gelişme için atılması gereken adımlar nelerdir? *

Your answer

2. Faydalı Yük Teknolojileri: Karmaşık ve zorlu İHA görevlerinin çok geniş bir yelpazede, her koşulda yüksek güvenilirlikle gerçekleştirilebilmesini sağlayacak faydalı yük sistemlerini geliştirme ve kullanma yeteneği *

- 1.Yetkin değil: Faydalı yük sistemleri çoğunlukla ithalat yoluyla COTS tedarik edilir ve yerli üretilen alt sistemler sınırlı yetenektedir.
- 2.Düşük düzeyde yetkin: Faydalı yük sistemleri geliştirmek için programlar başlatılmış ve AR-GE çalışmaları yürütülmektedir.
- 3.Orta düzeyde yetkin: Yerli olarak üretilmiş faydalı yük sistemleri gerçek operasyonlarda artan bir şekilde kullanılmaya başlanmıştır.
- 4.Yetkin: Yerli olarak üretilen faydalı yük sistemlerinin yerli içeriklerini, olgunluğunu artırmaya ve kritik alt sistemlerde yerlileştirmeye yönelik çalışmalar sürdürülmektedir.
- 5.Yüksek düzeyde yetkin: Her görevde yüksek güvenilirlikte kullanılabilecek her türlü faydalı yük sistemi kritik alt sistemler dâhil yerli olarak geliştirilebilmektedir.

Faydalı yük sistemlerinde gelişme için neler yapılmalıdır? *

Your answer

3. Güvenli Haberleşme Teknolojileri: İHA'ların her koşulda yerdeki, havadaki ve uzaydaki diğer platformlarla her zaman, güvenilir ve güvenli bir şekilde haberleşmesini sağlayan teknolojiler geliştirmek *

- 1.Yetkin değil: Haberleşme sistemleri düşük veri iletim hızına sahip olup, olumsuz koşullardan kolaylıkla etkilenmektedir.
- 2.Düşük düzeyde yetkin: Haberleşme teknolojilerinde iyileştirme çalışmalarına başlanmış olup, gerekli politikalar, prosedürler, teknikler geliştirilmektedir.
- 3.Orta düzeyde yetkin: Daha verimli, sağlam (robust) ve güvenli veri linkleri geliştirilmiştir.
- 4.Yetkin: Veri transfer hızı artırılmakla birlikte, zayıflık (vulnerability) değerlendirme ve siber saldırı dayanıklılığını artırma çalışmaları yapılmaktadır. Modem/dalga formu ve diğer kritik bileşenlerde yerlileştirmeye yönelik çalışmalar sürdürülmektedir.
- 5.Yüksek düzeyde yetkin: Yüksek veri iletim hızı, spektrum verimliliği, siber dayanıklılık (resilience), daha iyi tüm-hava-koşulları kapasitesi, sağlam elektronik koruma sağlayan haberleşme teknolojileri geliştirilmiştir.

Haberleşme teknolojilerinde ilerleme için neler yapılmalıdır? *

Your answer

4. Birlikte çalışabilirlik: İHA'ların platform ve faydalı yük düzeyinde diğer sistemlerle (İnsansız Deniz/Kara Araçları, insanlı araçlar, taşınabilir veya giyilebilir cihazlar vb.) birlikte çalışabilirliğini ve veri füzyonunu sağlamak *

- 1.Yetkin değil: Birlikte çalışabilirlik konusunda açık mimariler, veri füzyonu, modülerlik vb. konularda çalışmalar yapılmaktadır.
- 2.Düşük düzeyde yetkin: Makineler arası haberleşme ve ortak veri ambarları geliştirilmiştir.
- 3.Orta düzeyde yetkin: Makineler arası veri toplama ve veri füzyonu yüksek güvenilirlikte yapılmaktadır.
- 4.Yetkin: Sistemler hava aracı kontrolü/görev planlaması ve faydalı yük düzeyinde veri füzyonu yapabilmektedir.
- 5.Yüksek düzeyde yetkin: Farklı türde platformlardan oluşan takımlar yüksek güvenilirlikte ve esneklikte aralarında iş bölümü yaparak bir görevi başından sonuna yürütebilmektedir.

Birlikte çalışabilirlik konusunda gelişme için neler yapılmalıdır? *

Your answer

5. Otonomi: İHA'ların en az kontrol ile veya tamamen bağımsız bir şekilde görevleri yüksek güvenilirlikle ve verimlilikle yerine getirmesini sağlayacak teknolojileri geliştirme ve kullanma yeteneği *

- 1.Yetkin değil: İHA'lar tamamen uzaktan kontrol edilmektedir.
- 2.Düşük düzeyde yetkin: Otonomi konusunda Ar-Ge çalışmalarına başlandı ve bazı teknikler geliştirildi. Bu doğrultuda, İHA'lar görev planını kendisi uygulayabilmekte ve oluşan beklenmedik durumlarda önceden tanımlanmış başka bir uçuş planına geçebilmektedir.
- 3.Orta düzeyde yetkin: Yarı-otonom olarak grup koordinasyonu ve/veya daha az merkezden kontrol ile görev devamı sağlanmaktadır. Örneğin, durumsal farkındalığa sahip İHA'lar arıza durumlarını algılayarak göreve devam edip etmeyeceğine karar verebilmektedir.
- 4.Yetkin: Yüksek otonomiye sahip İHA'lar ve mühimmatlar geliştirilebilmektedir. Bu sistemler gelişen durumlara göre gerçek zamanlı karar verme, rota belirleme, reddedilmiş (GPS-denied) ortamlarda konum belirleme, navigasyon yapma gibi yeteneklere sahiptir. Sürü zekası çalışmalarında ilerleme sağlanmaktadır.
- 5.Yüksek düzeyde yetkin: Tam otonom sürüler, görevleri insan kontrolü/süpervizyonu olmaksızın yüksek emniyet ve verimlilikle gerçekleştirebilmektedir.

Otonomi konusunda gelişme için yapılması gerekenler nelerdir? *

Your answer

6. İnsan-Makine Etkileşimi: Görevlerin yüksek esneklik, çeviklik ve emniyetle gerçekleştirilmesi için İnsan–Makine etkileşimini sağlayan teknolojileri geliştirme ve kullanma yeteneği *

- 1.Yetkin değil: İnsan-Makine arayüzü bulunmamaktadır.
- 2.Düşük düzeyde yetkin: Basit İnsan-Makine arayüzleriyle araç kontrolü ve veri toplama yapılmaktadır.
- 3.Orta düzeyde yetkin: Gelişmiş arayüzlerle tekli aracın kontrolü ve görev yönetimi yapılmaktadır.
- 4. Yetkin: İnsan-Makine etkileşimi ile çoklu makine kontrolü ve görev yönetimi yapılmaktadır.
- 5.Yüksek düzeyde yetkin: İnsan niyeti makinelerce çıkarılabilmektedir. Tam İnsan-Makine etkileşimi sağlanmıştır. Birden çok araçtan gelen faydalı yük sensör bilgileri otonom olarak işlenmektedir ve çevik (agile), duyarlı (responsive), uyabilen (adaptive) etkileşim sağlanmıştır.

İnsan-Makine etkileşimi alanında gelişim için atılmasını gereken adımlar nelerdir? *

Your answer

Submit

E. FIRST ROUND DELPHI RESULT WITH CHARTS

Table E.1

Expertise of Respondents on Delphi Statements

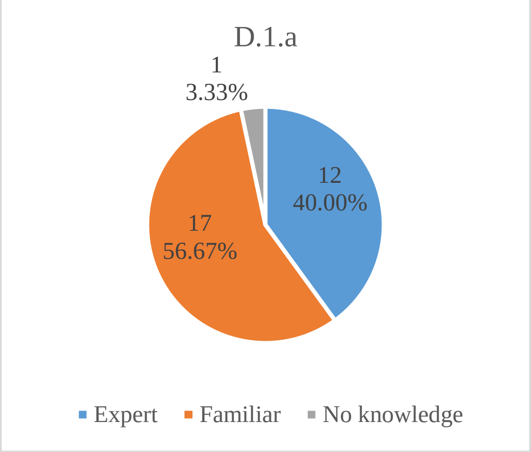
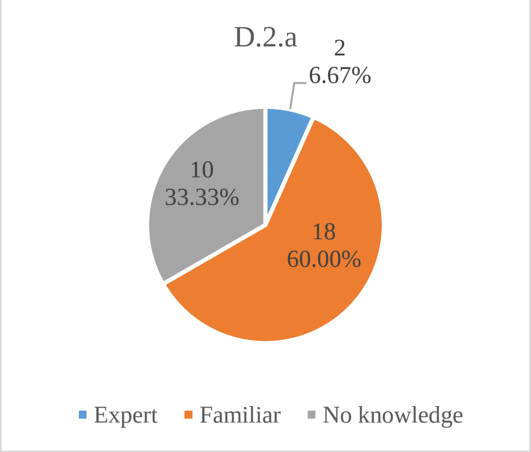
Delphi Statement	Expertise
D1: Intelligent systems have been developed to monitor and control for Unmanned Aerial Vehicle (UAV) and payloads.	
D2: Such as brain signals, speech recognition based control systems that will increase the human-machine collaboration have been developed.	

Table E.1 *(continued)*

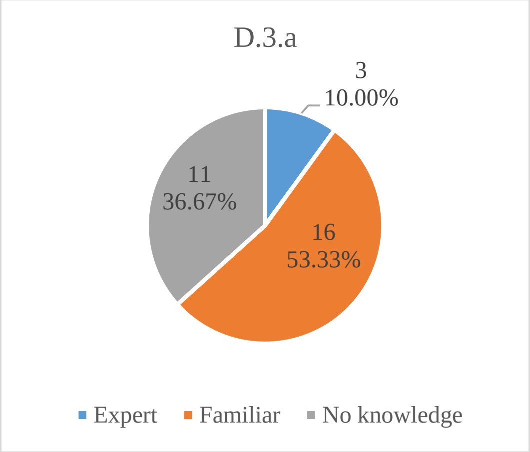
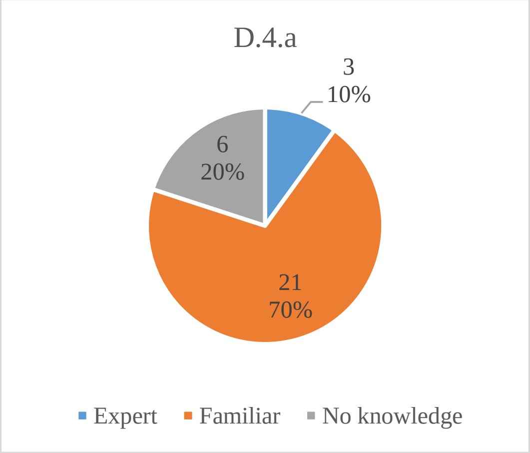
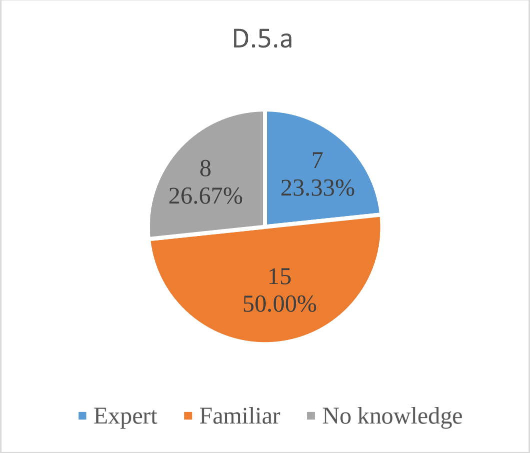
Delphi Statement	Expertise
D3: Autonomous air traffic management system which ensures airspace integration has been developed.	
D4: Data-driven, predictive intelligent production, maintenance systems, and test platforms based on autonomous modelling and simulation have been deployed for UAV and applications.	
D5: Intelligent flight control systems that are resistant to adverse conditions have been developed.	

Table E.1 *(continued)*

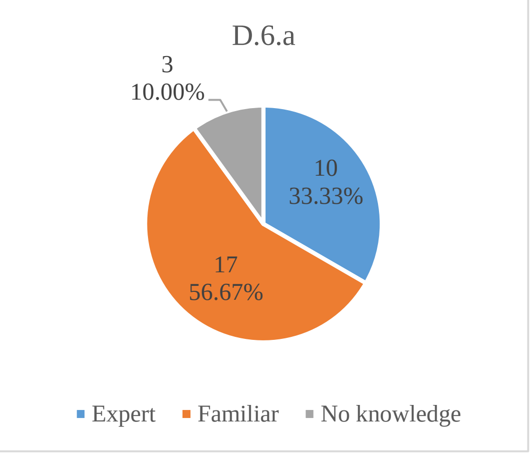
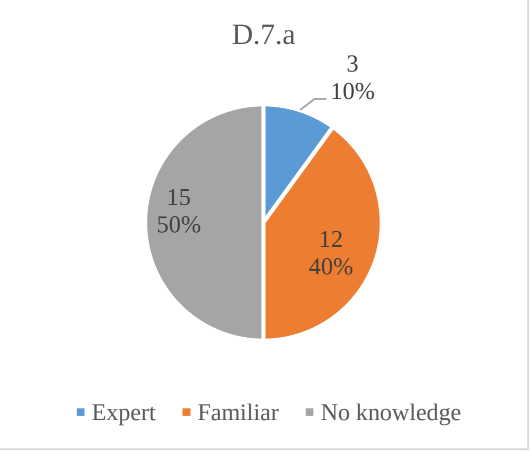
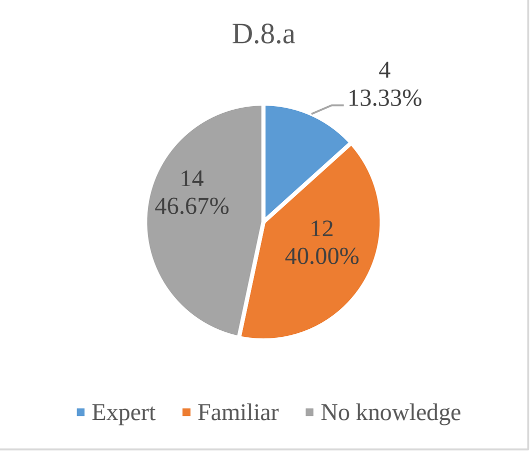
Delphi Statement	Expertise
D6: Intelligent systems have been developed for real-time route planning in all conditions (e.g. GPS denied environments, indoor navigation) during flight.	
D7: All weather-resistant IP-based communication systems which provide robust data links with a high data transfer rate (>100 GB/s) have been possessed.	
D8: Frequency spectrum constraints have been solved technologically.	

Table E.1 *(continued)*

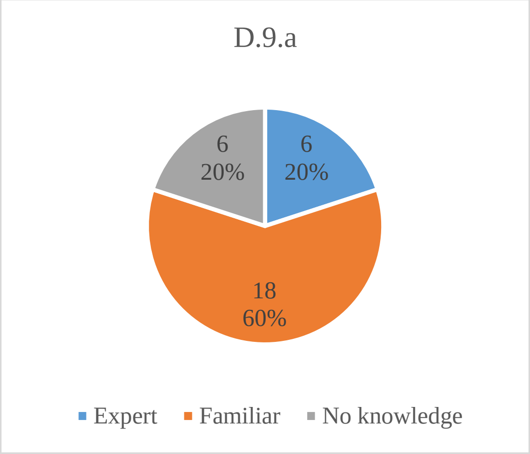
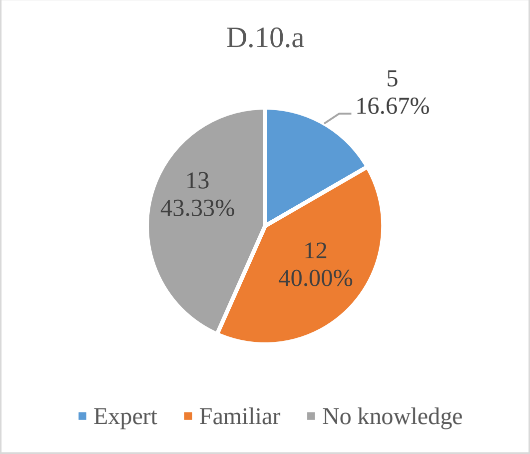
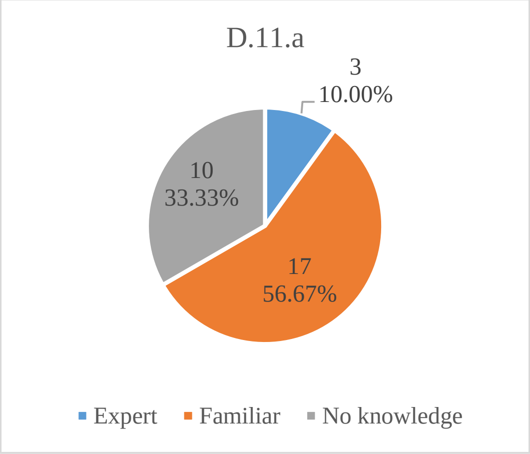
Delphi Statement	Expertise
D9: Intelligent decision support system which ensures to extract useful knowledge from UAV/other types of platforms/sensor network intense communication data and to react immediately in operation environment has been developed.	
D10: Satellite system which ensures intense communication and high-precision positioning of UAVs with robust, secure, and fast (>100 GB/s) data links has been deployed.	
D11: Such as smart sensor, micro-electro-mechanical systems (MEMS), robotics payloads which energy-efficient, lightweight, and configurable according to mission have been developed.	

Table E.1 *(continued)*

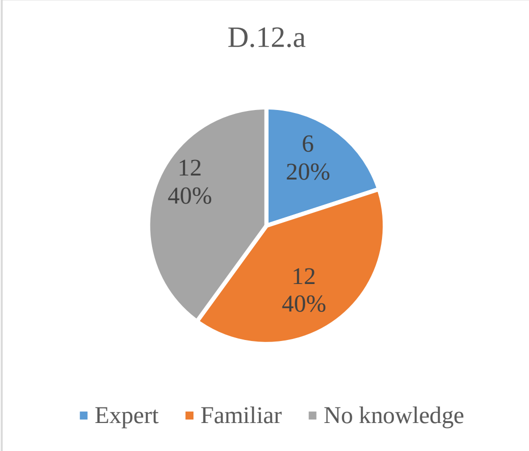
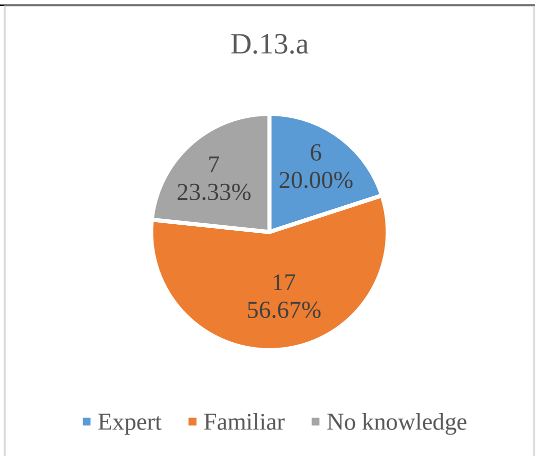
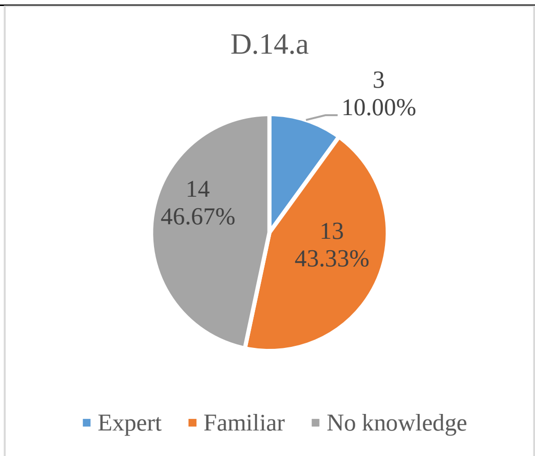
Delphi Statement	Expertise
D12: Advanced Electronic Warfare and Information Warfare systems which are providing absolute superiority in warfare environment have been developed.	
D13: Next-generation Artificial Intelligence-enabled weapons and technologies have been obtained.	
D14: Self-growing, morphing, self-healing, and impact/explosive-resistant light material technologies have been developed.	

Table E.1 *(continued)*

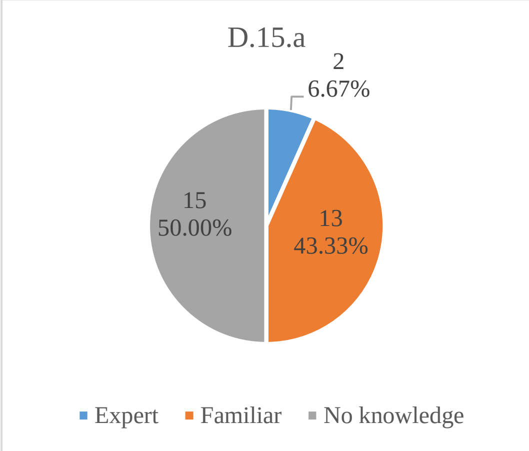
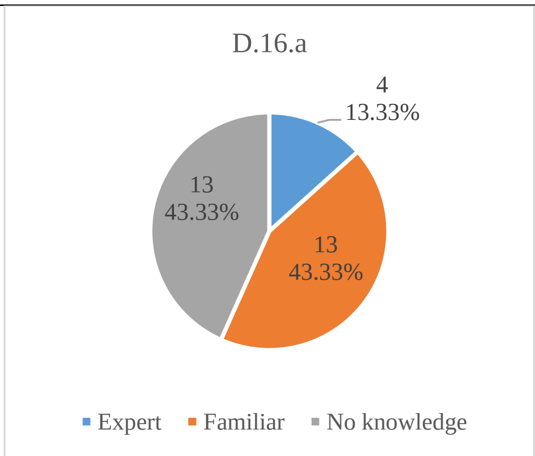
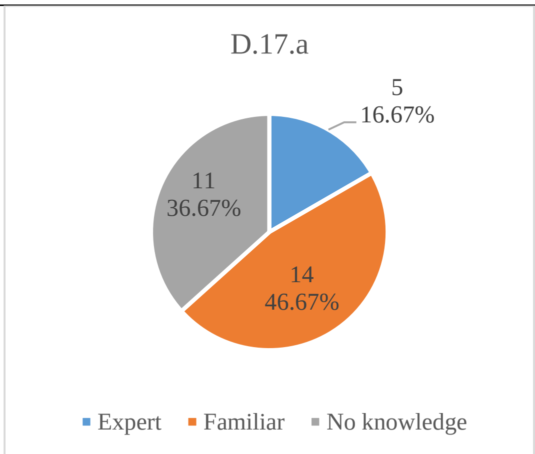
Delphi Statement	Expertise
D15: Hybrid propulsion systems with very low thermal/acoustic/electromagnetic footprint which were optimized in terms of Size-Weight-Power-Cost (SWaP-C) have been developed.	
D16: Battery with very long endurance (>200 h) providing very high energy density (>100 KWh/kg) has been developed.	
D17: Virtual, augmented, and mixed reality technologies are being used effectively to plan, conduct, review for UAV missions and crew/tactical training.	

Table E.1 *(continued)*

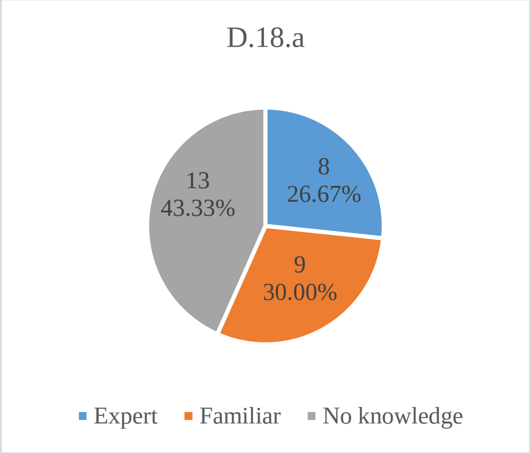
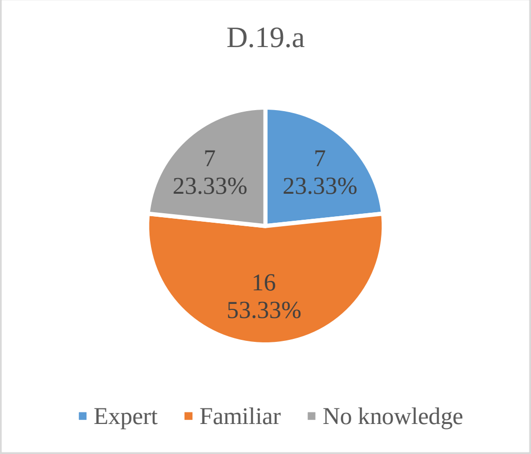
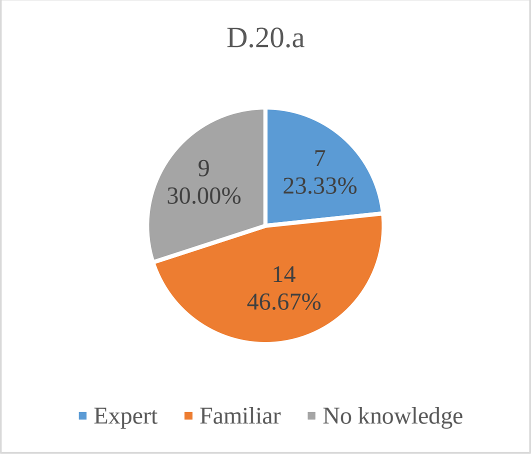
Delphi Statement	Expertise
D18: Interoperability of UAVs with different types of platforms (e.g. UGV/UMV, manned systems, wearable computers) has been ensured.	
D19: Fully autonomous scalable swarming has been ensured.	
D20: Anti-UAV system has been developed for detection, identification, classification, monitoring, and disposal of all threats through UAVs.	

Table E.2

Maturity Levels of Delphi Statements from Respondents' Perspective

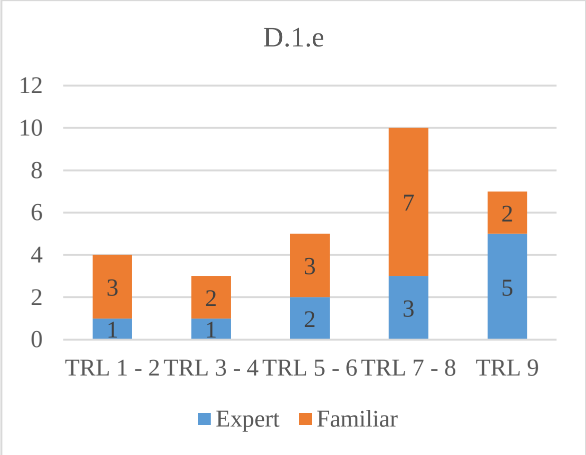
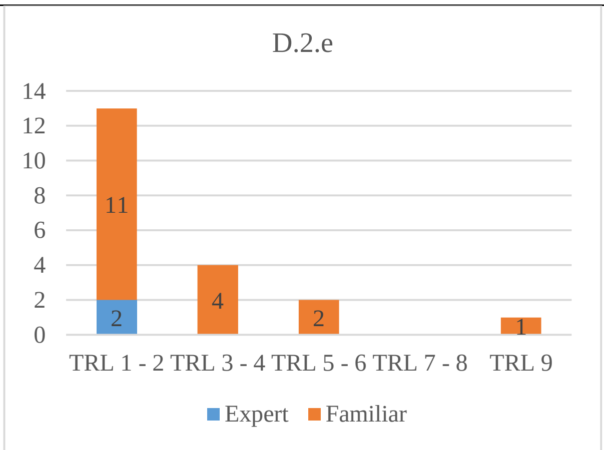
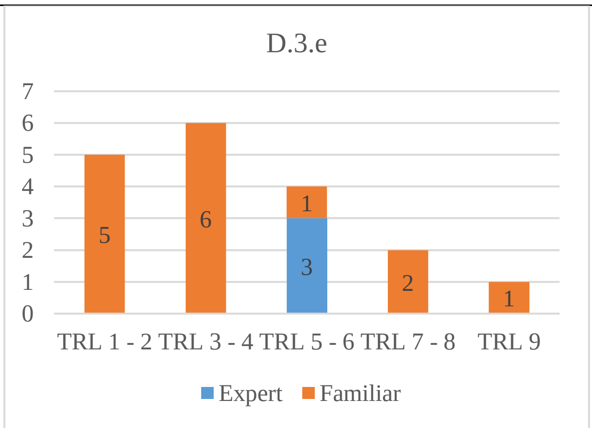
Delphi Statement	Maturity Level
D1: Intelligent systems have been developed to monitor and control for Unmanned Aerial Vehicle (UAV) and payloads.	
D2: Such as brain signals, speech recognition based control systems that will increase the human-machine collaboration have been developed.	
D3: Autonomous air traffic management system which ensures airspace integration has been developed.	

Table E.2 *(continued)*

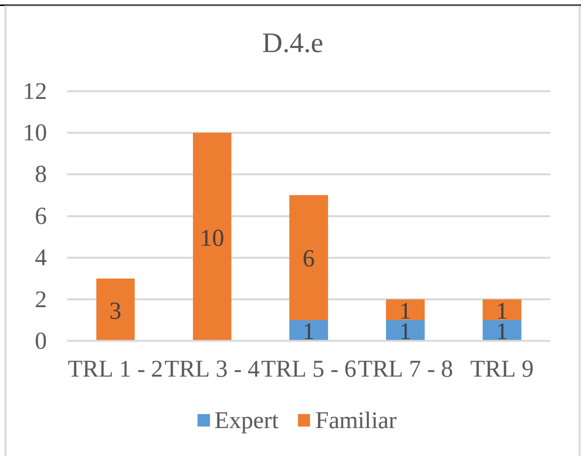
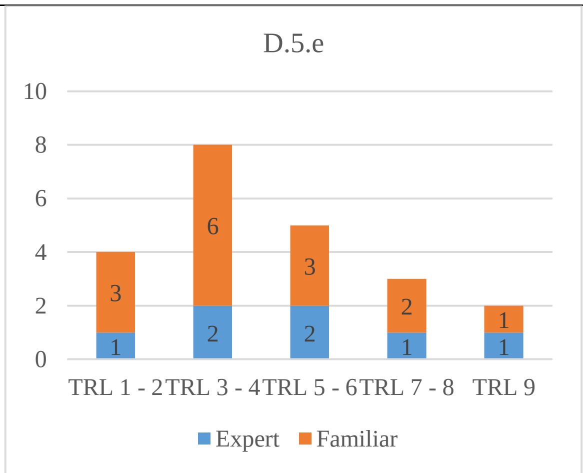
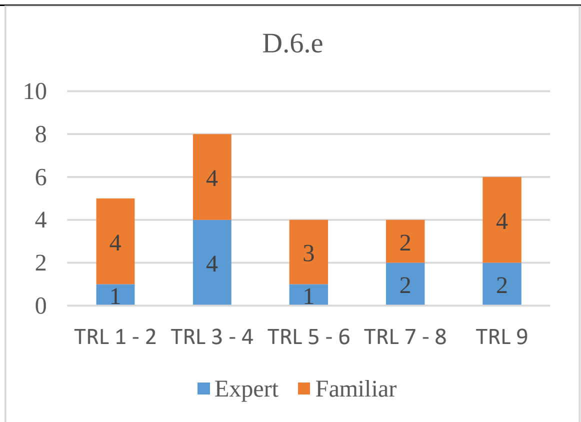
<table>
<tr><th>Delphi Statement</th><th>Maturity Level</th></tr>
<tr><td>D4: Data-driven, predictive intelligent production, maintenance systems, and test platforms based on autonomous modelling and simulation have been deployed for UAV and applications.</td><td>
</td></tr>
<tr><td>D5: Intelligent flight control systems that are resistant to adverse conditions have been developed.</td><td>
</td></tr>
<tr><td>D6: Intelligent systems have been developed for real-time route planning in all conditions (e.g. GPS denied environments, indoor navigation) during flight.</td><td>
</td></tr>
</table>

Table E.2 *(continued)*

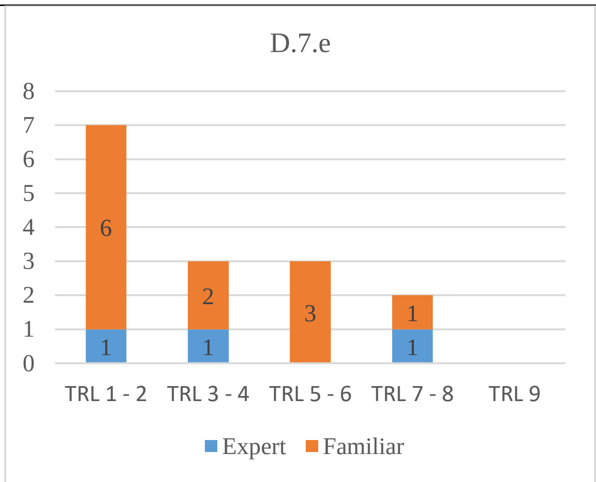
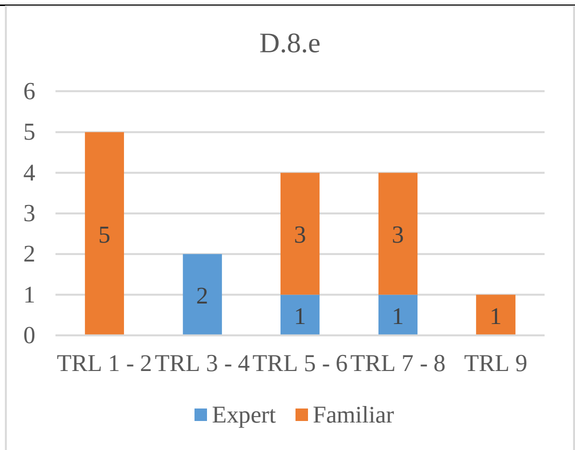
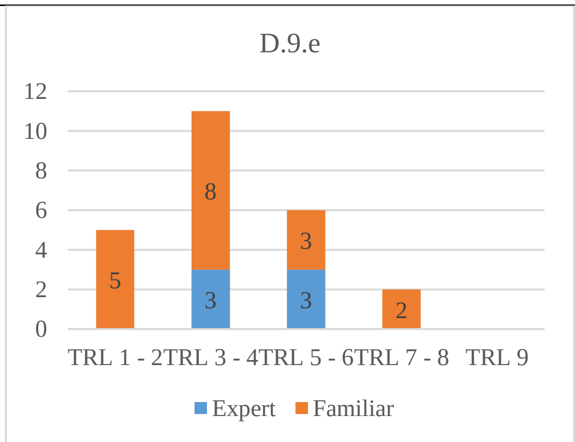
Delphi Statement	Maturity Level
D7: All weather-resistant IP-based communication systems which provide robust data links with a high data transfer rate (>100 GB/s) have been possessed.	
D8: Frequency spectrum constraints have been solved technologically.	
D9: Intelligent decision support system which ensures to extract useful knowledge from UAV/other types of platforms/sensor network intense communication data and to react immediately in operation environment has been developed.	

Table E.2 *(continued)*

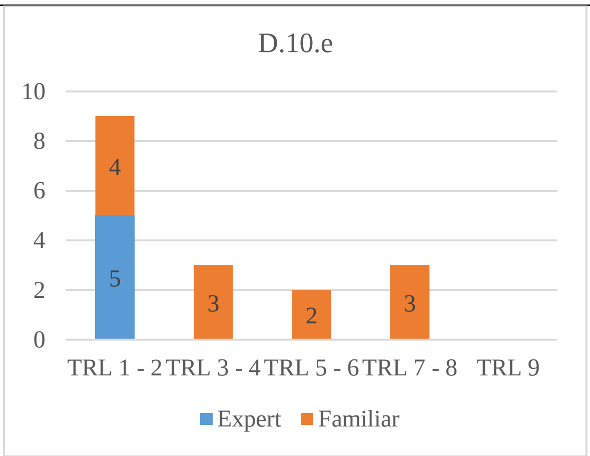
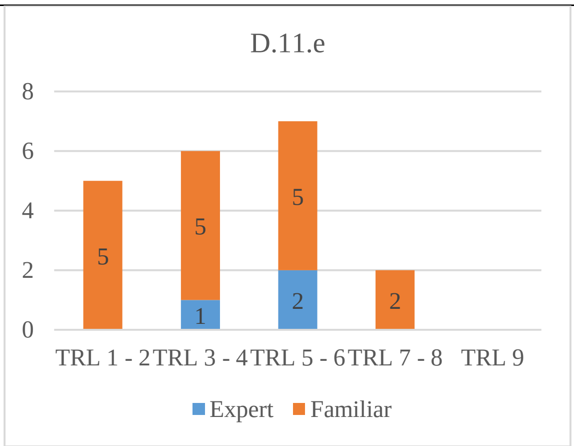
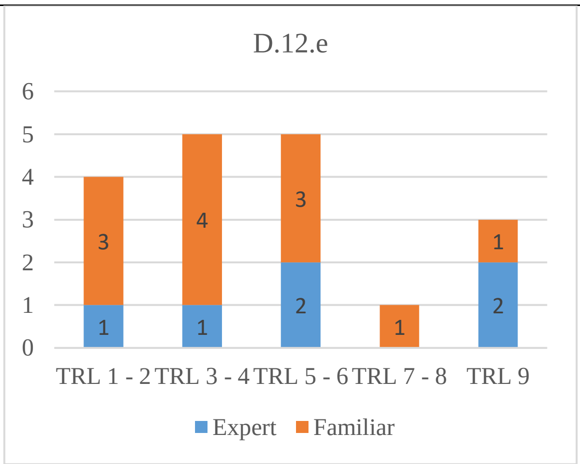
Delphi Statement	Maturity Level
D10: Satellite system which ensures intense communication and high-precision positioning of UAVs with robust, secure, and fast (>100 GB/s) data links has been deployed.	
D11: Such as smart sensor, micro-electro-mechanical systems (MEMS), robotics payloads which energy-efficient, lightweight, and configurable according to mission have been developed.	
D12: Advanced Electronic Warfare and Information Warfare systems which are providing absolute superiority in warfare environment have been developed.	

Table E.2 *(continued)*

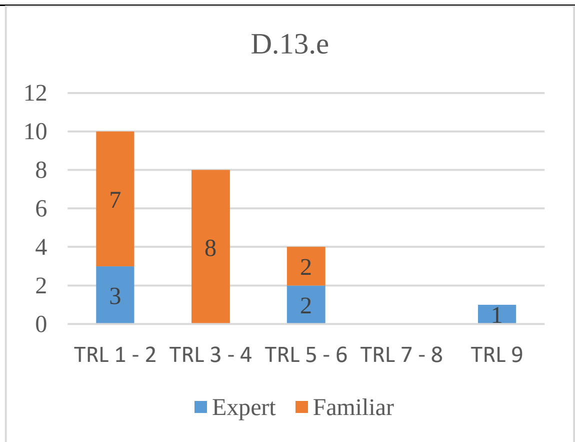
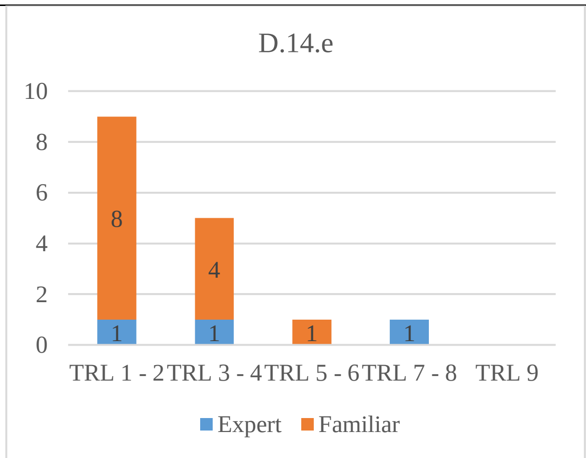
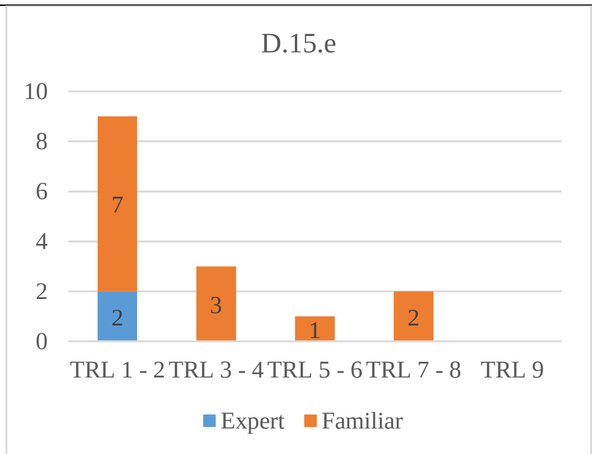
<table>
<tr><th>Delphi Statement</th><th>Maturity Level</th></tr>
<tr><td>D13: Next-generation Artificial Intelligence-enabled weapons and technologies have been obtained.</td><td>
</td></tr>
<tr><td>D14: Self-growing, morphing, self-healing, and impact/explosive-resistant light material technologies have been developed.</td><td>
</td></tr>
<tr><td>D15: Hybrid propulsion systems with very low thermal/acoustic/electromagnetic footprint which were optimized in terms of Size-Weight-Power-Cost (SWaP-C) have been developed.</td><td>
</td></tr>
</table>

Table E.2 *(continued)*

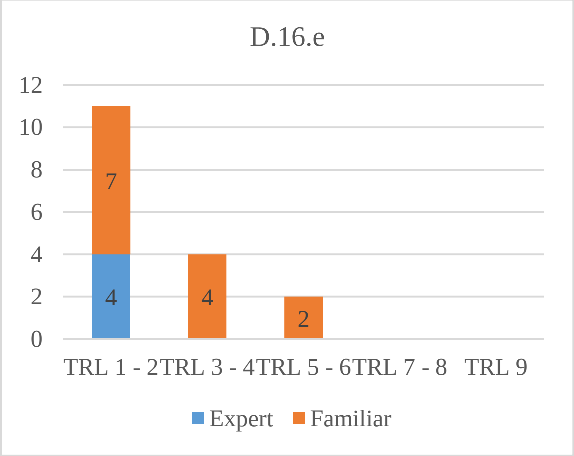
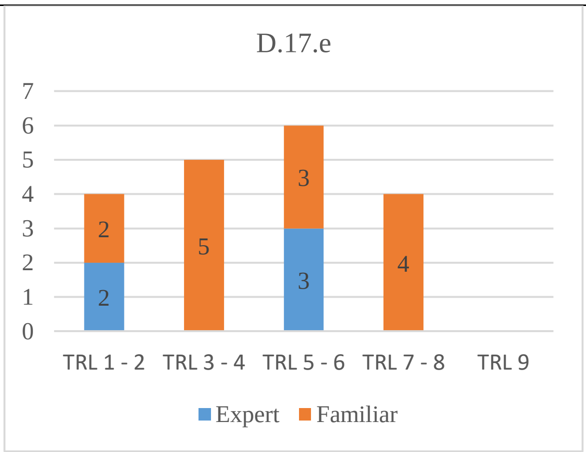
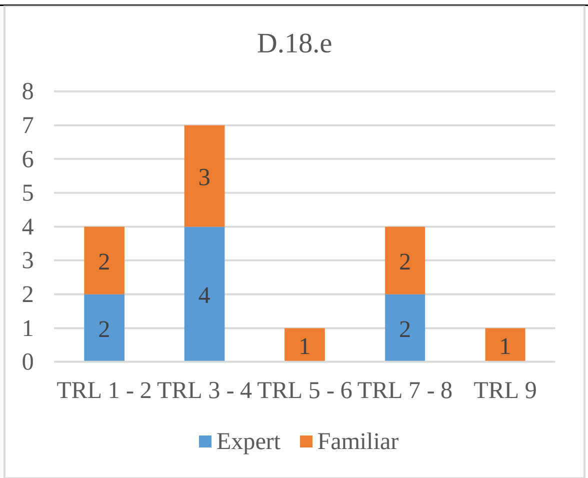
Delphi Statement	Maturity Level
D16: Battery with very long endurance (>200 h) providing very high energy density (>100 KWh/kg) has been developed.	
D17: Virtual, augmented, and mixed reality technologies are being used effectively to plan, conduct, review for UAV missions and crew/tactical training.	
D18: Interoperability of UAVs with different types of platforms (e.g. UGV/UMV, manned systems, wearable computers) has been ensured.	

Table E.2 *(continued)*

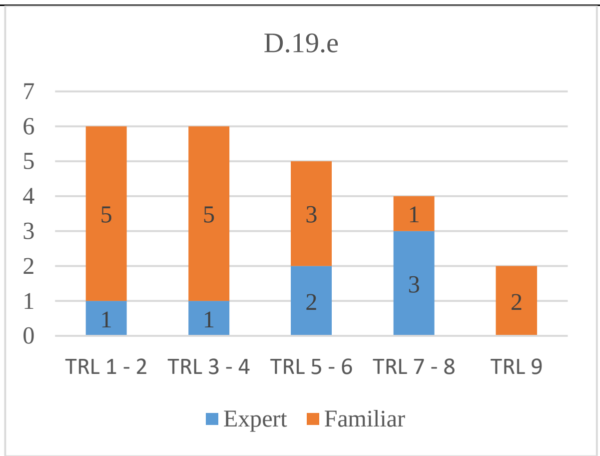
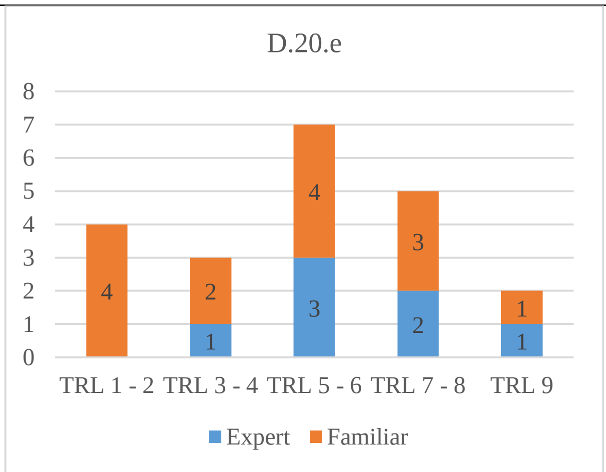
Delphi Statement	Maturity Level
D19: Fully autonomous scalable swarming has been ensured.	
D20: Anti-UAV system has been developed for detection, identification, classification, monitoring, and disposal of all threats through UAVs.	

Table E.3

Realisation Time Frame of Delphi Statements from Respondents' Perspective

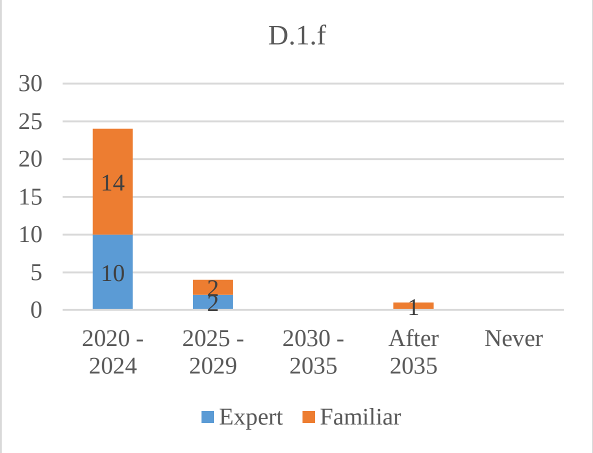
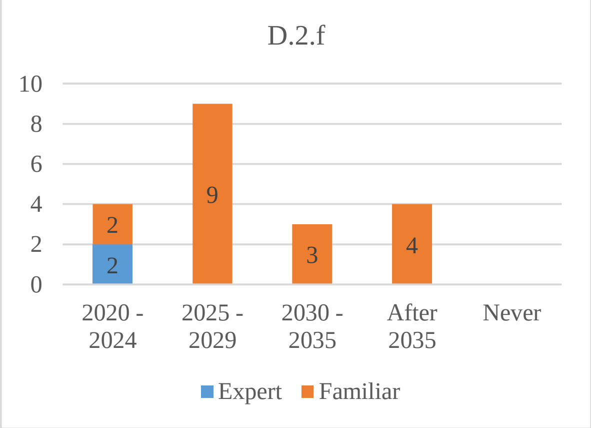
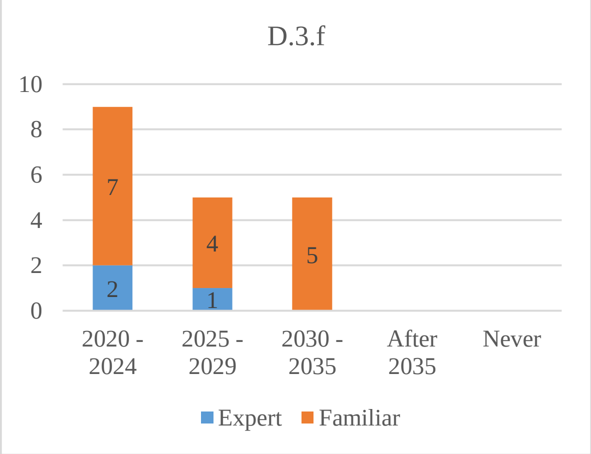
Delphi Statements	Time Frame
D1: Intelligent systems have been developed to monitor and control for Unmanned Aerial Vehicle (UAV) and payloads.	
D2: Such as brain signals, speech recognition based control systems that will increase the human-machine collaboration have been developed.	
D3: Autonomous air traffic management system which ensures airspace integration has been developed.	

Table E.3 *(continued)*

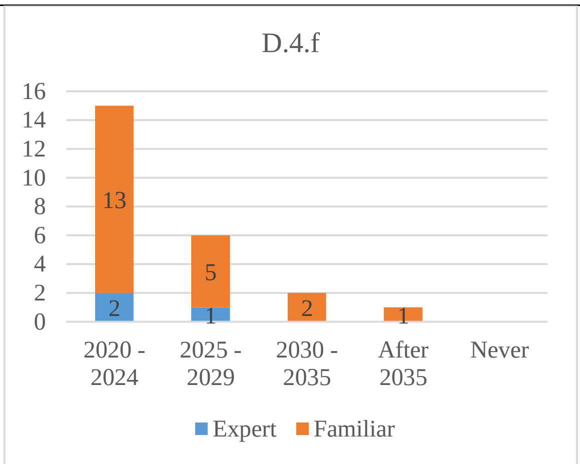
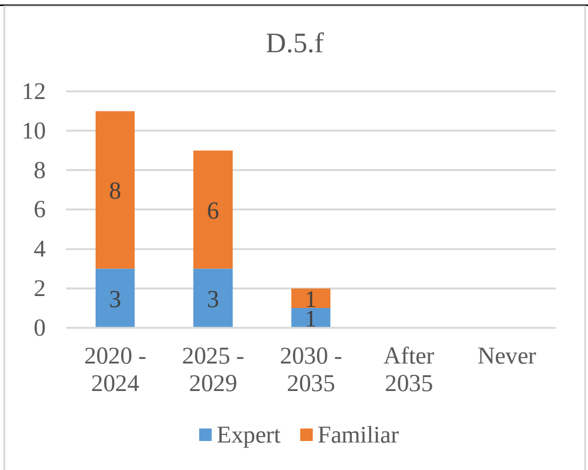
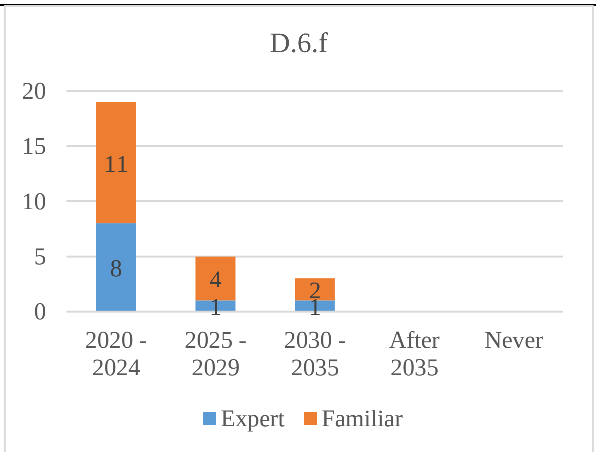
Delphi Statements	Time Frame
D4: Data-driven, predictive intelligent production, maintenance systems, and test platforms based on autonomous modelling and simulation have been deployed for UAV and applications.	
D5: Intelligent flight control systems that are resistant to adverse conditions have been developed.	
D6: Intelligent systems have been developed for real-time route planning in all conditions (e.g. denied environments, indoor navigation) during flight.	

Table E.3 *(continued)*

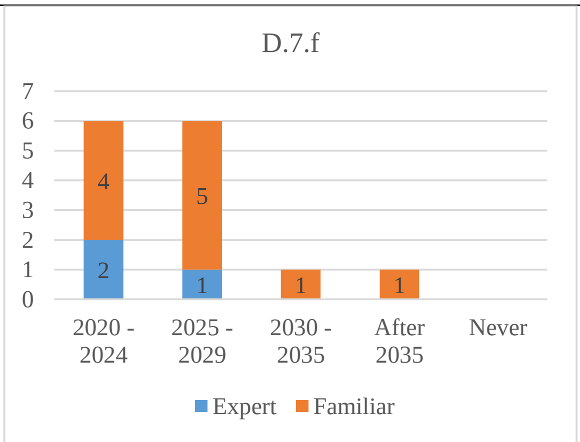
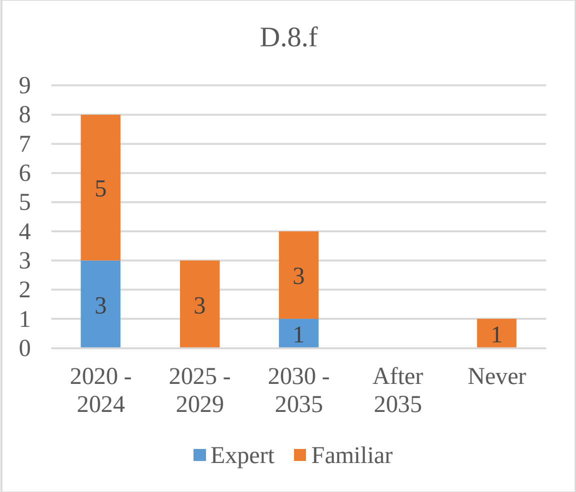
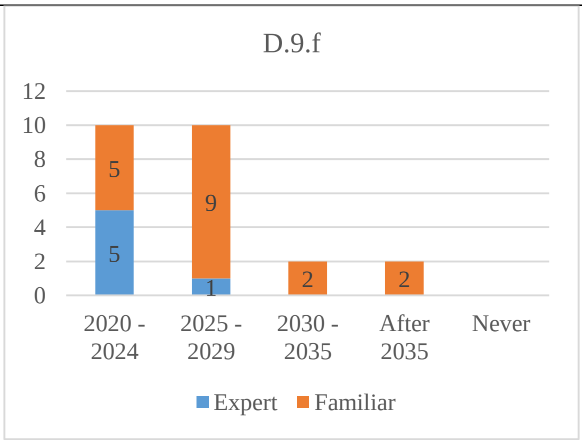
Delphi Statements	Time Frame
D7: All weather-resistant IP-based communication systems which provide robust data links with a high data transfer rate (>100 GB/s) have been possessed.	
D8: Frequency spectrum constraints have been solved technologically.	
D9: Intelligent decision support system which ensures to extract useful knowledge from UAV/other types of platforms/sensor network intense communication data and to react immediately in operation environment has been developed.	

Table E.3 *(continued)*

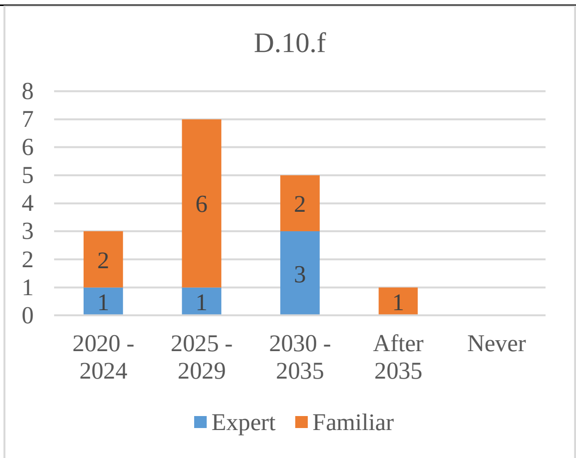
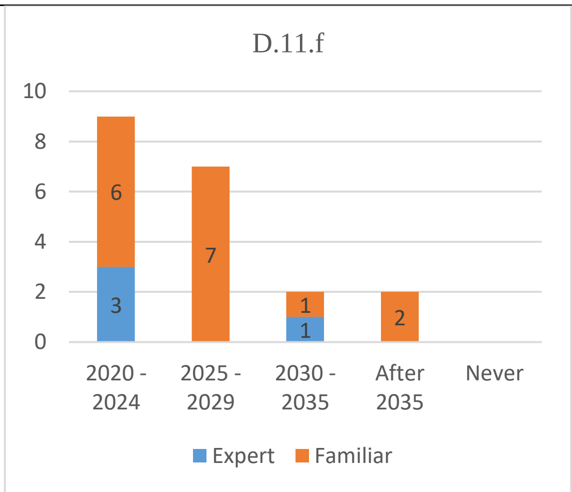
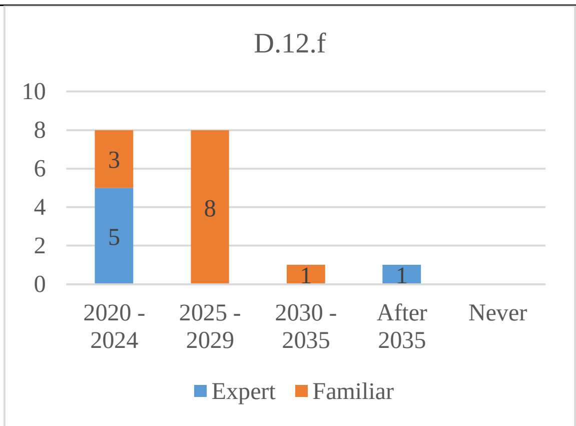
Delphi Statements	Time Frame
D10: Satellite system which ensures intense communication and high-precision positioning of UAVs with robust, secure, and fast (>100 GB/s) data links has been deployed.	
D11: Such as smart sensor, micro-electro-mechanical systems (MEMS), robotics payloads which energy-efficient, lightweight, and configurable according to mission have been developed.	
D12: Advanced Electronic Warfare and Information Warfare systems which are providing absolute superiority in warfare environment have been developed.	

Table E.3 *(continued)*

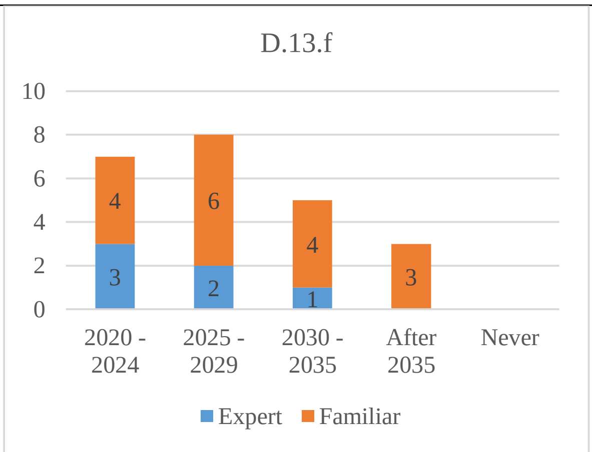
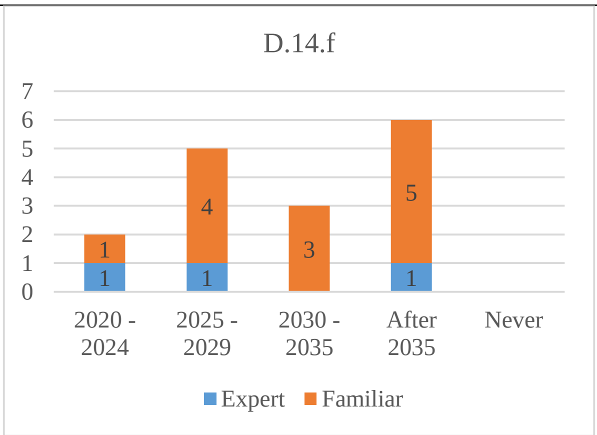
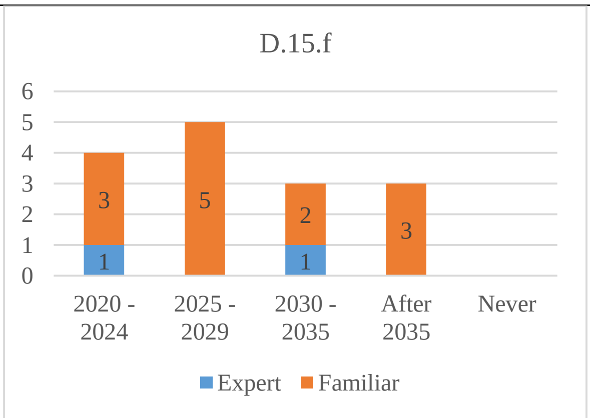
Delphi Statements	Time Frame
D13: Next-generation Artificial Intelligence-enabled weapons and technologies have been obtained.	
D14: Self-growing, morphing, self-healing, and impact/explosive-resistant light material technologies have been developed.	
D15: Hybrid propulsion systems with very low thermal/acoustic/electromagnetic footprint which were optimized in terms of Size-Weight-Power-Cost (SWaP-C) have been developed.	

Table E.3 *(continued)*

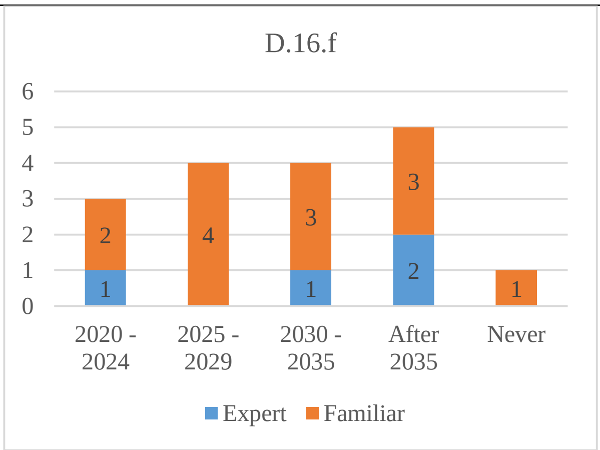
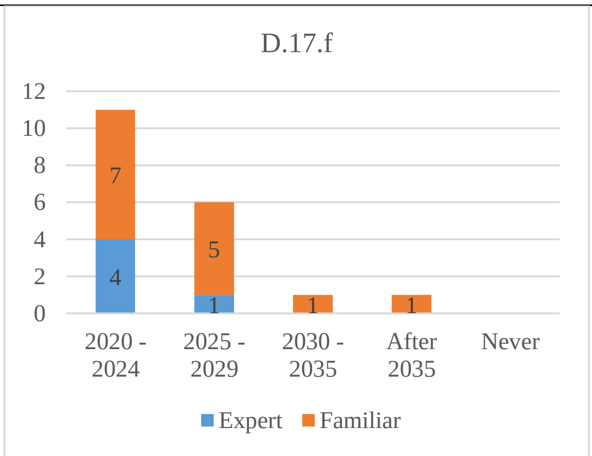
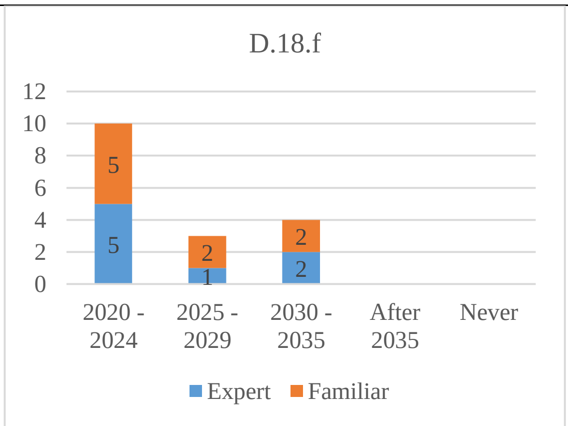
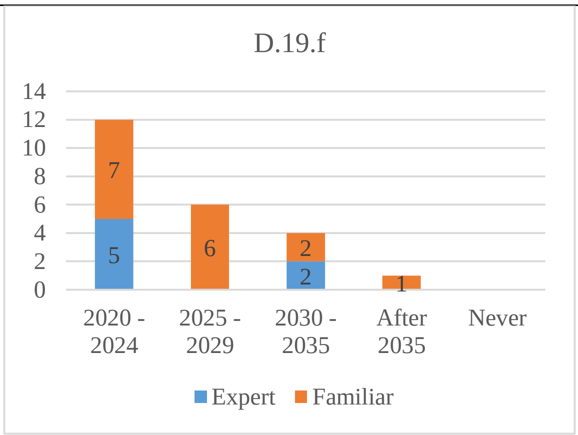
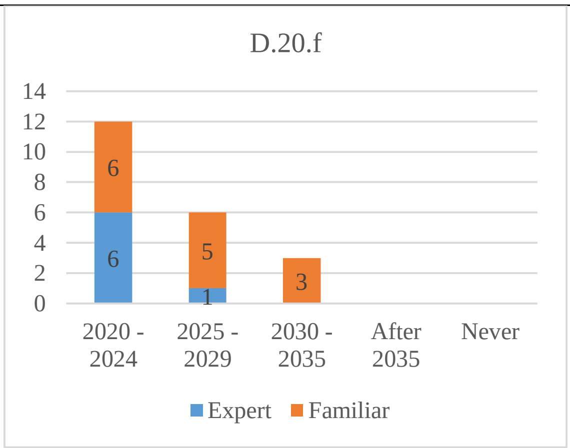
Delphi Statements	Time Frame
D16: Battery with very long endurance (>200 h) providing very high energy density (>100 KWh/kg) has been developed.	
D17: Virtual, augmented, and mixed reality technologies are being used effectively to plan, to conduct, to review for UAV missions and crew/tactical training.	
D18: Interoperability of UAVs with different types of platforms (e.g. UGV/UMV, manned systems, wearable computers) has been ensured.	

Table E.3 *(continued)*

Delphi Statements	Time Frame
D19: Fully autonomous scalable swarming has been ensured.	
D20: Anti-UAV system has been developed for detection, identification, classification, monitoring, and disposal of all threats through UAVs.	

F. SECOND ROUND DELPHI RESULTS WITH CHARTS

Table F.1

The Expertise of Respondents on Delphi Statements in Second Round

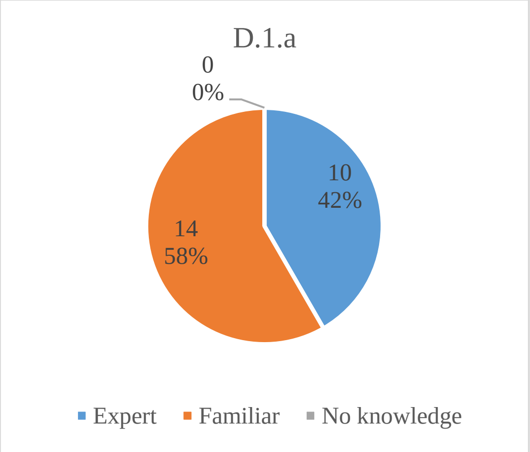
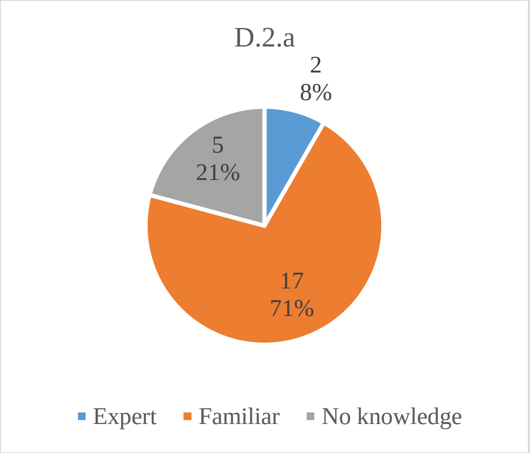
Delphi Statement	Expertise
D1: Intelligent systems have been developed to monitor and control for Unmanned Aerial Vehicle (UAV) and payloads.	
D2: Such as brain signals, speech recognition based control systems that will increase the human-machine collaboration have been developed.	

Table F.1 *(continued)*

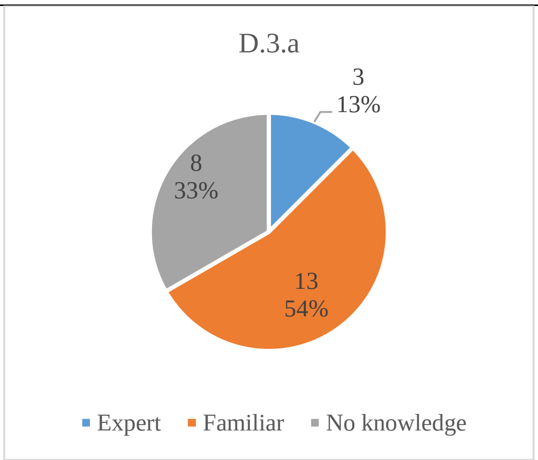
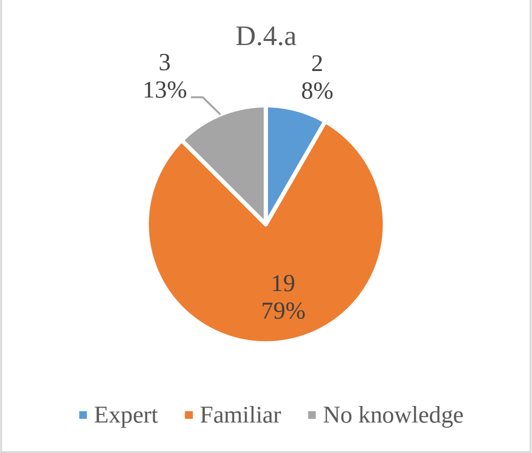
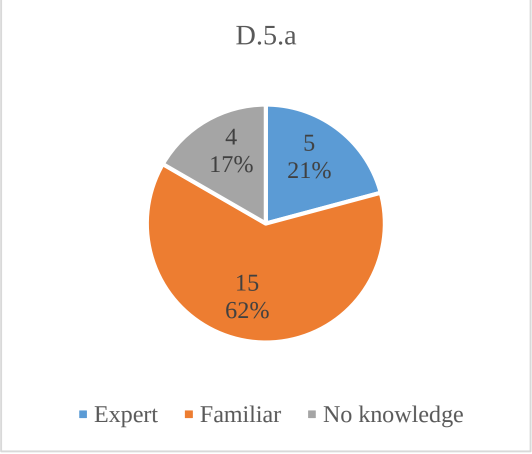
Delphi Statement	Expertise
D3: Autonomous air traffic management system which ensures airspace integration has been developed.	
D4: Data-driven, predictive intelligent production, maintenance systems, and test platforms based on autonomous modelling and simulation have been deployed for UAV and applications.	
D5: Intelligent flight control systems that are resistant to adverse conditions have been developed.	

Table F.1 *(continued)*

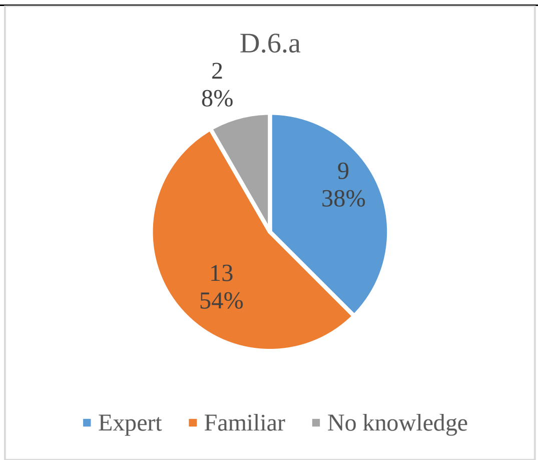
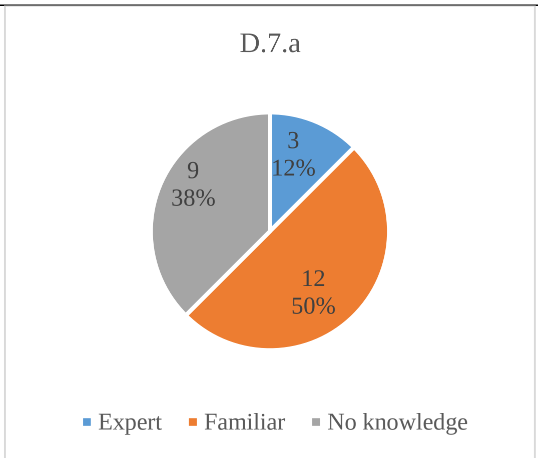
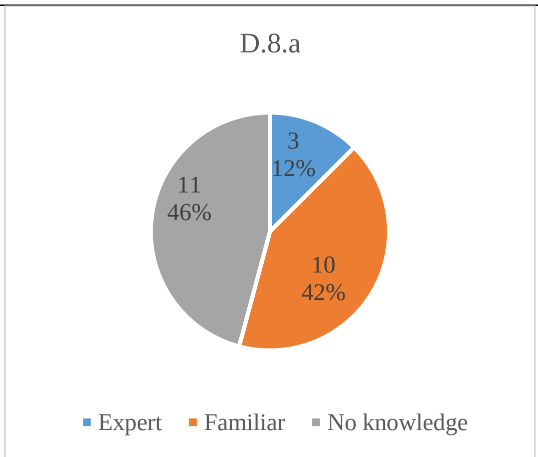
Delphi Statement	Expertise
D6: Intelligent systems have been developed for real-time route planning in all conditions (e.g. GPS denied environments, indoor navigation) during flight.	
D7: All weather-resistant IP-based communication systems which provide robust data links with a high data transfer rate (>100 GB/s) have been possessed.	
D8: Frequency spectrum constraints have been solved technologically.	

Table F.1 *(continued)*

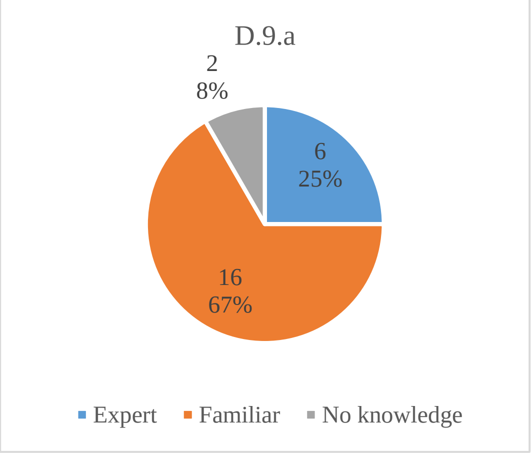
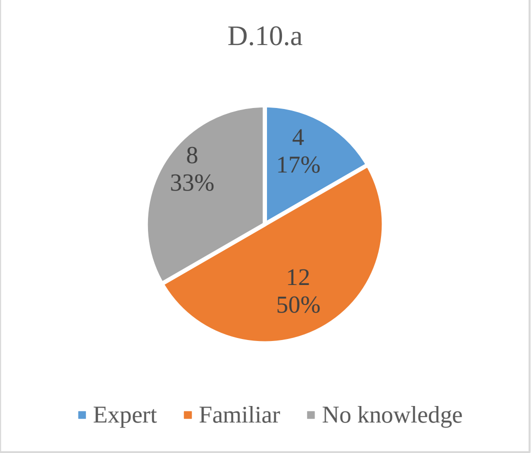
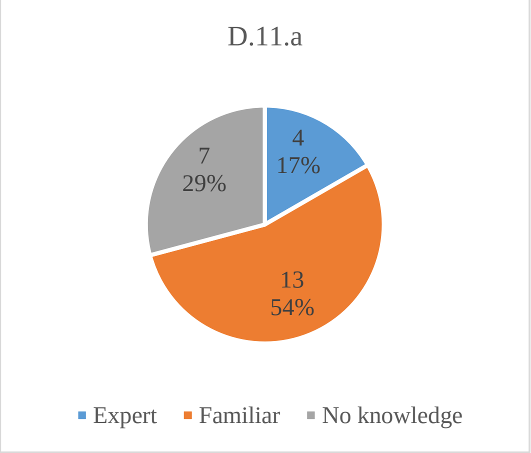
Delphi Statement	Expertise
D9: Intelligent decision support system which ensures to extract useful knowledge from UAV/other types of platforms/sensor network intense communication data and to react immediately in operation environment has been developed.	
D10: Satellite system which ensures intense communication and the high-precision positioning of UAVs with robust, secure, and fast (>100 GB/s) data links has been deployed.	
D11: Such as smart sensor, micro-electro-mechanical systems (MEMS), robotics payloads which energy-efficient, lightweight, and configurable according to mission have been developed.	

Table F.1 *(continued)*

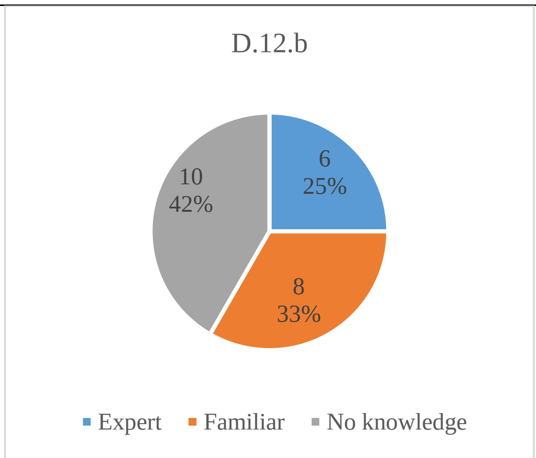
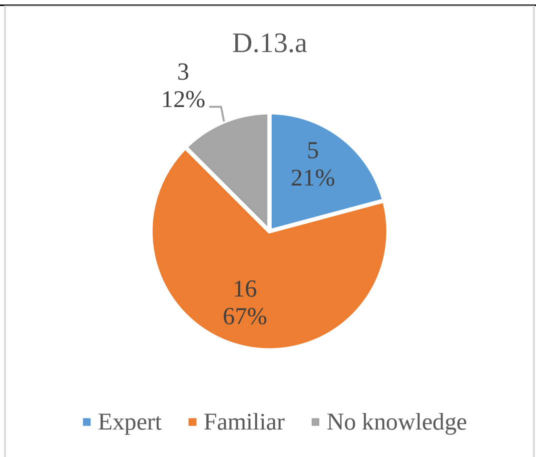
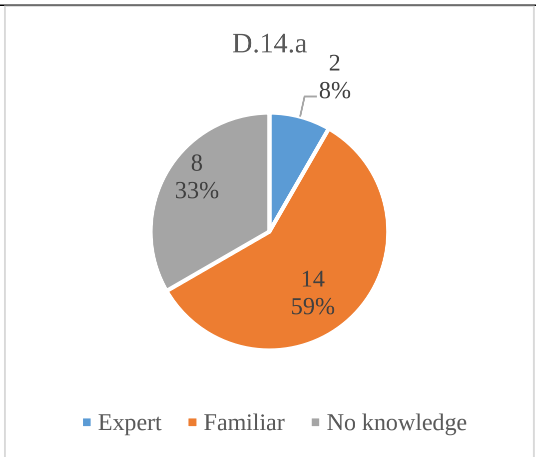
Delphi Statement	Expertise
D12: Advanced Electronic Warfare and Information Warfare systems which are providing absolute superiority in warfare environment have been developed.	
D13: Next-generation Artificial Intelligence-enabled weapons and technologies have been obtained.	
D14: Self-growing, morphing, self-healing, and impact/explosive-resistant light material technologies have been developed.	

Table F.1 *(continued)*

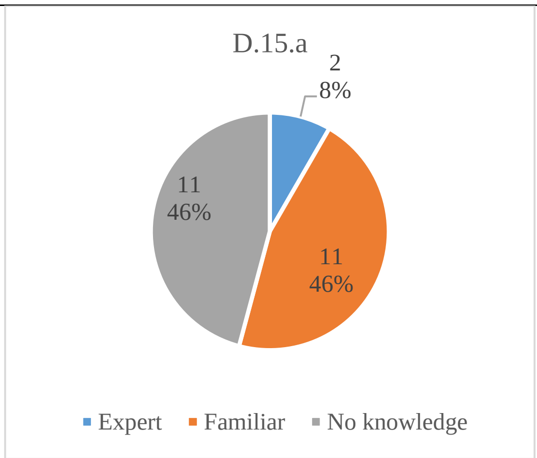
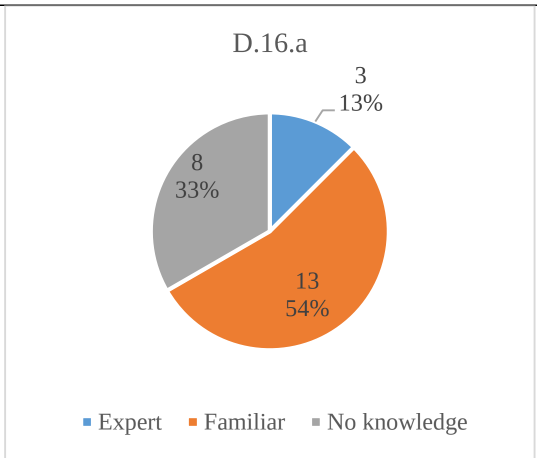
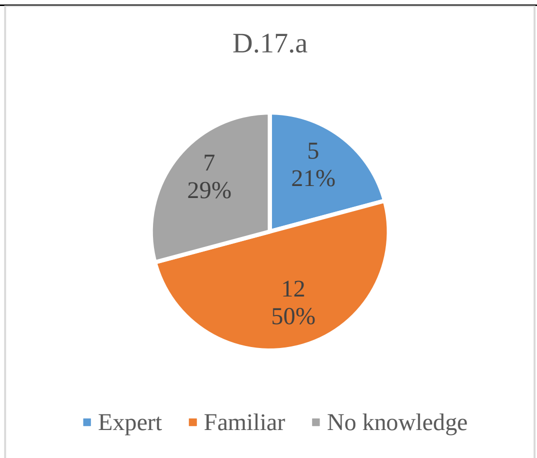
Delphi Statement	Expertise
D15: Hybrid propulsion systems with very low thermal/acoustic/electromagnetic footprint which were optimized in terms of Size-Weight-Power-Cost (SWaP-C) have been developed.	
D16: Battery with very long endurance (>200 h) providing very high energy density (>100 KWh/kg) has been developed.	
D17: Virtual, augmented, and mixed reality technologies are being used effectively to plan, conduct, review for UAV missions and crew/tactical training.	

Table F.1 *(continued)*

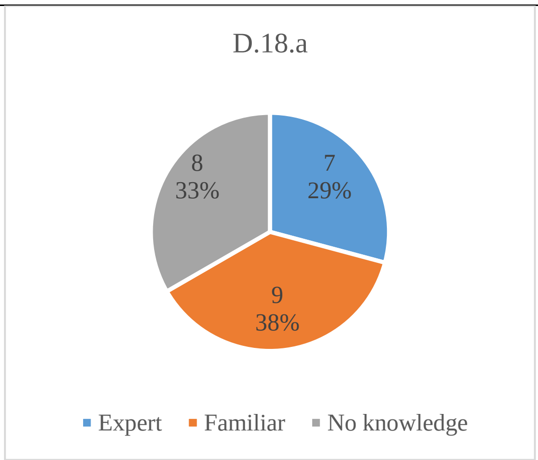
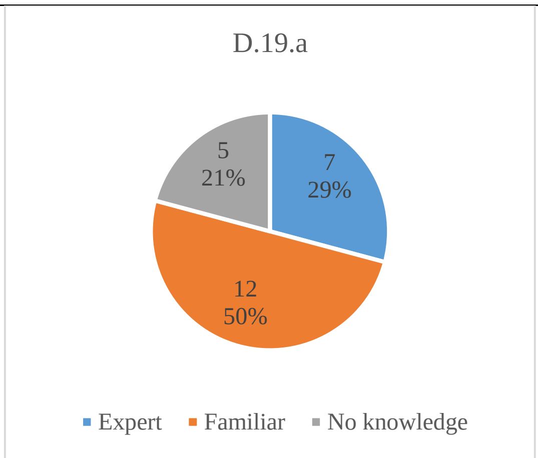
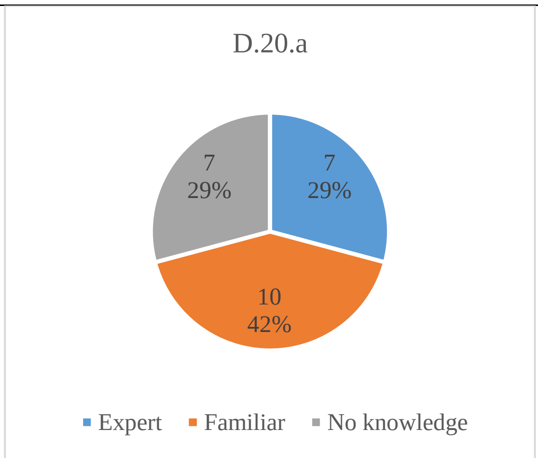
Delphi Statement	Expertise
D18: Interoperability of UAVs with different types of platforms (e.g. UGV/UMV, manned systems, wearable computers) has been ensured.	
D19: Fully autonomous scalable swarming has been ensured.	
D20: Anti-UAV system has been developed for detection, identification, classification, monitoring, and disposal of all threats through UAVs.	

Table F.2

Maturity Levels of Delphi Statements from Respondents' Perspective in Second Round

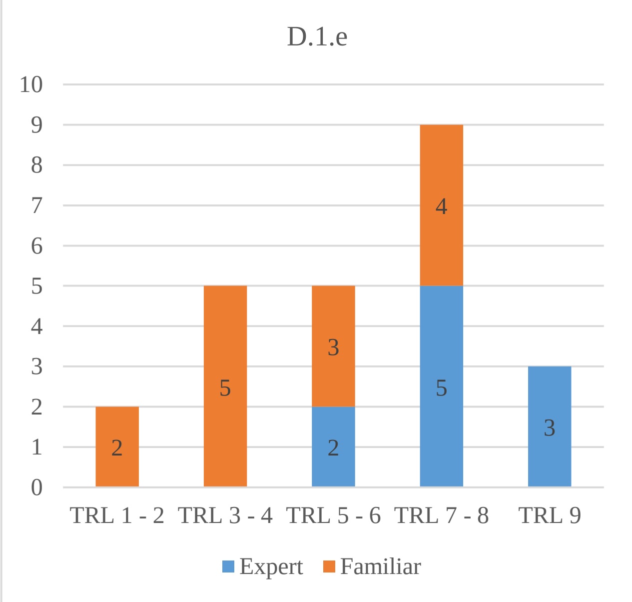
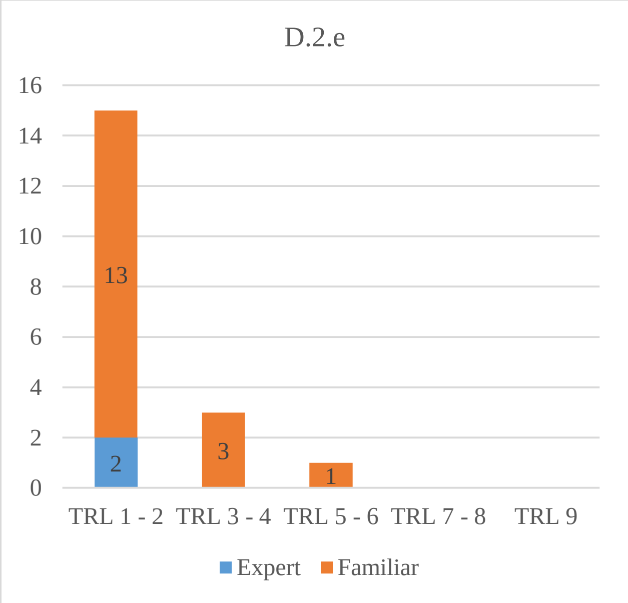
Delphi Statement	Maturity Level
D1: Intelligent systems have been developed to monitor and control for Unmanned Aerial Vehicle (UAV) and payloads.	
D2: Such as brain signals, speech recognition based control systems that will increase the human-machine collaboration have been developed.	

Table F.2 *(continued)*

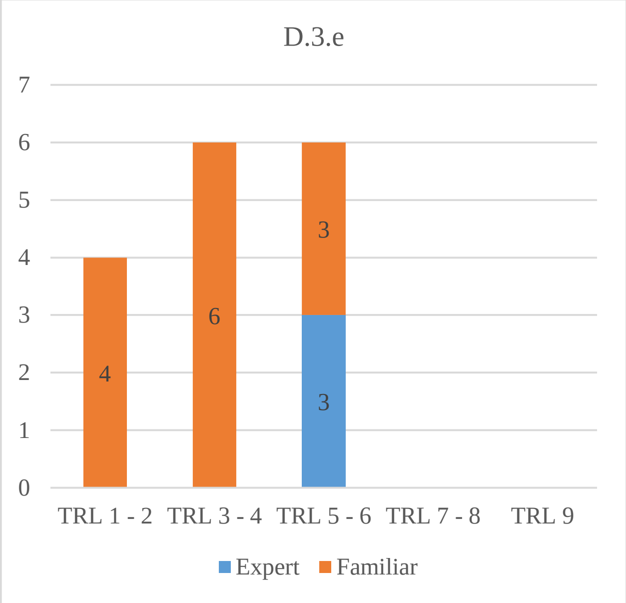
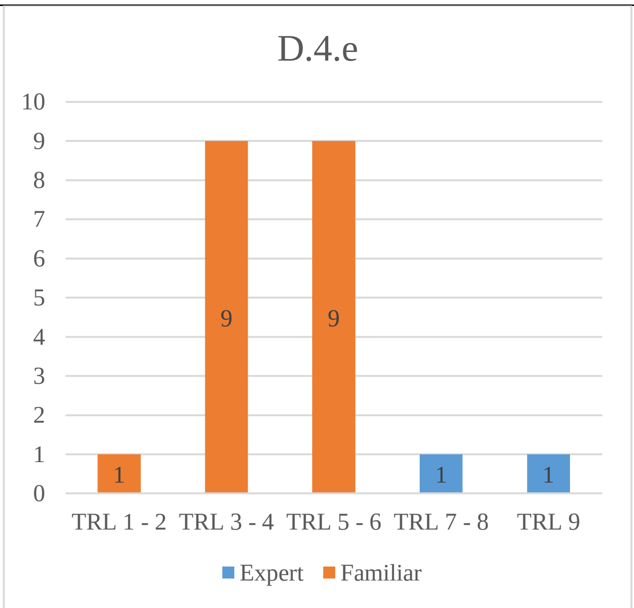
Delphi Statement	Maturity Level
D3: Autonomous air traffic management system which ensures airspace integration has been developed.	
D4: Data-driven, predictive intelligent production, maintenance systems, and test platforms based on autonomous modelling and simulation have been deployed for UAV and applications.	

Table F.2 *(continued)*

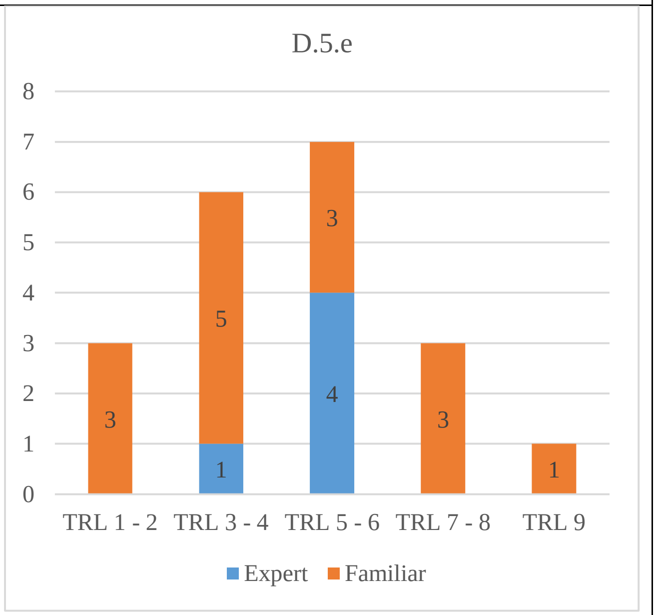
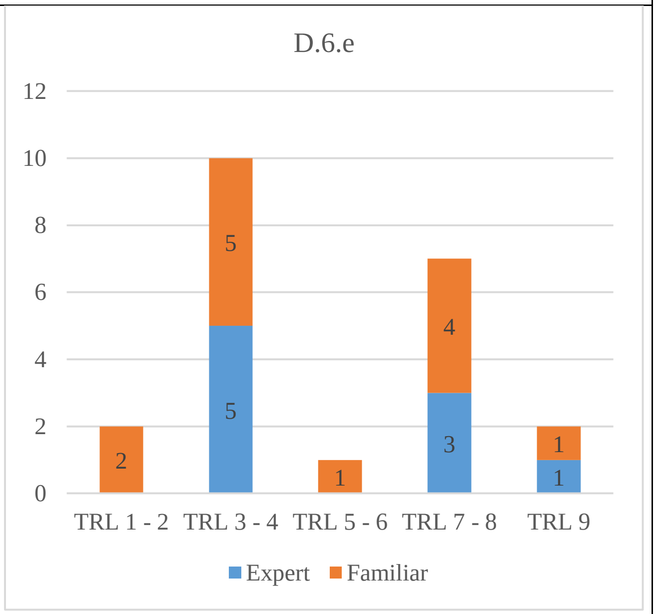
Delphi Statement	Maturity Level
D5: Intelligent flight control systems that are resistant to adverse conditions have been developed.	
D6: Intelligent systems have been developed for real-time route planning in all conditions (e.g. GPS denied environments, indoor navigation) during flight.	

Table F.2 *(continued)*

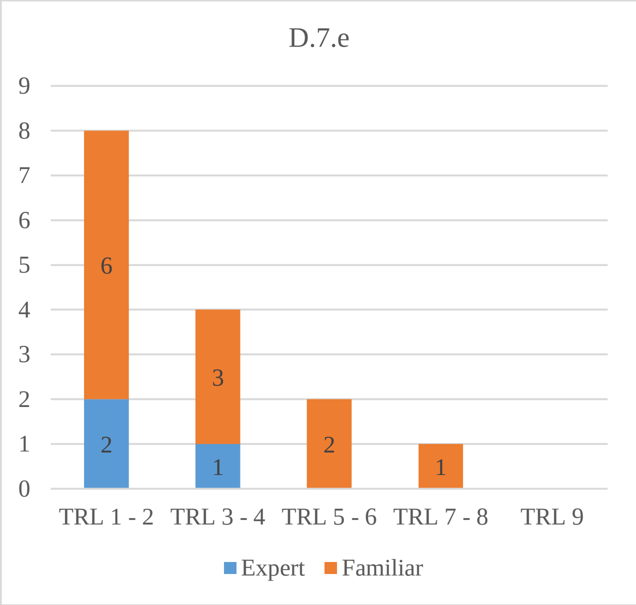
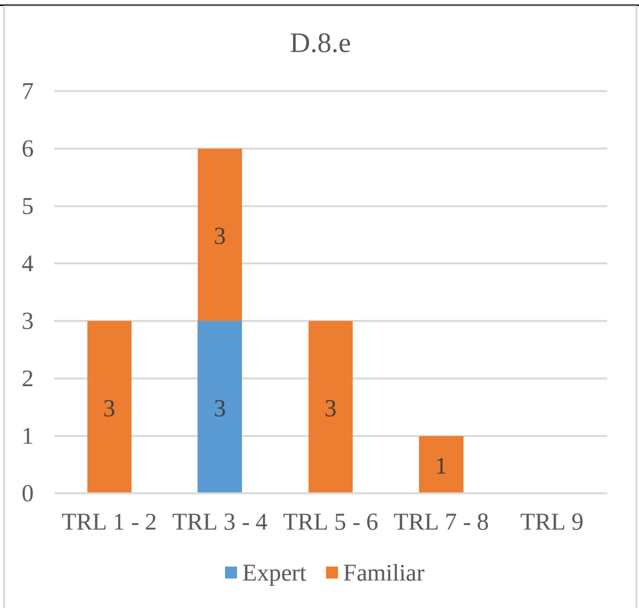
Delphi Statement	Maturity Level
D7: All weather-resistant IP-based communication systems which provide robust data links with a high data transfer rate (>100 GB/s) have been possessed.	
D8: Frequency spectrum constraints have been solved technologically.	

Table F.2 *(continued)*

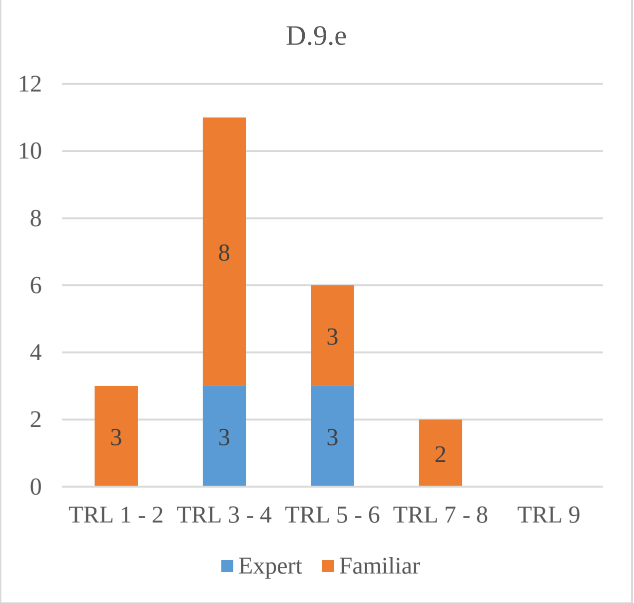
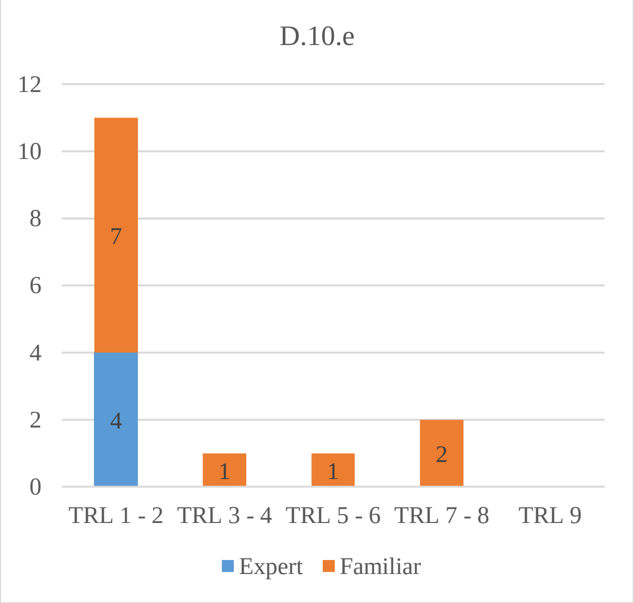
Delphi Statement	Maturity Level
D9: Intelligent decision support system which ensures to extract useful knowledge from UAV/other types of platforms/sensor network intense communication data and to react immediately in operation environment has been developed.	
D10: Satellite system which ensures intense communication and high-precision positioning of UAVs with robust, secure, and fast (>100 GB/s) data links has been deployed.	

Table F.2 *(continued)*

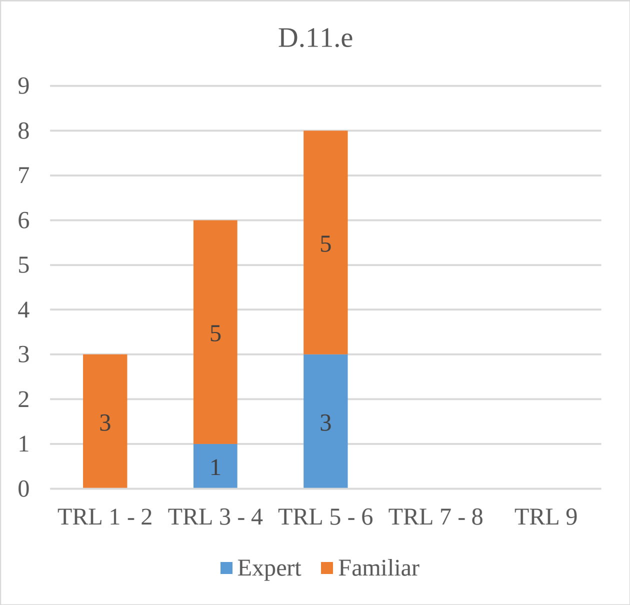
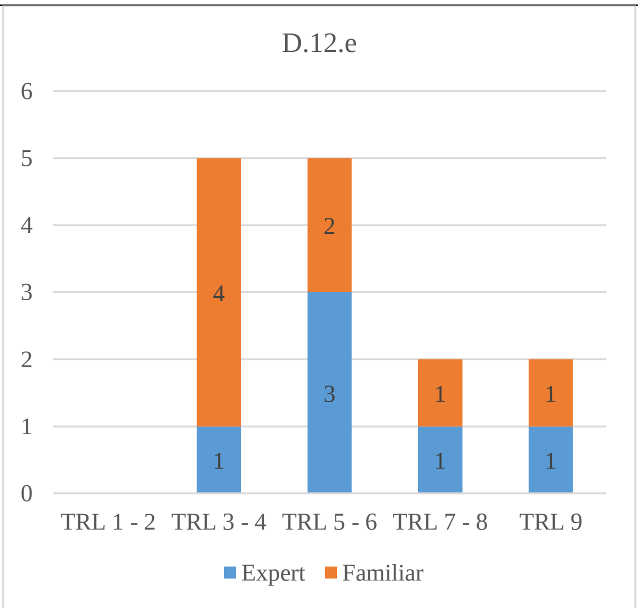
Delphi Statement	Maturity Level
D11: Such as smart sensor, micro-electro-mechanical systems (MEMS), robotics payloads which energy-efficient, lightweight, and configurable according to mission have been developed.	
D12: Advanced Electronic Warfare and Information Warfare systems which are providing absolute superiority in warfare environment have been developed.	

Table F.2 *(continued)*

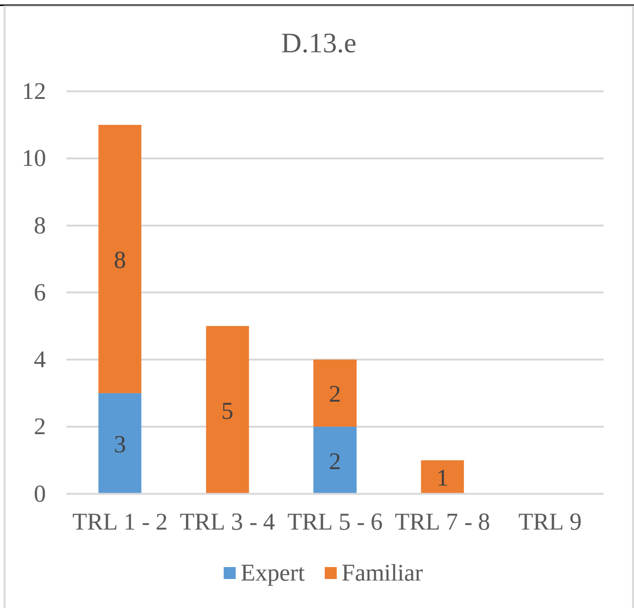
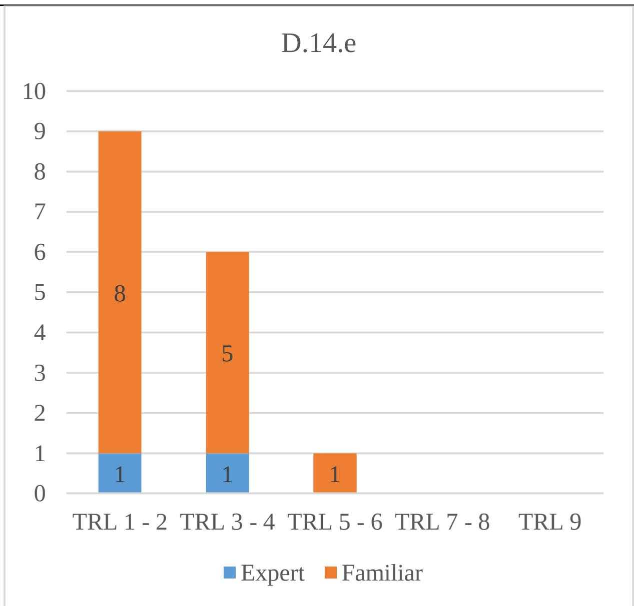
Delphi Statement	Maturity Level
D13: Next-generation Artificial Intelligence-enabled weapons and technologies have been obtained.	
D14: Self-growing, morphing, self-healing, and impact/explosive-resistant light material technologies have been developed.	

Table F.2 *(continued)*

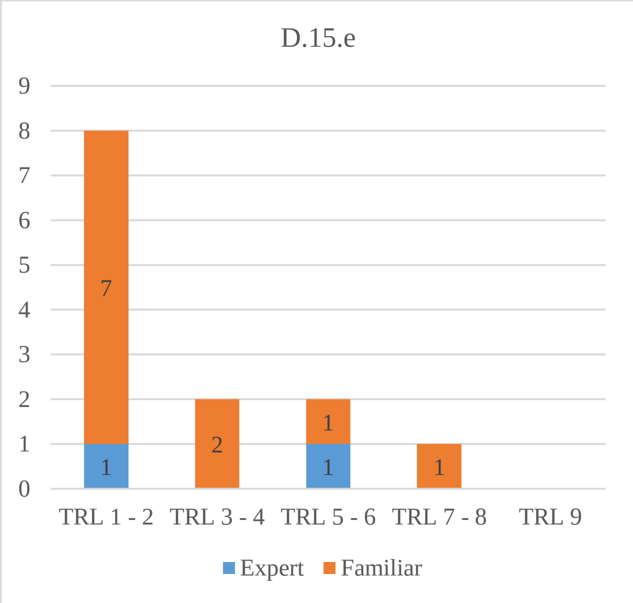
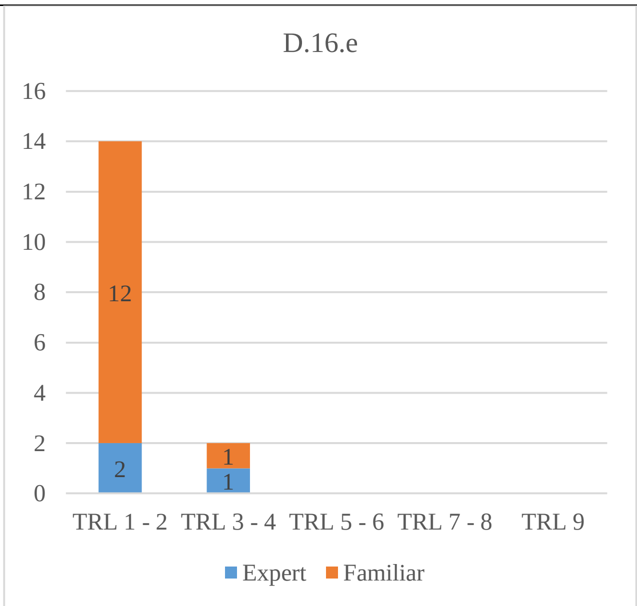
Delphi Statement	Maturity Level
D15: Hybrid propulsion systems with very low thermal/acoustic/electromagnetic footprint which were optimized in terms of Size-Weight-Power-Cost (SWaP-C) have been developed.	
D16: Battery with very long endurance (>200 h) providing very high energy density (>100 KWh/kg) has been developed.	

Table F.2 *(continued)*

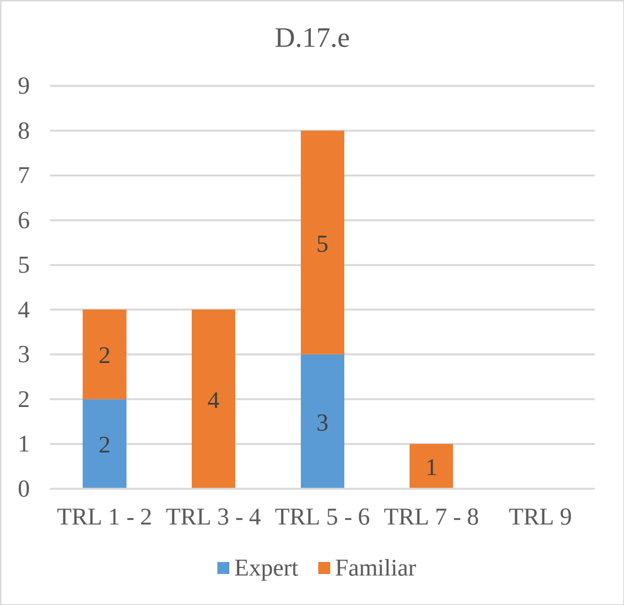
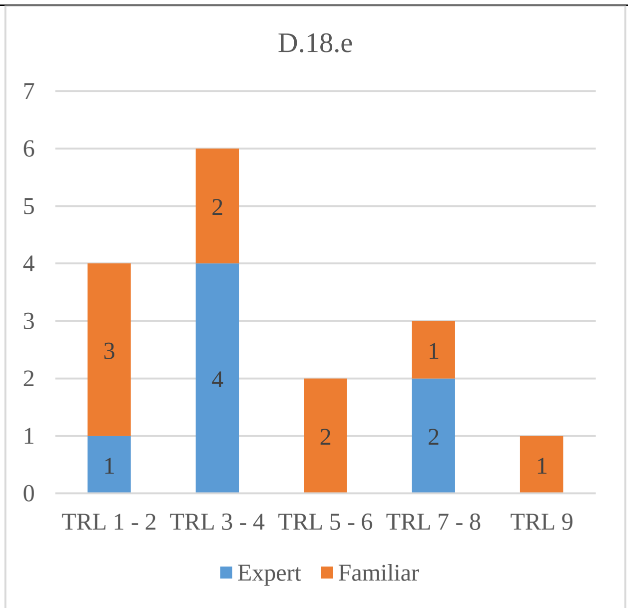
Delphi Statement	Maturity Level
D17: Virtual, augmented, and mixed reality technologies are being used effectively to plan, conduct, review for UAV missions and crew/tactical training.	
D18: Interoperability of UAVs with different types of platforms (e.g. UGV/UMV, manned systems, wearable computers) has been ensured.	

Table F.2 *(continued)*

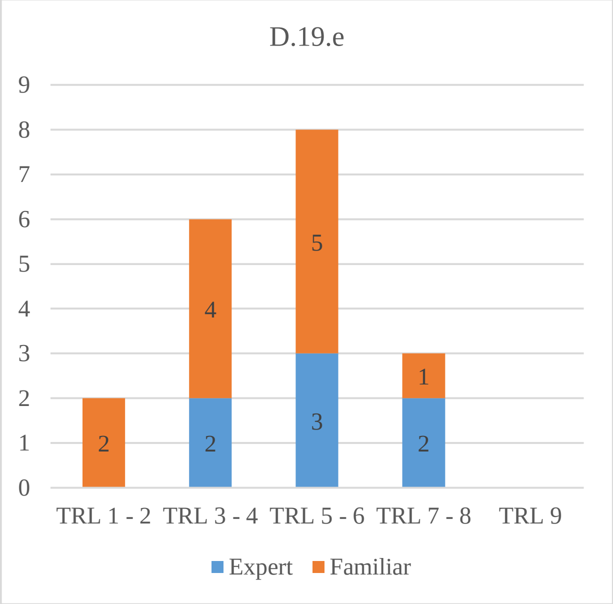
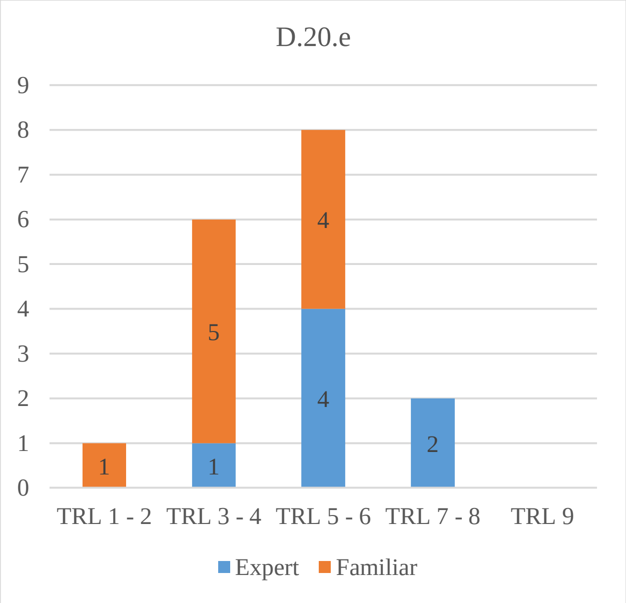
Delphi Statement	Maturity Level
D19: Fully autonomous scalable swarming has been ensured.	
D20: Anti-UAV system has been developed for detection, identification, classification, monitoring, and disposal of all threats through UAVs.	

Table F.3

Realisation Time Frame of Delphi Statements from Respondents' Perspective in Second Round

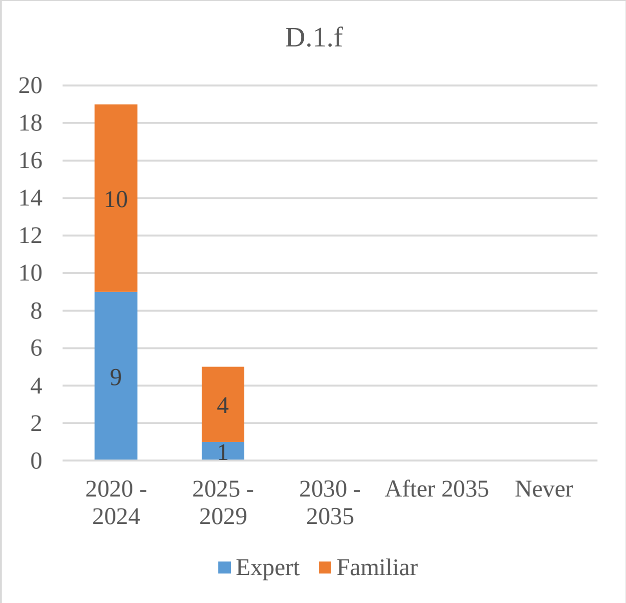
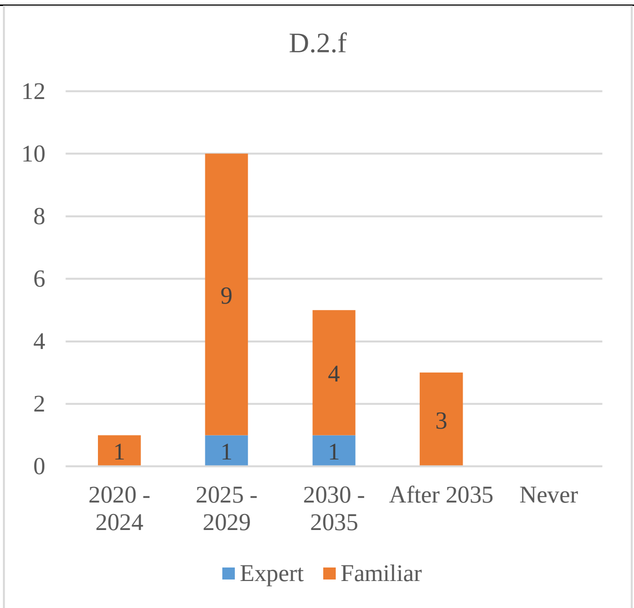
Delphi Statements	Time Frame
D1: Intelligent systems have been developed to monitor and control for Unmanned Aerial Vehicle (UAV) and payloads.	
D2: Such as brain signals, speech recognition based control systems that will increase the human-machine collaboration have been developed.	

Table F.3 *(continued)*

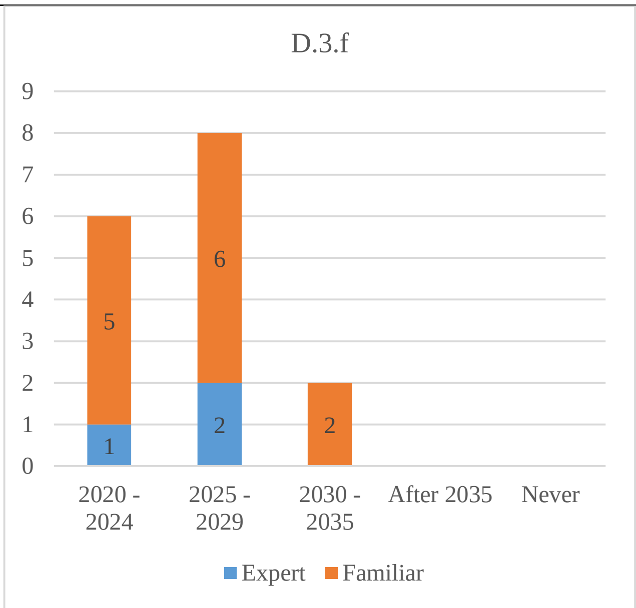
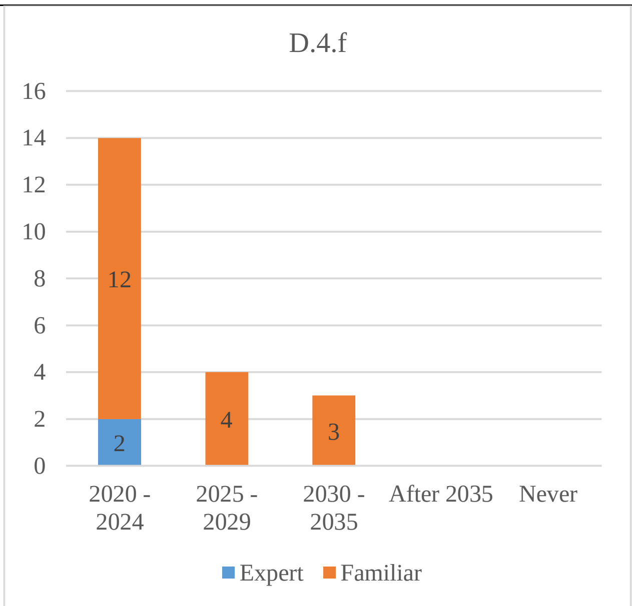
Delphi Statements	Time Frame
D3: Autonomous air traffic management system which ensures airspace integration has been developed.	
D4: Data-driven, predictive intelligent production, maintenance systems, and test platforms based on autonomous modelling and simulation have been deployed for UAV and applications.	

Table F.3 *(continued)*

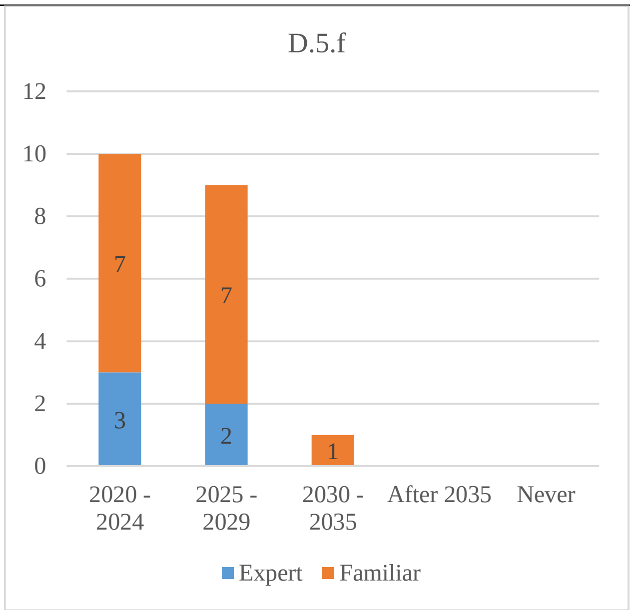
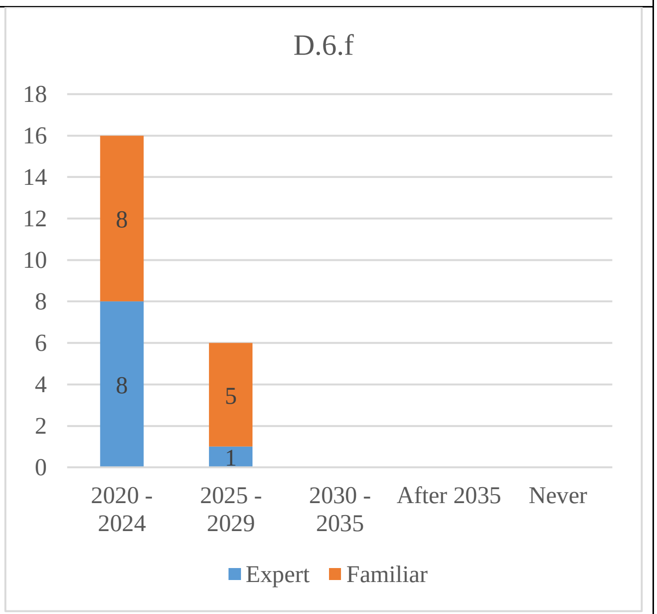
Delphi Statements	Time Frame
D5: Intelligent flight control systems that are resistant to adverse conditions have been developed.	
D6: Intelligent systems have been developed for real-time route planning in all conditions (e.g. GPS denied environments, indoor navigation) during flight.	

Table F.3 *(continued)*

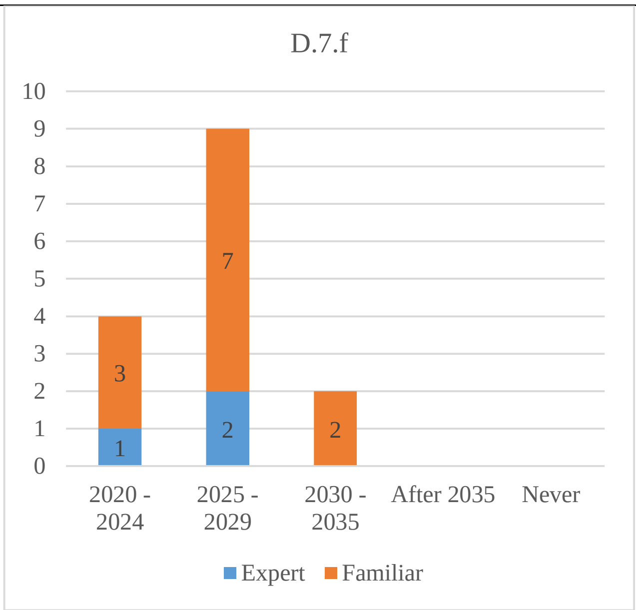
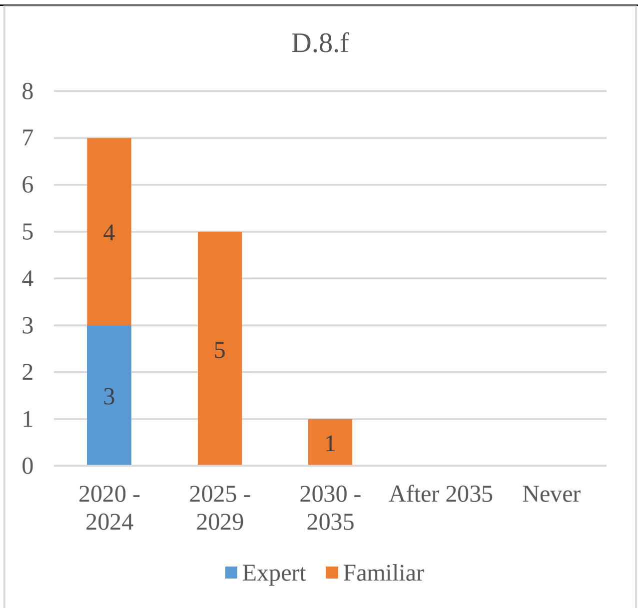
Delphi Statements	Time Frame
D7: All weather-resistant IP-based communication systems which provide robust data links with a high data transfer rate (>100 GB/s) have been possessed.	
D8: Frequency spectrum constraints have been solved technologically.	

Table F.3 *(continued)*

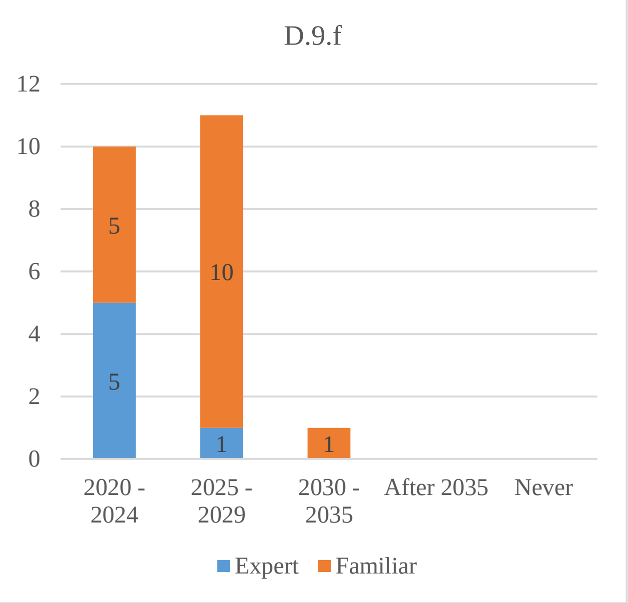
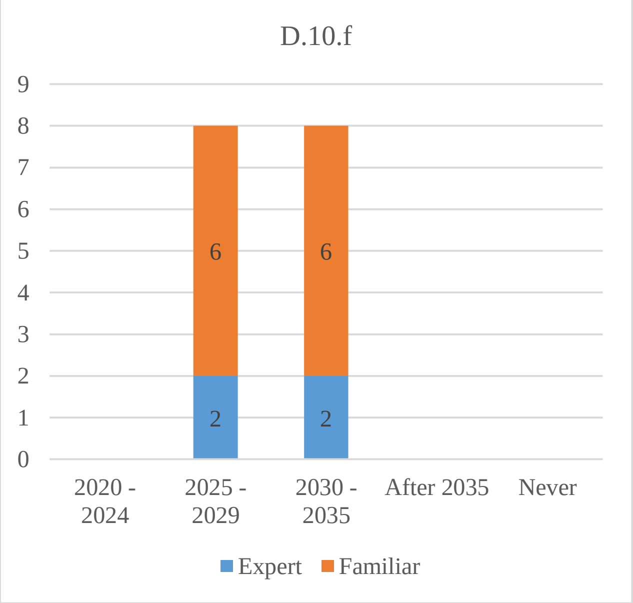
Delphi Statements	Time Frame
D9: Intelligent decision support system which ensures to extract useful knowledge from UAV/other types of platforms/sensor network intense communication data and to react immediately in operation environment has been developed.	
D10: Satellite system which ensures intense communication and high-precision positioning of UAVs with robust, secure, and fast (>100 GB/s) data links has been deployed.	

Table F.3 *(continued)*

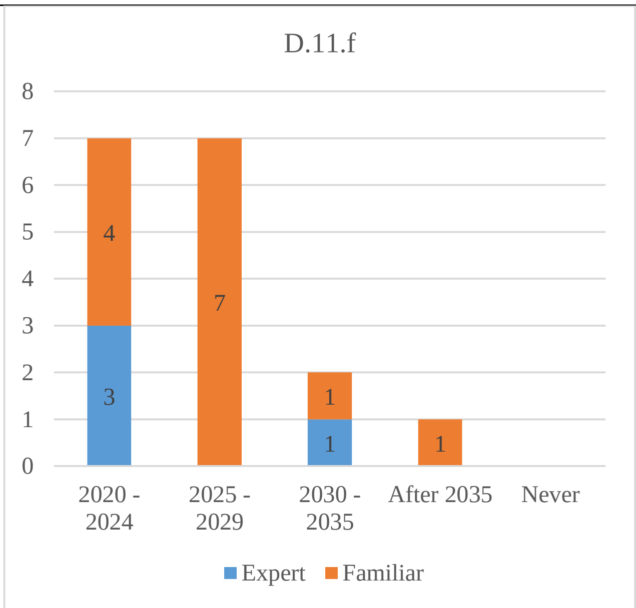
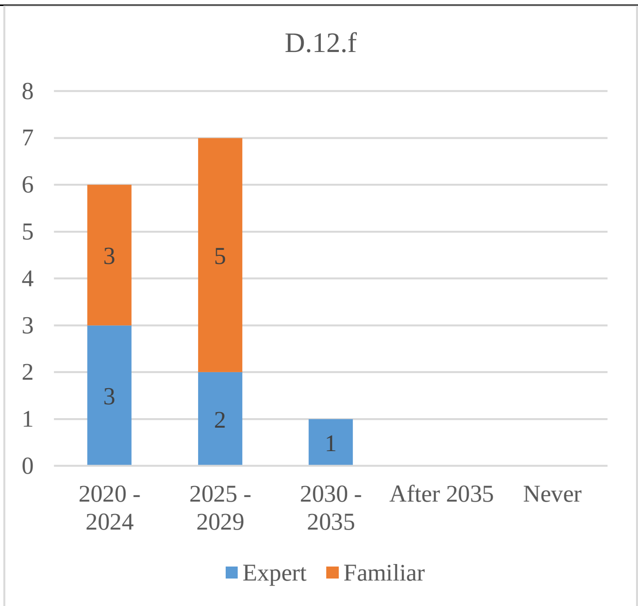
Delphi Statements	Time Frame
D11: Such as smart sensor, micro-electro-mechanical systems (MEMS), robotics payloads which energy-efficient, lightweight, and configurable according to mission have been developed.	
D12: Advanced Electronic Warfare and Information Warfare systems which are providing absolute superiority in warfare environment have been developed.	

Table F.3 *(continued)*

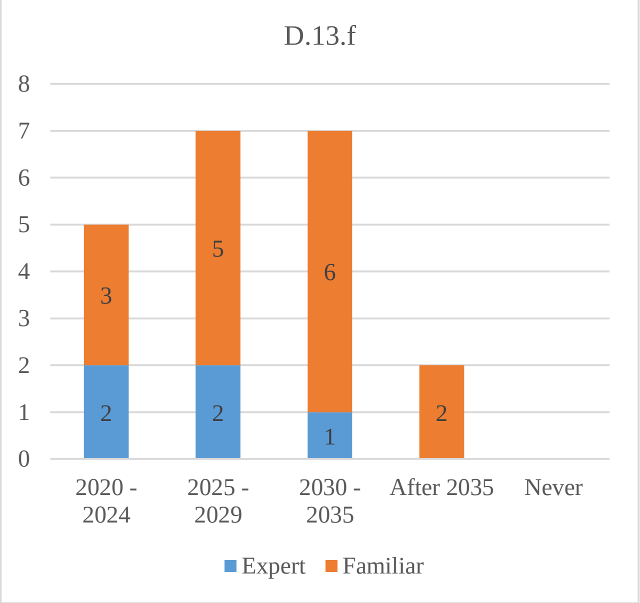
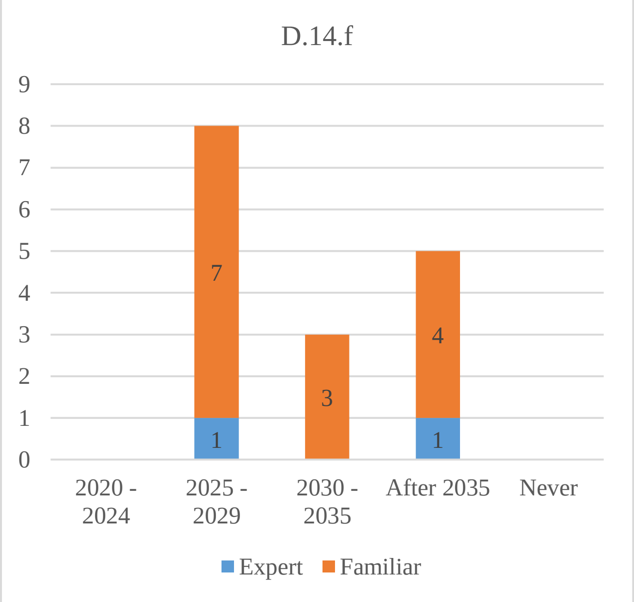
Delphi Statements	Time Frame
D13: Next-generation Artificial Intelligence-enabled weapons and technologies have been obtained.	
D14: Self-growing, morphing, self-healing, and impact/explosive-resistant light material technologies have been developed.	

Table F.3 *(continued)*

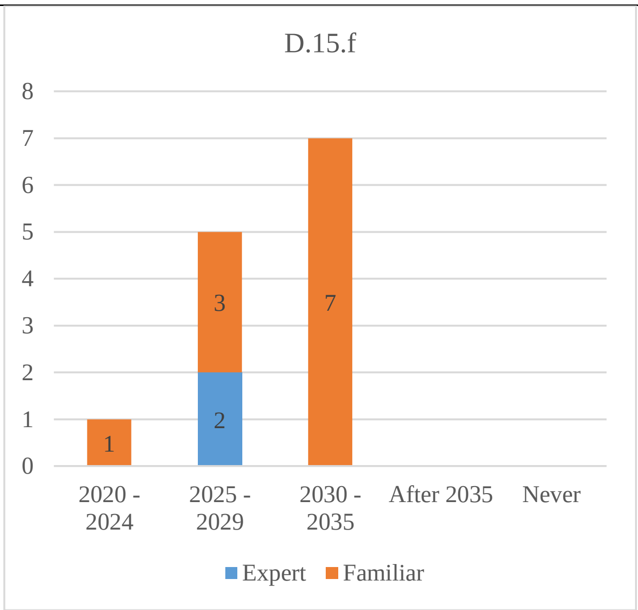
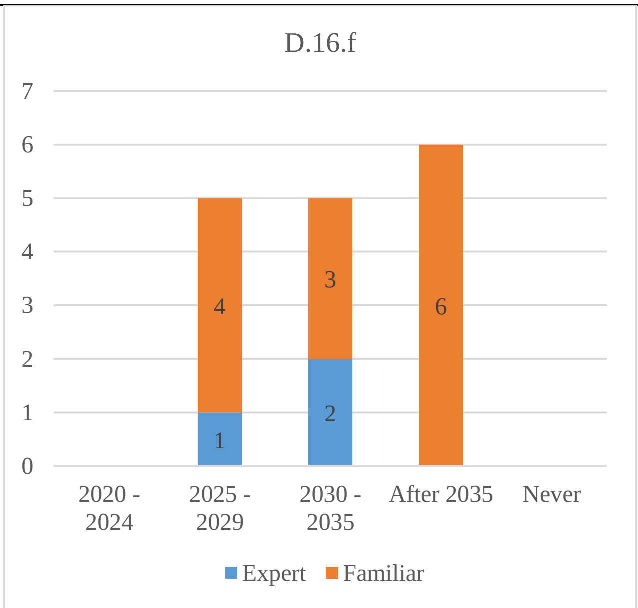
Delphi Statements	Time Frame
D15: Hybrid propulsion systems with very low thermal/acoustic/electromagnetic footprint which were optimized in terms of Size-Weight-Power-Cost (SWaP-C) have been developed.	
D16: Battery with very long endurance (>200 h) providing very high energy density (>100 KWh/kg) has been developed.	

Table F.3 *(continued)*

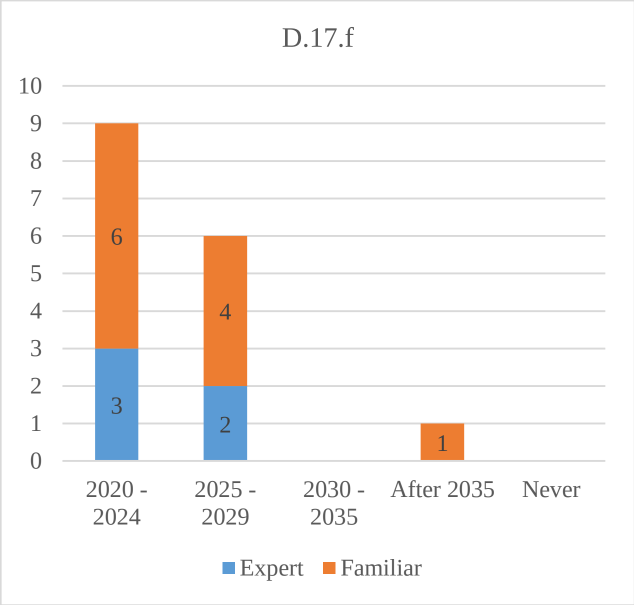
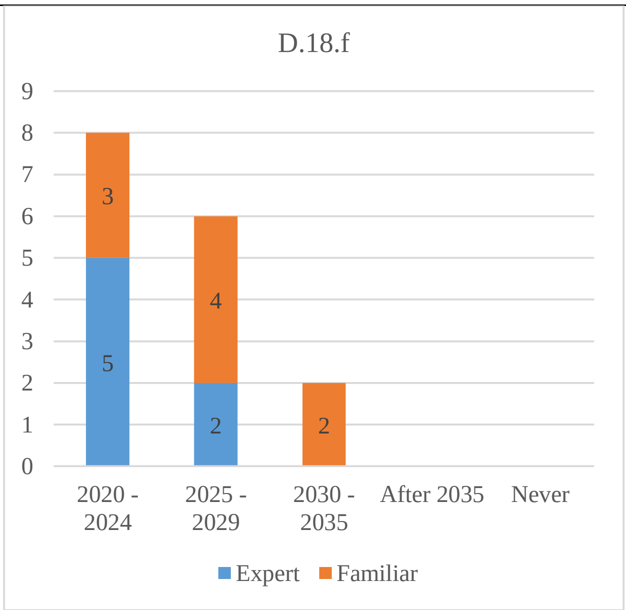
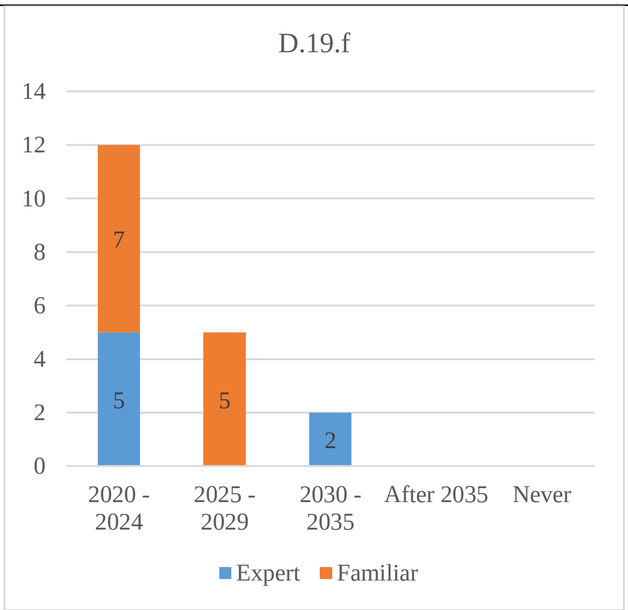
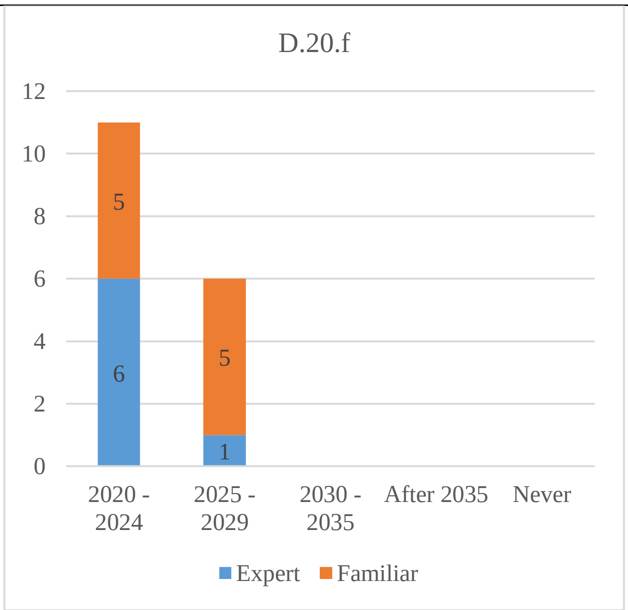
Delphi Statements	Time Frame
D17: Virtual, augmented, and mixed reality technologies are being used effectively to plan, to conduct, to review for UAV missions and crew/tactical training.	
D18: Interoperability of UAVs with different types of platforms (e.g. UGV/UMV, manned systems, wearable computers) has been ensured.	

Table F.3 *(continued)*

Delphi Statements	Time Frame
D19: Fully autonomous scalable swarming has been ensured.	
D20: Anti-UAV system has been developed for detection, identification, classification, monitoring, and disposal of all threats through UAVs.	

G. ETHICS COMMITTEE APPROVAL LETTER

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
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04 EKİM 2019

Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Doç.Dr. Serhat ÇAKIR

Danışmanlığını yaptığınız **Afşar TÜRK'ün "Türkiye'de İnsansız Hava Aracı Teknolojilerinin, Olgunluğu ve Yol Haritası İçin Bir İnceleme"** başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülmüş ve **334 ODTÜ 2019** protokol numarası ile onaylanmıştır.

Saygılarımızla bilgilerinize sunarız.

Prof. Dr. Tülin GENÇÖZ
Başkan

Prof. Dr. Tolga CAN
Üye

Doç.Dr. Pınar KAYGAN
Üye

Dr. Öğr. Üyesi Ali Emre TURGUT
Üye

Dr. Öğr. Üyesi Şerife SEVİNÇ
Üye

Dr. Öğr. Üyesi Müge GÜNDÜZ
Üye

Dr. Öğr. Üyesi Süreyya Özcan KABASAKAL
Üye

H. CURRICULUM VITAE

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EDUCATION

Degree	Institution	Year of Graduation
MS	Çankaya University, Electronics and Communication Engineering	2010
MS	Ahmet Yesevi University, Computer Engineering	2006
BS	Ahmet Yesevi University, Computer Engineering	2012
BS	Eskişehir Technical University, Aviation Electrical-Electronics	1999

FOREIGN LANGUAGE

English

PUBLICATIONS

1. Türk, A., Özdoğan, C., and Baykal, Y. "Heating Effect of Electromagnetic Fields on Human Head at GSM Frequencies", Çankaya University 3rd Engineering and Technology Symposium, Ankara, Türkiye, 29-30 April 2010. Çankaya University 3rd Engineering and Technology Symposium Proceedings Book, 326-332, (2010).

ADDITIONAL INFORMATION

Lecturer Experience:

- Introduction to Computer Use, Ahmet Yesevi University, Computer Programming, Management Information Systems, Industrial Engineering Departments, 2006-2007, 2007 - 2008.
- Information Systems and Technologies, Ahmet Yesevi University, Industrial Engineering Department, 2005-2006.

I. TURKISH SUMMARY/TÜRKÇE ÖZET

Giriş

İnsansız Hava Araçları (İHA)'lar teknolojiye dayalı olarak İHA'ların insanlı hava araçlarına, uydulara ve benzer sistemlere göre daha etkin, verimli, sürdürülebilir ve emniyetli çözümler sunması ve artan ihtiyaçlar nedeniyle sivil ve askeri alanda daha fazla kullanılmaya başlanmış olup, İHA endüstrisinde küresel rekabet giderek artacaktır. İHA'lar Ar-Ge, doğal afetler, arama ve kurtarma operasyonları, sınır gözetimi, hassas tarım, askeri görevler, deniz karakol, trafik izleme, medya, fotoğraf ve film çekimi, kritik altyapı izleme, yapı inceleme ve teşhis, lojistik, haritacılık ve fotogrametri, çevre ve iklim izleme ve arkeoloji gibi çok fazla alanda kullanılabilir. İHA'lar için farklı alanlarda yeni uygulama fırsatları her zaman mevcuttur. VNTSC (2013) askeri ve sivil alanda İHA'lar ile gerçekleştirilen operasyonların sayısının insanlı hava araçlarıyla gerçekleştirilen operasyonların sayısını 2035 yılına kadar geçeceğini tahmin etmektedir. Türkiye jeopolitik konumu ve ABD'den tedariklerde teknoloji transferi engeli ile gelecek on yıl için dört milyar ABD doları karşılığı gereksinimi vardır ve bu gereksinimi karşılamak için yurt içi endüstrisini geliştirmeye çalışmaktadır (Hayward, 2013). İHA en temel sekiz yükselen teknoloji alanı arasında gösterilmektedir (Quindazzi, 2016; Eckert, 2016).

Türk İHA endüstrisinin nasıl geliştirilebileceği üzerinde çalışılmalıdır, teknoloji öngörüsü yapılmalıdır, iyileştirme önlemleri araştırılmalıdır.

Bu çalışmanın amaçları Türk İHA endüstrisinin sorunlarını, ihtiyaçlarını ve gelecek için yapılması gerekenleri incelemek, İHA teknolojilerinde seçilen bir alanda teknoloji yol haritası geliştirmek, Türk İHA endüstrisinin yetkinliklerinin olgunluk düzeylerini değerlendirmek için prensipleri ortaya koyan bir olgunluk modeli önermektir.

Bu tezin çıktıları Devlet, İHA firmaları, Teknoloji Geliştirme Bölgeleri/Teknoparklar, araştırma enstitüleri, üniversiteler ve yatırımcılara yönelik çıkarımlar sunmaktadırlar. Dolayısıyla tezin çıktılarının potansiyel kullanıcıları da sayılan aktörlerdir. Bu çalışma bütüncül ve kapsamlı yaklaşımı ile literatür ve Türk İHA endüstrisi için önem arz etmektedir.

İHA Kavramı

Bir İHA onboard insan pilot olmaksızın çalışan bir hava aracıdır. Onboard pilotsuz uçan füzeler dışında çeşitli tip hava araçları vardır. Bunlar İHA, İnsansız Uçak Sistemi (UAS), Uzaktan Pilotlu Uçak Sistemi (RPAS) ve Dron. Dron terimi 1936'da ABD Deniz Kuvvetleri tarafından başlatılan hedef hava aracı projesinin adı olarak seçilmiştir. Daha sonra Dron terimi hedef hava araçlarının genel adı olarak kullanılmaya başlanmıştır. 2011 yılında ICAO tarafından tam otonom olan İHA sistemleri sınırlandırılarak RPAS terimi belgeye girdi. Literatürde UAS terimi kullanılmaktadır bazen, Bir UAS gövde, itki, navigasyon, uçuş kontrol, haberleşme sistemi, yer kontrol istasyonu, faydalı yükler gibi alt sistemleri olan bir sistemdir (Fahlstrom ve Gleason, 2012; Karaağaç, 2016). Bu tezde, İHA terimi bütün alt sistemleri kapsayacak şekilde ele alınmaktadır ve İHA terimi kullanılmaktadır.

Tarihsel Perspektif

"Uçan makine" fikri ilk olarak yaklaşık 2500 yıl önce eski Yunanistan ve Çin'de ortaya çıkmıştır. İlk rapor edilen otonom uçan makine Arkitas'a atfedilir (Valavanis, Vachtsevanos ve Antsaklis, 2007). Milattan önce 425'de Arkitas "uçan güvercin" adı verilen mekanik bir kuş yaptı. Cornelius Gellius'a göre güvercin tahtadan yapılmıştı, karnında kapalı durumdaki havayı (muhtemelen buhar) kullanarak uçuyordu (Gellius, 1927'den akt. Dalamagkidis, Valavanis ve Piegl, 2012). Arkitas'ın güvercininin bütün enerjisini kullanana kadar yere düşmeden önce yaklaşık 200 metre yükseklikte uçtuğu belirtilir. Güvercin, mekanizması resetlenmeden tekrar uçamıyordu. Aynı dönemlerde yaklaşık milattan önce 400'de Çinliler ilk dikey uçan hava aracı fikrini dokümante ettiler. Bunu uygulamak için ucunda kuş tüyleri olan bir çubuğu ellerin arasında yeterince döndürerek serbest uçuşa bıraktılar. 1483'de Leonardo Da Vinci, "hava vidası" adı verilen havada asılı kalma yeteneğine sahip bir hava aracı tasarladı. Bu makinanın bugünkü helikopterin atası olduğu yorumlanır (Hiller Aviation Museum, 2004'den akt. Dalamagkidis, Valavanis ve Piegl, 2012). 1916'da ilk İHA Hewitt-Sperry üretildi (Nonami, Kendoul, Suzuki, Wang ve Nakazawa, 2010).

İHA Sınıfları

İHA'ların sınıflandırılması için farklı yaklaşımlar mevcuttur. Bunların bazıları çalışma kapsamında sunulmaktadır.

- Yüksek İrtifa Yüksek Süre (HALE): 15,000 metrenin üzeri irtifada 24 saatten fazla uçabilirler. Uzun menzilli keşif ve gözetim görevlerini yürütürler.
- Orta İrtifa Yüksek Süre (MALE): 5,000 - 15,000 metre irtifada 24 saat süreyle görev yapabilirler. MALE, HALE ile benzer görevleri yürütürler fakat MALE'ler daha kısa menzilde görev yaparlar.
- Orta Menzil veya Taktik İHA (TUAV): Menzili 100-300 kilometredir. Bu tip İHA'lar HALE ve MALE'ye göre daha küçük ve daha basit sistemlerdir.
- Yakın-mesafe İHA: Yaklaşık 100 kilometreye kadar menzilde görev yürütür.
- Mini İHA (MUAV): Ağırlıkları genel olarak 20 kilogramın altındadır. 30 kilometreye kadar menzilde görev yapıp, elle fırlatılabilirler.
- Mikro İHA (MAV): Genellikle elle fırlatılırlar. Kanatlı versiyonlarının kanat açıklığı 150 milimetrenin altındadır, minyatür kanat yükleri taşırlar ve atmosferik türbülanslardan daha çok etkilenirler.
- Nano İHA (NAV): Radar karıştırma gibi görevler için sürü formunda kullanılırlar. Kamera, itki, haberleşme alt sistemleri yeterince küçük imal edilebilirse, kısa mesafeler için keşif görevi gerçekleştirebilirler.
- Dikey Kalkan İHA (VTUAV): Dikey kalkış ve iniş yapma, havada asılı kalma gibi operasyonel üstünlükleri vardır.
- İnsansız Savaş Hava Aracı (UCAV) ve İnsansız Savaş Silahlı Rotorkraft (UCAR): UCAV'lar bomba, füze ve lazer tabancası gibi silahlar taşırlar. UCAV'lar yaygın bir şekilde keşif, gözetim, hedefe ateş, istihbarat toplama, lazerle hedef işaretleme ve saldırı sonrası hasar değerlendirme gibi görevlerde kullanılır. UCAR, DARPA ve ABD ordusu tarafından yürütülen bir ileri teknoloji geliştirme programıdır. UCAR silahlı keşif ve saldırı görevlerini yürütür.
- Balon destekli İHA ve Hava Gemisi İHA: Bu özel tasarım tipi havadan hafif sistem veya hava gemisidir. Bu İHA'lar diğer sistemlere göre oldukça büyük boyutlarıyla çok yüksek uçuş süresine sahiptirler ve düşük hızlarda uçarlar. Bu avantaj onları hava sensörü platformuyla daimi alan gözetleme gibi çeşitli görevler için ideal yapmaktadır (Austin, 2010; Nonami, Kendoul, Suzuki, Wang ve Nakazawa, 2010).

Başka bir sınıflandırmada İHA'lar dört kategoride değerlendirilmektedir (Limnaios, Tsourveloudis ve Valavanis, 2012).

- Sabit-kanat İHA'lar: Kalkış için piste gereksinim duyarlar. Uzun süre uçabilirler ve yüksek hızda izleme görevi yapabilirler.
- Döner-kanar İHA'lar: Dikey olarak kalkış ve iniş yapabilirler, piste ihtiyaç duymazlar. Havada asılı kalma ve yüksek manevra yeteneklerine sahiptirler. Bu yetenekler onları robotik işler, belirli bir alan izleme, dağıtım hizmetleri gibi görevler için uygun hale getirir.
- Zeplinler: Genellikle düşük hızda hareket eden balonlar, hava gemileri gibi havadan daha hafif olan ve uzun süre havada kalabilen büyük İHA'lardır. Uzun süreli görevler için ağır faydalı yükler taşıyabilirler.
- Hibrit veya değiştirilebilir tasarımlar: Diğer kategorilerin bir karışımı olarak tasarlanan sistemlerdir.

NATO'nun ağırlık, irtifa, menzil ve uçuş süresine göre Sınıf I, Sınıf II ve Sınıf III olarak sınıflandırılmaktadır. SHGM (2016) tarafından yayınlanan SHT-İHA'ya göre İHA'lar 500 gram (dâhil) – 4 kilogram arası İHA0, 4 kilogram (dâhil) – 25 kilogram arası İHA1, 25 kilogram (dâhil) – 150 kilogram arası İHA3 ve 150 kilogram ve üzeri İHA4 olarak sınıflandırılır.

İHA Teknolojileri

Minimal olarak, tipik bir İHA sistemi bir hava aracı, Yer Kontrol İstasyonu (YKİ), faydalı yükler ve veri bağlantısından oluşur. Ayrıca, bazı sistemler fırlatma ve kurtarma alt sistemleri, hava aracı taşıyıcıları ve diğer yer hizmetleri ve bakım ekipmanlarını içerir.

Hava aracı, sistemin gövde, itki, uçuş kontrol ve elektrik güç sistemlerini içeren havadaki kısmıdır. Hava veri terminali hava aracına monte edilmiş halde olup haberleşme veri linkinin havadaki bileşenidir. Faydalı yükler de hava aracına monte edilmiş olsa da bağımsız sistemler olarak ayrı değerlendirilir. Hava aracı sabit-kanat, döner-kanat, kanal içi pervane ve hibrit olabilir. Hava gemileri ve balonlarda İHA olarak değerlendirilirler.

YKİ: YKİ, hava aracından gelen video, komut ve telemetri verilerinin işlendiği ve görüntülendiği İHA sisteminin operasyonel kontrol merkezidir.

Faydalı yükler: Faydalı yük terimi, bir operasyonel görevi yerine getirmek için İHA'ya eklenen ekipmanı, yani genel İHA'nın bir platform ve ulaşım sağladığı ekipmanı açıklar. Faydalı yük terimi, sensörler, keşif, gözetim, haberleşme, Elektronik Harp (EH) gibi görevleri gerçekleştiren silahlar gibi belirli sistemleri kapsar (Fahlstrom ve Gleason, 2012).

Dünya'daki İHA Çalışmaları

Dünya'daki çalışmalar uygulama alanları, endüstrinin büyümesi önündeki engeller, İHA'ların hava sahasına entegrasyonu ve regülasyon konuları yönüyle incelenmiştir.

İHA'ların hava sahasında emniyetli bir şekilde navigasyon yapmasını sağlayan sistemler için frekans spektrumu gereksinimi önemlidir. Frekans spektrumu kıt bir kaynaktır çünkü bütün askeri ve sivil hava araçları tarafından paylaşılmaktadır ve ITU'nun regülasyonlarına dayalı olarak tahsis edilmektedir. Frekans spektrumunun elverişliliği İHA uygulamalarının büyümesi için önemli bir etkendir. İHA'lar halen ayrılmış hava sahalarında operasyon yürütmektedir, İHA'ların Avrupa hava sahasına entegrasyonu konusunda Avrupa Havacılık Emniyeti Ajansı (EASA) çalışmalar yürütmektedir.

İHA operatörlerini kapsayacak şekilde uygulamalardaki risklere yönelik sigorta düzenlemeleri çözülmesi gereken bir konu olarak durmaktadır (AB, 2012).
İHA endüstrisi için bir başka önemli konu da gizlilik ve veri güvenliğidir. Gizlilik ve veri güvenliğine etki eden bazı İHA sistemleri şu şekildedir:

- Görüntü kaydetme cihazları: İHA'lar görüntüleme koşullarından bağımsız bir şekilde ve yüz tanıma özelliğine de sahip video, resim, ses kaydetme ve iletme yeteneğine sahip faydalı yükler taşıyabilir.
- RF cihazlar: İHA'lara Wi-Fi erişim noktalarını veya hücresel baz istasyonlarını dinleme özelliğine sahip cihazlar monte edilebilir.
- EO, termal kamera, IR tarayıcı, SAR gibi sensörler duvar, duman veya diğer tür

engellerin arkasından herhangi bir nesneyi tanımak ve konum gibi bilgilerini elde etmek için kullanılabilir (CSA, 2016).

Toplum kabulü İHA teknolojilerinin yayılmasına etki etmektedir. İnsanlar, çoğunlukla askeri operasyonlara kullanılması nedeniyle halen İHA'lar konusunda endişelidir. Sivil İHA uygulamaları için politika geliştirme süreçlerine paydaşlar tarafından katılım ve şeffaflık sağlanmalıdır.

Pek çok alanda olduğu gibi İHA'lar da öncelikle askeri amaçla kullanıldı ve askeri uygulamalarda hâlihazırda çözülmüş konuların sivil alana aktarımı yapılması ve tekrarlı çalışmaların engellenmesi gereklidir.

De Garmo (2004) İHA'ların sivil hava sahasına entegrasyonu için gerekli konuları ortaya koyan bir çalışma gerçekleştirmiştir.
Bu konular:

- Emniyet: Çarpışma önleme, sistem güvenilirliği, insan faktörü, hava durumu.
- Güvenlik: Yer altyapısı, haberleşme sinyal güvenliği, veri güvenliği.
- Hava trafik: Hava Trafik Yönetimi, sistem birlikte çalışabilirliği, bilgi ağları, haberleşme, navigasyon, ekipmanlar, acil uçuş kurtarma, hava sahası entegrasyonu, yüzey (pist) operasyonları.
- Regülasyon: Tanımlama ve sınıflandırma şemaları, standartlar, regülasyonlar, uçuşa elverişlilik sertifikasyonu, pilot sertifikasyonu.
- Sosyo-ekonomik: Sigorta, toplum kabulü, devlet yatırımları, pazar, işgücü ve kullanıcılar.

İHA'lar geleneksel insanlı hava araçlarından farklı olduğu için yerleşim bölgelerindeki hava sahasına entegrasyonu için risk yönetiminde düşünülmesi gereken konular mevcuttur. Bunları bazıları:

- Teknoloji: Karmaşık sistemler, C2 link kaybı, otonom İHA'ların güvenilirliği gibi teknoloji konuları.
- Operasyon ortamı: Örneğin ideal olmayan hava koşulları, yüksek irtifalardaki görevler, yüksek düzeyde şehirleşmenin olduğu veya çok yüksek binaların olduğu

yoğun bölgelerdeki operasyonlar üzerinde özel olarak düşünmek ve önlemler geliştirmek gereklidir.

- Performans: İHA'ların tırmanma hızı, uçuş süresi gibi performans ve yetenekleri belirlenmelidir.
- İnsan faktörü: Operasyonel rollerin, insan-makine etkileşimi konuları ve insanın emniyet üzerindeki etkisi gibi karmaşık konular çalışılmalıdır.
- Güvenlik: İHA istenmeyen unsurlardan hackleme veya araya girme gibi siber güvenlik konularına maruzdur (Pathiyil, Low, Soon ve Mao, 2016).

Alsalam, Morton, Campbell ve Gonzalez (2017) hassas tarım uygulamaları için bilgisayarla görme tekniğini kullanan jenerik bir sistem tanımlamışlardır. Bilgisayarla görme fonksiyonu İHA'ya daha yakından teşhis yapma, ilaçlama operasyonları, daha yüksek çözünürlükte tarımsal görüntü toplama gibi amaçlarla uçuş yolunu uygun bir şekilde değiştirebilmesini sağlamaktadır. Gerçekleştirdikleri testler sistemin hedefini dinamik bir şekilde değiştirebildiğini ve hedefi tespit ettikten sonra gerekli manevrayı gerçekleştirebildiğini göstermiştir. Görme temelli navigasyon ve onboard karar verme yetenekleri bu testlerde gösterilmiştir. Bununla birlikte yabani ot tespitinin güneş açıcı ve mevsimsel değişkenlikler gibi faktörlerden etkilenen belirli özelliklere dayandığını ve bu nedenle mevcut tespit yönteminin modifiye edilmesinin günün farklı zamanlarında ve büyümenin farklı aşamalarında daha doğru tespit yapılmasını sağlayacağını belirtmişlerdir.
Tespit yönteminin iyileştirilmesi için önerileri şu şekildedir:

1. Mikro multispektral ve hiperspektral kamera kullanmak,
2. Daha hassas yabani ot tespiti için algoritmaları eğitmek amacıyla yüksek miktarda veri toplamaya dayalı derin öğrenme gibi makine öğrenmesi tekniklerini kullanmak.

Boeing, Lockheed Martin, UPS, FAA, US Department of Homeland Security gibi çok katılımcılı bir ekibin hazırladığı, Afet Müdahale ve Yardım Operasyonları için Dronlar (2015) raporunda felaketlerin öncesinde ve sonrasında İHA'ların kullanılması için insani, emniyet ve ekonomi ile ilgili gerekçeler sunulmuştur. Rapora göre İHA'lar felaket durumlarında:

- Gözetim ve haritalama,
- Yapıların değerlendirilmesi,
- Geçici altyapı,
- Yangın tespit ve söndürme,
- Yüksek bina yangınları,
- Kimyasal, Biyolojik, Radyolojik, Nükleer ve Patlayıcı (KBRNP) olaylar,
- Arama ve kurtarma operasyonları,
- Lojistik destek.

İHA teknolojileri felaketlerde harcanan çabaları ve maruz kalınan riskleri, tehlikeleri düşürebilir. Örneğin Fukushima Daiichi nükleer santralinde nükleer radyasyonu ölçmek için İHA'lar kullanılmıştır. Bu İHA'lar çok daha yakından uçarak ölçüm yapabilmişlerdir. İHA'lar felaket durumlarında çok iyi durumsal farkındalık sağlarlar. İHA teknolojisi maliyet etkin ve yüksek kullanılabilirliktedir. Döner-kanat İHA'lar bir piste ihtiyaç duymaksızın çeşitli zeminlerden kalkış gerçekleştirebilirler.

Türkiye'deki İHA Çalışmaları

Türkiye'de yerli İHA geliştirme girişimleri, tez çalışmaları ve Türk firmaları tarafından geliştirilmiş platformlara örnekler sunulmuştur.

İHA-X1 (1989-1992) Türkiye'nin ilk İHA projesidir. İHA-X1 başlangıçta herhangi bir stratejik amaç güdülmeden yeni ortaya çıkan bu teknolojiye uyum sağlamak için girişilmiş bir projedir. İHA-X1 projesi çerçevesinde iki prototip hazırlandı ve ikisinin de uçuş testleri gerçekleştirildi. Uçuş testleri 1992 yılı ilkbaharında Sivrihisar'da başladı ve yazın Denizli-Çardak'ta devam etti. 1992 sonbaharında Afyon'da bir meydan uçuşunun ardından proje tamamlandı (Kaynak, 2018).

TAI, İHA-X1 projesinden sonra çeşitli İHA projeleri yürüttü. Turna ve Keklik hedef İHA projeleri, pilot eğitimi bazı testlerde kullanılan Baykuş ve Pelikan İHA projeleri, kıyı erozyonunu izlemek için geliştirilen Martı, kısa mesafe keşif-gözetim, istihbarat faaliyetleri için geliştirilmiş Gözcü İHA projeleri bunlardandır.

2004, Türk İHA endüstrisinin yolunun değiştiği bir yıl olmuştur. SSM, İHA tedariği konusunda tek yetkili kurum olarak belirlenmiş, acil ihtiyaçlar dışında yurt dışından alım yapılmamasına karar verilmiş, milli tasarım ve geliştirme projelerine önem verilmeye başlanmıştır.

SSM, Türkiye'nin gereksinimlerini mini İHA, taktik İHA ve MALE olarak tanımlamış ve bu her sınıftan projeler başlatılmıştır. TAI geçmişten gelen deneyimi düşünülerek MALE sınıfı İHA geliştirmekle görevlendirilmiştir. Bu karara uygun olarak taktik sınıfta Çaldıran Kale Kalıp-Baykar ve Karayel Vestel Savunma tarafından geliştirilmiştir.

Baykar tarafından dikey kalkış-iniş yapabilen bir mini İHA geliştirilmiştir. Vestel savunma bir mikro İHA olan Arı ve mini İHA olan Efe'yi geliştirmiştir.

Bu dönemde üniversitelerin de çalışmaları olmuştur. ODTÜ bir mini İHA olan Güventürk'ü geliştirdi ve başarıyla uçurdu. İstanbul Teknik Üniversitesi döner-kanat İHA sistemleri üzerine tasarım ve prototip geliştirme çalışmalarında bulundu. Ayrıca pek çok üniversite, enstitü ve organizasyon İHA sistem ve alt sistemleri geliştirme çalışmaları yürütmektedir (Altunok, 2010).

Türkiye'de İHA konusunda yüksek lisans ve doktora düzeyinde hazırlanmış ve erişime açık olan tezler incelenmiştir. Tezlerde en çok incelenen konular; 46 tezde uçuş kontrol sistemi, 29 tezde İHA tasarımı/uygulaması, 25 tezde İHA uygulamaları (en fazla fotogrametri), 13 tezde rota planlama ve dokuz tezde otopilot olmuştur.

Birden fazla konuyu kapsayan tezler en yakın olduğu konuya göre değerlendirilerek kategorilendirilmiştir. İnceleme bu haliyle büyük resmi gösterecek durumdadır.

Tezlerde otonomi, sürü zekası, birlikte çalışabilirlik, sensör füzyonu ve insan-makine işbirliği konuları daha fazla çalışılmalıdır. Tez çalışmalarının, endüstri uygulamalarına dönüşümü sağlanmalıdır. Bu amaçla üniversiteler ve endüstri uzun dönemli bir işbirliği içerisinde çalışmalıdır.

Teknoloji Yol Haritası

Petrick ve Echols (2004) teknoloji yol haritasını, organizasyonların daha bilinçli karar vermesini sağlayan, zaman ve kaynak israfını engelleyen ve teknoloji alanlarında karar verme risklerini azaltan bir araç olarak tanımlar.

Phaal, Farrukh ve Probert (2004) teknoloji yol haritasını teknoloji yönetimini ve planlamayı destekleyen ve kaynaklar, organizasyonel amaçlar ve çevresel değişimlerinin dinamik etkileşimlerini ortaya çıkaran yararlı bir araç olarak tanımlamaktadır.

Teknoloji yol haritası mimarisi genel olarak dört boyut içerir:

- Zaman: Yıllık veya gereksinimlere dayalı belirli bir zaman aralıklarına göre periyotlar kullanılabilir.
- Katmanlar: Teknoloji yol haritasının dikey ekseninin oluştururlar ve çok kritiklerdir. Bu katmanlar istenen stratejik planlamayı (piyasa, ürünler, uygulamalar, teknoloji, yetenekler, bilgi, Ar-Ge projeleri gibi) oluşturacak şekilde tanımlanmalıdır.
- Açıklamalar: Katmanlardaki nesneler arası bağlantılar, notlar, karar noktaları gibi bileşenleri içerir.
- Süreç: Teknoloji yol haritasını tamamlamak için gerekli adımları içerir (Phaal, Farrukh ve Probert, 2004).

Amaca göre aşağıdaki tiplerde teknoloji yol haritası tanımlanabilir:

1. Ürün planlama: En çok kullanılan teknoloji yol haritası tipidir. Teknolojinin ürünlere uygulanması ile ilgilidir.
2. Servis/yetenek planlama: Servis odaklı kurumlar için daha uygun olup, teknolojinin organizasyonel yetenekleri nasıl destekleyebileceğine odaklanır.
3. Stratejik planlama: Teknoloji yol haritası pazarlar, iş, ürünler, teknolojiler, yetenek, kültür yönüyle belirlenen boşluklar için gelecek vizyonu tanımlamaya ve bugünkü durumla gelecek vizyonunu kıyaslamaya ve boşlukları köprülemek için stratejik seçenekleri keşfetmeye yoğunlaşır.
4. Uzun dönemli planlama: Bu tip teknoloji yol haritaları sektör veya ulusal düzeyde

potansiyel yıkıcı teknolojileri ve pazarları tanımlamak için kullanılırlar. Uzun dönemli teknoloji planlamaları için kullanılır.

5. Süreç planlama: Belirli bir süreç alanına (örn. yeni ürün geliştirme) yoğunlaşarak bilgi yönetimini destekler.
6. Entegrasyon planlama: Farklı teknolojilerin ürünlerde, sistemlerde veya yeni bir teknoloji formunda nasıl birleştirilebileceği yönüyle teknolojinin entegrasyonuna ve evrimine yoğunlaşır.

Bu çalışmada uzun dönemli planlamayı amaçlayan bir teknoloji yol haritası hazırlanmıştır.

Olgunluk Modeli

Olgunluk modelleri bir yapının bir konuda aşama temelli değerlendirmesini sağlar. Olgunluk modellerinden mevcut ve istenen olgunluk düzeylerini ve atılması gereken adımları içermesi beklenir. Olgunluk modelleri şu amaçlarla kullanılabilir:

- Tanımlayıcı: Olgunluk modeli teşhis edici araç olarak kullanılabilir (Maier, Moultrie ve Clarkson, 2009'den akt. Pöppelbuß ve Röglinger, 2011). Bir olgunluk modeli tanımlanan kriterler altında mevcut yeteneklerin değerlendirilmesi için tanımlayıcı rol sunabilir (Becker, Knackstedt ve Pöppelbuß, 2009'den akt. Pöppelbuß ve Röglinger, 2011).
- Yol gösterici: Bir olgunluk modeli istenen olgunluk düzeylerinin nasıl tanımlanabileceğini göstermek ve gelişme adımları üzerine rehberler sağlamak için yol gösterici rol sunabilir (Becker, Knackstedt, ve Pöppelbuß, 2009'den akt. Pöppelbuß ve Röglinger, 2011).
- Karşılaştırıcı: Bir olgunluk modeli iç ve dış kıyaslama için karşılaştırıcı rol sunabilir. Elde edilen yeterli veri ile benzer yapılar karşılaştırılabilir (de Bruin, Rosemann, Freeze ve Kulkarni, 2005; Maier, Moultrie ve Clarkson, 2009'den akt. Pöppelbuß ve Röglinger, 2011).

Olgunluk modeli kritik tasarım prensipleri şu şekildedir:

- Temel tasarım prensipleri
    - Uygulama alanı ve uygulanabilirlik için ön gereklilikler,

    - Kullanım amacı,
    - Olgunluk ve olgunluğun boyutları,
    - Olgunluk düzeyleri ve olgunlaşma yolu,
    - Mevcut olgunlaşma düzeyi,
    - Gelişme ve değişime ilişkin teorik temelleri desteklemek.
- Tanımlayıcı kullanım için tasarım prensipleri
    - Her olgunluk düzeyi için doğrulanabilir kriterler,
    - Hedef kitle odaklı değerlendirme metodolojisi.
- Yol gösterici kullanım için tasarım prensipleri
    - Her olgunluk düzeyi için iyileştirme önlemleri,
    - İyileştirme önlemlerini seçmek için karar metodolojisi,
    - Hedef grup odaklı karar metodolojisi (Pöppelbuß ve Röglinger, 2011).

Araştırma Yöntemi

Araştırma nitel ve nicel yöntemlerin kullanıldığı karma modelde tasarlanmıştır. Karma yöntem ile nitel ve nicel yöntemlerin sınırlılıkları dengelenir (Creswell, 2008).

Görüşme

Patton (2004)'e göre görüşme "Açık uçlu sorulardan oluşan ve cevaplayanın konu hakkındaki deneyim, düşünce, bilgi ve duygularını elde etmek için kullanılan bir araştırma türüdür."

Görüşme türleri:

- Yapılandırılmamış görüşme: Önceden tanımlanmış soru yoktur. Sorular belirli konularda bir konuşma şeklinde ve bu konuşmayı kaydederek oluşturulur.
- Yapılandırılmış görüşme: Farklı insanlardan aynı türden bilgi edinmeyi amaçlamaktadır. Bu görüşme yaklaşımı görüşme sırasında incelenecek soruların veya konuların bir listesini içerir.
- Yarı-yapılandırılmış görüşme: Bu yaklaşım dikkatlice yazılan ve sıralanan bir dizi sorudan oluşur. Bu sorular her bir görüşmeciye sorulur. Bu yaklaşım görüşmeci öznelliğini artırabilir. Verilen cevaplara göre görüşmenin akışı belirlenebilir.

Bu çalışmada yarı-yapılandırılmış görüşme benimsenmiştir. Yüz yüze veya video konferans yoluyla yapılan görüşmelerde alınan cevaplara göre detaylandırmalara gidilmiştir. Bazı katılımcılarla yüz yüze veya video konferans yoluyla görüşme imkânı olmamış, mail yoluyla yazılı olarak cevap alınmıştır. Belirlenmiş sorulara verilen cevaplar şeklinde kalmıştır.

Delfi Tekniği

Delfi tekniği görüşleri bir grup fikir birliğine doğru birleştirmek için tasarlanmış çok aşamalı bir süreçtir (Grisham, 2009; Hasson ve Keeney, 2011).

Gordon (1994) gerçekleştirilmiş çoğu Delfi çalışmasının 15-35 arası uzman içerdiğini vurgular.

Araştırmanın Güvenilirliği ve Geçerliliği

Bu araştırma, nitel ve nicel yöntemlerin kullanıldığı karma yöntemde tasarlanmıştır. Karma yöntem araştırmalarında veri analizinin özelliklerinden biri, hem nicel verilerin geçerliliğini hem de nitel bulguların doğruluğunu kontrol etmek için izlenen yöntemleri sunma gerekliliğidir.

Tashakkori ve Teddlie (1998), geçerleme prosedürlerinin karma yöntem araştırmalarında hem nicel hem de nitel çalışma aşamaları için kullanılması gerektiğini savunmaktadır.

Yıldırım ve Şimşek'e (2011) göre araştırmacı, elde edilen verileri ve elde edilen sonuçları doğrulamak için bazı ek yöntemler (ör. Veri çeşitleme, katılımcı onayı, uzman onayı) kullanabilir. Geçerlilik dış geçerlilik ve iç geçerlilik olarak ikiye ayrılır:

1. Dış geçerlilik, araştırmada elde edilen sonuçların benzer gruplara veya ortamlara aktarılabilirliğini ifade eder. Başka bir deyişle, dış güvenilirlik, araştırmanın sonuçlarının benzer ortamlarda aynı şekilde elde edilip edilemeyeceğidir.
2. İç geçerlilik, sürecin yeterliliği ile ilgilidir, ardından incelenen gerçekliği ortaya çıkarmak için araştırma sonuçlarına ulaşılır. Yani, iç güvenilirlik, diğer araştırmacıların aynı verileri kullanarak aynı sonuçları elde edip etmeyeceği ile ilgilidir.

Araştırmanın güvenilirliği ve geçerliliği için:

1. Endüstrinin sorunlarına odaklanan mülakatın sorulara ihtiyacı iki uzman tarafından incelenmiştir.
2. Nitel veri toplama aşamasına geçmeden önce iki uzmanla pilot görüşmeler yapılmıştır.
3. Bazı görüşmeler yüz yüze yapılmış, bazıları video konferans yöntemi ile yapılmıştır; e-posta yoluyla bazı katılımcılardan yazılı cevaplar alınmıştır. Yüz yüze görüşmelerde veriler not alma yöntemi ile kaydedilmiş ve daha sonra bu notlar teyit ve düzeltme amacıyla katılımcılara gönderilmiştir. İki katılımcı cevapları güncelleyerek ve geri göndermiştir. Video konferans görüşmeleri katılımcının onayı ile kaydedilmiş ve video kayıtları üzerinden yazıya dökülmüştür.
4. Nitel verilerin analizi (kodlama) uzman görüşleri ile geçerlenmiştir.
5. Nitel analiz sonuçları uzmanlar tarafından geçerlenmiştir.
6. Veri toplama araçları, veri toplama süreci ve analiz aşamaları araştırma süreci bölümünde açıklanmıştır.

Bu araştırmada veri kaynakları ve veri toplama sürecine ilişkin varsayımlar:

- Literatür taramasında bilgi ve kaynakların doğru olduğu varsayılmaktadır.
- Örneklemin popülasyonu uygun bir şekilde temsil ettiği varsayılır.
- Katılımcıların yeterli bilgi ve deneyime sahip olduğu varsayılmaktadır.
- Görüşme ve anketlerdeki cevapların doğru ve objektif olduğu varsayılmaktadır.

Geçerlilik doğrudan uzman seçimi ile ilgilidir, çünkü içerik Delfi çalışmalarında uzman görüşleri kullanılarak oluşturulur (Fish ve Busby, 2005). Patton'a (1987) göre, amaçlı örnekleme, zengin bilgiye sahip olduğu düşünülen durumların incelenmesini olanaklı kılar. Panel üyelerinin sahip olması gereken nitelikleri açık bir şekilde tanımlamak ve araştırmanın geçerliliğini sağlamak için bu niteliklere sahip üyeleri seçmek önemlidir (Clayton, 1997).

Bu bağlamda, çalışmada amaçlı örnekleme yöntemlerinden ölçüt örnekleme yöntemi kullanılmıştır. Bu kritere göre; İHA teknolojileri üzerine faaliyet gösteren kurum ve kuruluşlarda çalışanlar, İHA teknolojileri üzerine çalışan akademisyenler katılım için belirlenmiştir. Katılımcılardan Delfi formunu, cevaplayabilecek durumda olan bağlantılarına iletmeleri de istenmiştir.

Delfi çalışmasının ikinci turunda katılımcılara, “Seçtiğiniz olgunluk seviyesinin nedenlerini açıklar mısınız? İlgili teknolojinin geliştirilmesi için önerilerinizi belirtir misiniz?” sorusu yöneltilmiştir. Bu soru ile nitel veri toplanmasına ek olarak, araştırma güvenilirliği için bir kontrol sağlamak amaçlanmıştır.

Araştırmada geçerlik ve güvenilirliğin sağlanmasında kullanılan önemli kriterlerden biri çeşitlemedir (Yıldırım ve Şimşek, 2011). Bu çalışmada, farklı kişi ve ortamlardan farklı yöntemlerle veri toplanarak çeşitleme sağlanmıştır. Çalışmaya katılanlardan elde edilen veriler iki uzman tarafından teyit edilerek de çeşitleme sağlanmıştır.

Olgunluk modelinin örnek bir uygulamasını yapmak için Google Forms platformunda bir anket formu hazırlanarak belirlenen katılımcılara iletilmiş ve cevap verebilecek durumdaki bağlantılarına da iletmeleri istenmiştir. Altı katılımcı ile video konferans yoluyla görüşülmüş verdikleri cevaplar sonrasında araştırmacı tarafından anket formu ile kaydedilmiştir. Anket cevapları IBM SPSS Statistics 22 kullanılarak analiz edilmiş ve Cronbach’ın Alfa katsayısı hesaplanmıştır.

Tüm öğeler için elde edilen Cronbach’ın Alfa katsayısı, bu anketin toplam güvenilirliğini gösterir ve genel kabul olarak bu değerin 0.7 ve daha yüksek olması gerektiğidir.

Olgunluk modelinin geçerliliğini sağlamak için ayrıca henüz olgunluk modelinin geliştirme aşamasında geliştirilen taslaklar üzerinde iki uzman ile nasıl bir olgunluk modelinin daha yararlı ve kullanışlı olacağı konusunda fikir alış verişleri yapılmıştır. Uzman görüşü doğrultusunda olgunluk modelinin geliştirilmesine devam edilmiş, geliştirme tamamlandıktan sonra anket uygulamasına geçilmiştir.

Araştırma Süreci

Türk İHA endüstrisinin sorunlarını, ihtiyaçlarını ve gelecek için yapılması gerekenleri incelemek üzere endüstriden aktörlerle görüşmeler gerçekleştirilmiştir. Ek A'da bulunan sorular katılımcılara yöneltilmiştir. Onüç katılımcı ile yüz yüze görüşmeler gerçekleştirilmiş ve üç katılımcıdan mail yoluyla yazılı cevap alınmıştır.

Yüz yüze görüşmelerde not tutma yöntemiyle kayıt yapılmış, sonrasında katılımcılara gönderilmiş ve iki katılımcı tarafından cevaplar güncellenerek mail yoluyla geri alınmıştır.

MS Excel 2013 uygulaması görüşmelerinden toplanarak oluşturulan nitel içeriğin analizini kolaylaştırmak için bir veri tabanı olarak kullanılmıştır. Katılımcıların her bir soru için verdiği cevap bir Excel hücresine yerleştirilmiştir. Her soruya verilen cevaplar birkaç kez gözden geçirilmiş, durumu en iyi şekilde temsil eden kodlara ulaşmaya çalışılmıştır. Kod, metinde açık veya kapalı kavramları, fikirleri etiketlemek için kullanılır. Farklı katılımcıların benzer görüşleri aynı kodlarla etiketlenmiştir.

Kodların güvenilirliği iki kodlayıcının anlaşmasıyla sağlanır (Campbell, Quincy, Osserman ve Pedersen, 2013). İlk olarak, kodlar araştırmacı tarafından çıkarılmış ve bir uzman tarafından incelenmiştir. Yeniden inceleme ve uzlaşma araştırmacı tarafından yapılmıştır. Kodlama, iki iterasyonda uzlaşmaya varılana kadar gerçekleştirilmiştir.

Kodlar ve tanımları bir tabloda sunulmuştur. Tanımlanan kodlar; finans, dışa bağımlılık, devlet, işbirlikleri, teknolojiler, rekabet, uygulamalar, insan kaynakları ve Teknoloji Geliştirme Bölgeleri/Teknoparklar olmuştur. Nitel çalışmanın güvenilirliği sonuçların uzman görüşü ile geçerlenmesi yapılarak sağlanmıştır.

Türk İHA endüstrisi için teknoloji hedeflerinin belirlenmesi için önce kapsamlı bir literatür taraması yapılarak, teknolojik zorluklar, boşluklar, gelecek trendleri gibi bakış açılarıyla değerlendirmelerle Delfi ifadeleri oluşturulmuştur. Bu Delfi ifadeleri uzman görüşmeleri ve araştırmacının gözden geçirmeleri ile son haline getirilmiştir.

Son haline getirilmiş 20 ifade uzman değerlendirmesine sunmak üzere Delfi çalışmasına başlanmıştır. Google Forms platformunda hazırlanan 20 Delfi ifadesinin içerildiği anket formunun linki 12.02.2020 tarihinde daha önce hazırlanmış olan listede bulunan katılımcılara gönderilmiştir. Katılımcılardan on gün içinde cevap vermeleri ve anket formunun linkini katılabilecek durumda olan bağlantılarına iletmeleri istenmiştir. İlk cevap 12.020.2020'de alınmıştır. On gün içinde yeterli sayıda cevap gelmemiş, bunun üzerine katılımcılara ek süre tanındığı ve formu cevaplayabilecekleri yönünde bir e-mail gönderilmiştir. Son cevap 12.03.2020'de alınmıştır ve form erişime kapatılmıştır. Otuz bir katılımcıdan cevap alınmıştır. Bir katılımcı Delfi ifadelerinin çoğunda sorulara eksik cevaplar vermiştir. Bu nedenle formda belirttiği e-mail adresine eksik cevapları tamamlaması yönünde hatırlatma e-maili gönderilmiş fakat belirlenen süre içinde cevap alınamayınca bu katılımcının cevapları silinmiş ve otuz katılımcının cevapları analize dâhil edilmiştir.

Birinci tur Delfi çalışmasının cevapları virgülle ayrılmış değer (.CSV) formatında Google Forms platformundan indirilmiştir. MS Excel 2013 uygulamasında Veri menü başlığında Metinden veri al seçeneği ile indirilen dosya okutularak veriler MS Excel tablosuna aktarılmıştır. Bu aktarım sonrasında veriler analiz edilmiştir.

İkinci tur Delfi çalışması için her soruda birinci turdaki toplam cevaplar ve her katılımcının kendi cevabı yan yana görünecek şekilde her katılımcı için ayrı anket formu yine Google Forms platformunda hazırlanmış ve birinci turda cevapları analiz edilen 30 katılımcıya ayrı Google Form linki gönderilerek on gün içinde cevaplamaları istenmiştir. İkinci turda ilk cevap 27.03.2020'de alınmıştır. On gün içerisinde yeterli sayıda cevap gelmemesi üzerine katılımcılara ek süre verildiğini ve formu cevaplayabilecekleri bildirilen hatırlatma e-maili gönderilmiştir. 14.04.2020'de alınan cevapla birlikte form erişime kapatılmıştır ve böylece ikinci tur Delfi çalışmasında katılımcı sayısı 24 olmuştur.

Birinci tur Delfi çalışmasındaki aynı yöntemle cevapların olduğu veri seti Google Forms platformundan indirilmiş ve MS Excel 2013 uygulaması tarafından açılarak cevaplar analiz edilmiştir.

İkinci tur cevapları IBM SPSS Statistics 22 uygulaması ile analiz edilmiş ve merkezi eğilim ölçüleri bulunmuştur.

Çalışmanın sonucunda Delfi ifadelerinin tamamı, İHA ve uygulamaları için önemi, Türkiye'nin gelişimine ve rekabet gücüne etkisi ve daha fazla araştırmayı tetiklemesi yönüyle milli teknolojiler için önemi kriterleri için grup uzlaşısı sağlanmış ve ifadeler uzmanlar tarafından Yüksek veya Çok Yüksek düzeyde önemli görülmüştür. Bu yönüyle Delfi çalışması amacına ulaşmıştır.

Hazırlanan Teknoloji Yol Haritası

Delfi çalışmasında değerlendirilen ifadelerden D5, D6 ve D19 birlikte ele alınarak "Olumsuz koşullara dayanıklı İHA sürülerinin zeki uçuş yönetimi" üzerine bir teknoloji yol haritası hazırlanmasına karar verilmiştir. Teknoloji yol haritası için teknoloji alanları araştırmacı tarafından belirlenmiştir. Konu ile ilgili çalışan akademi ve endüstriden uzmanlarla video konferans yoluyla görüşmeler gerçekleştirilmiştir. Bir uzmandan e-mail yoluyla yazılı cevap alınmıştır.

Görüşmelerde şu konulara değinilmiştir:

- İlgili teknoloji alanları,
- İlgili teknolojilerin Türkiye'deki mevcut durumunun değerlendirilmesi,
- İlgili teknolojileri etkileyen faktörler,
- Geliştirme aşamaları,
- Paydaşlar.

Hazırlanan Olgunluk Modeli

Taslak olarak geliştirilen olgunluk modeli iki uzmanla gerçekleştirilen görüşmelerde incelenerek nasıl bir olgunluk modelinin daha yararlı ve kullanışlı olacağı yönünde fikir alış verişleri yapılmıştır. Bu doğrultuda olgunluk modeli geliştirilmiş ve geliştirilen modelin örnek bir uygulamasını yaparak Türk İHA endüstrisini değerlendirmek ve modelin güvenilirlik analizlerini yapmak amacıyla Google Forms platformunda anket formu hazırlanmıştır. Anket linki belirlenen katılımcılara iletilmiş, ayrıca cevaplayabilecek bağlantılarına iletmeleri istenmiştir. Anket formunda katılımcıların iyileştirme önerileri için nitel veri toplamayı amaçlayan sorular eklenmiştir. Bazı katılımcılardan görüşlerini çevrimiçi görüşme ile belirtme talebi gelmiş ve bu katılımcılarla video konferans yöntemiyle görüşmeler gerçekleştirilmiş, katılımcıların cevapları daha sonra araştırmacı tarafından anket formuna kaydedilmiştir. Video konferans yöntemiyle görüşülen uzmanlara modelin geçerliliği de sorulmuş ve olgunluk modeli görüşülen altı uzman tarafından da geçerlenmiştir.

İlk cevap 05.06.2020'de ve son cevap 16.07.2020'de alınmıştır. Daha fazla cevap için bir süre daha beklenmiş ancak yeni bir cevap gelmemiş ve anket formu 21.07.2020'de erişime kapatılmıştır. Alınan 25 cevabın oluşturduğu veri seti Delfi çalışmasında olduğu gibi Google Forms platformundan virgülle ayrılmış değer (.CSV) formatında indirilmiş, MS Excel 2013 içine aktarılarak düzenlenmiş ve düzenlenen veriler IBM SPSS Statistics 22 ile analiz edilmiştir. Olgunluk Modeli uygulaması sonucu Cronbach's Alpha güvenilirlik katsayısı 0.905 bulunmuştur. Bu değerin 0.70'den yüksek olması ve uzman değerlendirmeleri araştırmanın güvenilir ve olgunluk modelinin geçerli olduğunu göstermektedir.

Geliştirilen modelde olgunluk; hava aracı teknolojileri, faydalı yük teknolojileri, güvenli haberleşme teknolojileri, birlikte çalışabilirlik, otonomi ve insan-makine işbirliği boyutlarına dayanmaktadır.

Sonuç

Bu tez Türk İHA endüstrisini yeni bir bakış açısı geliştirerek değerlendirmeyi amaçlamaktadır. Bu amaç doğrultusunda kapsamlı ve özgün bir çalışma gerçekleştirilmiştir. Bununla birlikte çalışmaya katılım beklenen düzeyde sağlanamamıştır. Tüm paydaşların katılımının sağlanması problemlerin daha detaylı bir şekilde tanımlanmasını ve çözüm önerilerine farklı bakış açılarının getirilmesini destekleyebilirdi. Paydaşların çalışmaya katılmak konusundaki isteksizliği olumsuz faktör olmuştur.

Çalışmanın ilk aşamasında Türk İHA endüstrisinin sorunları, ihtiyaçları ve gelecek için yapılması gerekenler incelenmiş, saha araştırması sonundaki bulgular doğrultusunda politika önerilerinde bulunulmuştur.

İHA uygulamaları teşvik edilmelidir: İHA'ların özellikle sivil uygulamalar olmak üzere yeni alanlarda kullanımı sağlanmalıdır. Sivil uygulamalar için regülasyonlar yapılmalıdır, kamu alımları yapılabilir.

Rekabet artırılmalıdır: Endüstriye ne kadar çok firma dâhil olabilirse ve bu firmalar da yenilikçi çözümlerini ortaya koyabilirlerse Türk İHA endüstrisi olumlu etkilenecektir. Proje konsorsiyumları kurulabilir, skor kartları kullanılabilir, bağımsız bir koordinasyon ve izleme kuruluşu oluşturularak bu çalışmalar gerçekleştirilebilir.

Türkiye'de yerli İHA Teknolojileri geliştirme stratejisi açık bir şekilde modellenmelidir: Dışarıdan tedarik edilen sistemlerin yerlileştirilmesi sağlanmalıdır. Dışa bağımlılığın giderilmesi ve özgün İHA teknolojilerinin geliştirilmesi için teknoloji öngörüsü, TRL araçları, yerli teknoloji geliştiricilerine teşvik sağlanması, uzun vadeli üniversite-sanayi işbirliği, yurt içi tedarik zinciri için imalat sektörünü canlandırmak gibi araçlar kullanılabilir.

Teknoloji Geliştirme Bölgeleri (TGB)'ler/Teknoparklar daha etkin hale getirilmelidir: TGB'ler/Teknoparklar firmaların yenilikçi çözümler geliştirmelerini tetikleyecek adımlar atmalılar. Ar-Ge ve yenilik indeksleri, akademik çalışmalara katılım kullanılabilecek araçlardır.

Firmalar finansal olarak güçlendirilmelidir: Politika araçları; öngörülen teknolojilere yönelik Ar-Ge projeleri için artan fonlama programları, yeni teşvik modelleri, Devlet kurumları tarafından verilen eğitim ve destek hizmetleri (ör. finansal, pazarlama), teknoloji geliştiren KOBİ'ler için uzun dönemli destekler.

İşbirlikleri artırılmalıdır: Bu işbirlikleri kaynak verimliliği, bilgi paylaşımı, gereksinimlerin açıkça ortaya konulması, geliştirilen teknolojilerin sistem düzeyinde entegrasyonu, endüstriye yeni aktörlerin katılımı, yenilikçi çözümlerin artırılması gibi yönlerden yararlıdır. Politika araçları seti olarak, proje konsorsiyumları kurulabilir, Ar-Ge ortağı indeksi geliştirilebilir, fikri mülkiyet uygulamaları iyileştirilmeli, skor kartları kullanılmalı, üniversite-sanayi işbirliği sağlanmalıdır.

İnsan kaynakları daha nitelikli hale getirilmelidir: Gerekli düzeyde teknolojilerin geliştirilebilmesi için nitelikli insan kaynağı mutlaka yetiştirilmelidir. Farklı alanlarda farklı görevler için insan kaynağını karşılamak için doğru adımlar atılmalıdır. Öngörülen teknolojilerin gerekliliklerine uygun üniversite müfredatları düzenlenmelidir, uzun-dönemli üniversite sanayi işbirlikleri oluşturulmalıdır.

Belirli teknolojiler geliştirilmelidir: Sivil ve askeri alanda gereksinimler açık bir şekilde belirlenerek bu gereksinimleri karşılayacak teknolojiler geliştirilmelidir. Bunun için en etkili politika aracı think-tank grupları ve teknoloji yol haritalarıdır.

Devlet bürokrasisi azaltılmalıdır: Regülasyonlar, izinler vb. yasal süreçlerin endüstrinin önünde olumsuz bir faktör olduğu görülmektedir. Bürokrasinin getirdiği engellerin ortadan kaldırılması için gerekli önlemler alınmalıdır. Süreç iyileştirme yaklaşımları uygulanmalıdır.

"Olumsuz koşullara dayanıklı İHA sürülerinin zeki uçuş yönetimi" üzerine bir teknoloji yol haritası hazırlama çalışması yapılmıştır. Araştırmacı tarafından literatür taraması gerçekleştirilerek ilgili teknoloji alanları belirlenmiş ve uzman görüşüne sunulmuştur.

İlgili teknoloji alanları:

1. Yüksek-performanslı onboard işlemci,
2. Sağlam ve güvenli Yerden Havaya/Havadan Havaya veri linkleri,
3. Gelişmiş yer kontrol istasyonu,
4. Sensör füzyonu,
5. GNSS-reddedilmiş ortamlarda çalışan navigasyon sensörü ve görme temelli navigasyon algoritmaları,
6. Çarpışmadan sakınma/algıla-sakın sistemi,
7. Bireysel otonomi,
8. Merkezi olmayan kontrol için sürü içinde iletişim, Flying Ad-hoc Network,
9. Dağıtık sensör ve otonom silah ağları,
10. Sürü zekası,

11. İnsan-makine/sürü işbirliği, sürülerin denetimsel kontrolü.

TA1: Sürü paradigmasında onboard işlemci gereksinimi mevcut duruma göre artacaktır. Gereksinimleri karşılayacak yüksek kapasitede enerji verimli işlemcilerin geliştirilmesi gereklidir. Özellikle savunma uygulamaları için onboard işlemcilerin yerli olarak üretilmesi gerekli görülmektedir.

TA2: Merkezi kontrol paradigmasında halihazırda yerden havaya veri linkleri kullanılmaktadır. Merkezi olmayan control paradigmasına geçilse de yerden havaya veri linklerine ihtiyaç olacaktır. Bununla birlikte sürü dışındaki bir İHA veya bir insanlı hava aracı ile haberleşme için havadan havaya veri linkleri de gerekli olacaktır.

TA3: Sürü paradigmasına uygun yer control istasyonları geliştirilmeli ve gelişen teknolojiler doğrultusunda uyarlamalar yapılmalıdır. Merkezi olmayan control paradigması yer control istasyonundan bağımsızlığı sağlasa da yer control istasyona ihtiyaç olacaktır.

TA4: Sürü uygulamalarında çok başarılı bir şekilde sensor füzyonu yapılabilmelidir. Sürünün bir elemanlarının elde ettiği bilgilerin birleştirilebilmesi için çok başarılı sensor füzyonu gereklidir.

TA5: Reddedilmiş ortamlarda zeki ve adaptif navigasyon yapabilmek için sensor ve algoritmalar gibi gerekli teknolojiler geliştirilmelidir.

TA6: Otonomi düzeyi arttıkça sürü uygulamalarında çarpışma riskleri de artmaktadır. Algıla sakın sistemleri dinamik yapıda geliştirilmelidir. Sürü bireyleri birbirinin hareketlerini tahmin edebilecek olgunlukta olurlarsa collision-free sürü oluşturulabilir.

TA7: Bir İHA bir sürüden ayrı kaldığında durumsal ve çevresel farkındalığa sahip olmalı ve görevlerini sürdürmelidir. Bir İHA'nın sahip olduğu otonomi düzeyi dahil olduğu sürünün otonomi düzeyini etkilemektedir. Bu nedenle İHA'ların bireysel otonomi düzeyi yükseltilmelidir.

TA8: Merkezi olmayan control paradigmasında sürü içi haberleşme yani sürüyü oluşturan bireylerin haberleşmesi çok önemlidir. Sürü içinde veriler sürü içi haberleşme teknolojisi sayesinde paylaşılacaktır. Sürü içi haberleşme konusunda bütün durumlar için geçerli bir teknolojiden bahsetmek zordur. Sürüyü oluşturan İHAların tipleri (döner-kanat, sabit-kanat gibi ayrıca bunların boyutları), bu İHAların birbirine ne kadar yaklaşacağı, birbirlerinden ne kadar uzaklaşacağı, görevin tanımı gibi durumlar kullanılacak teknolojinin seçilmesi için önemlidir. Gereksinimlere göre birden fazla teknolojiyi içeren hibrit haberleşme sistemleri geliştirilmesi uygun olur.

TA9: Doğrudan sürü ile ilgili bir konu olmayıp gelecek trendinde sürü uygulamalarının dağıtık sensor veya otonom silahlarla birlikte çalışabilirliği sağlanmalıdır. Kritik altyapıların izlenmesi için sensor ağları ile sürülerin karşılıklı etkileşimle çalışması sivil uygulamalar için bir örnektir. Gelecek nesil otonom silahların sürülerle birlikte çalışabilirliği hazırlanılması gereken bir savunma gereksinimidir.

TA10: Sürü içinde ortak karar alınması, görev paylaşımı yapılması, görevlerin yerine getirilmesi, sürü üyelerinin koordinasyonu gibi konular sürü zekası içerisindedir. Sürü zekası ne kadar ileri düzeyde olursa o derece yüksek başarımlı sürüler oluşturulabilir. Parçacık sürü optimizasyonu, Yapay arı kolonisi optimizasyonu, Karınca kolonisi optimizasyonu, Meyve sineği optimizasyonu ve Yarasa algoritması gibi biyolojiden esinlenilmiş hesaplama yöntemleri ve uygulamaları çalışılmalıdır. Doğadaki davranışlar (ör. stigmerji) modellenmelidir.

TA11: Gelecek trendinde bir veya birden fazla sürünün insan-makine arayüzleri ile supervisory kontrolünün sağlanması önemlidir. Bu teknoloji görevlerin yerine getirilmesinde esneklik ve çeviklik sağlayacaktır.

Etkileyen faktörler:

1. İHA’ların sivil hava sahasında kullanımı mevcut regülasyonlarda (SHT-İHA) durumda Görsel Görüş Hattı ile sınırlıdır. Bu regülasyon İHA’ların tüm yetkinliklerinden yararlanılması ve sürü uygulamaları için Görüş Hattı Dışı ve

otonom uçuşlar dâhil olacak şekilde düzenlenmelidir. Regülasyonların geliştirilecek teknolojileri destekleyecek özellikte olması gerekir. Mevcut haliyle regülasyonlar teknolojiler önünde engeldir ve önemli bir faktördür.

2. KOBİ/Start-up firmaları arasında tekrarlı çalışmalar ve finansal riskleri ortadan kaldırmak için rehberlik ve stratejik planlama sağlanmalıdır. Özellikle yazılım bileşenleri konusunda çevik geliştirme için KOBİ/Start-up firmaları desteklenmelidir.
3. Savunma, havacılık firmaları arasında entegrasyon ve işbirliği gerekli düzeyde sağlanmalıdır. Bu sistem-düzeyinde geliştirme için gereklidir.
4. Özellikle sürü zekası ve sensör füzyonu üzerine yüksek performanslı algoritmalar geliştirilmesi gereklidir. Farklı yapıda İHA'lardan oluşan ve İHA'lar ile birlikte farklı tip platformlarla sürü oluşturulduğu düşünüldüğünde görev paylaşımı zor bir problem haline gelmektedir. Sürü içinde bozulmalar oluşmaması için sürü zekasının yüksek başarımlı olması gereklidir. Benzer şekilde sensör füzyonu önemli bir problem alanıdır. Farklı İHA'ların üzerindeki farklı yapıdaki sensörlerin füzyonu zor bir konudur. Örneğin farklı zamanlarda elde edilen verilerin, görüntü verilerinin füzyonu için çok gelişmiş düzeyde algoritmalar gereklidir. Üniversitelerde bu gerekliliklere uygun matematiksel modelleme gibi eğitimler verilmelidir. Üniversitelerdeki eğitim düzeyi ne kadar desteklerse bu algoritmalar bu doğrultuda başarıyla geliştirilebilecektir. Yerli teknolojilerin geliştirilebilmesi için nitelikli insan kaynağının yetiştirilmesi gereklidir. Aynı zamanda üniversitelerde temel araştırmaların çok iyi gerçekleştirilmesi gereklidir. Akademik çalışmalar genelde incelediği problemin bir yönünü ele alarak diğer yönleri ideal kabul etmektedir. Üniversite-Sanayi işbirliği ile gerçek gereksinimlere uygun olarak problemleri bütün yönleriyle ele alan bütüncül çalışmalar gerçekleştirilmelidir.
5. Yüksek başarımlı algoritmaların çalıştırılmasını destekleyecek donanım bileşenleri geliştirilmelidir. Hesaplama gücü yönüyle işlemciler, veri transferi yönüyle haberleşme sistemleri darboğaz oluşturabilir. Bu tür darboğazların aşılması için yazılım bileşenlerinin başarıyla çalışmasını destekleyen donanım bileşenleri de yerli olarak geliştirilmelidir.
6. Bu konu kapsamında incelenenler olgunluk düzeyi düşük teknolojiler olup uzun-

dönemli Ar-Ge çalışmaları gerektirmektedir. Bu nedenle uzun dönemli Ar-Ge çalışmaları için yatırımcılar ve finansal destekler gereklidir.

TA9 ve TA11 gelecek trendinde ortaya çıkacak gereksinimler olduğu için kaynak verimliliği açısından bu çalışmalara hemen başlaması gerekli görülmemektedir. Diğer teknoloji alanlarındaki çalışmalara parallel bir şekilde başlanabilir. Bir teknoloji alanındaki çalışmalar tamamlanınca kaynakların devam eden teknoloji alanlarına yönlendirilmesi uygun olacaktır. Bu teknoloji yol haritasında incelenen teknoloji alanları içerisinde en uzun vadeli çalışma gerektiren zorlu konular TA4, TA5, TA7 ve TA10 olarak değerlendirilmektedir.

Gelişme aşamaları:
Çalışmalar eş zamanlı bir şekilde sürdürülebilir.
2020-2024 döneminde tamamlanacaklar:
- Sağlam ve güvenli Yerden Havaya/Havadan Havaya veri linkleri,
- Gelişmiş yer kontrol istasyonu,

2025-2029 döneminde tamamlanacaklar:
- Çarpışmadan sakınma/algıla ve sakın sistemi,
- Merkezi olmayan kontrol için sürü içinde iletişim, Flying Ad-hoc Network.

2030-2035 döneminde tamamlanacaklar:
- Yüksek-performanslı onboard işlemci,
- Sensör füzyonu,
- GNSS-reddedilmiş ortamlarda çalışan navigasyon sensörü ve görme temelli navigasyon algoritmaları,
- Bireysel otonomi,
- Dağıtık sensör ve otonom silah ağları,
- Sürü zekası,
- İnsan-makine işbirliği, sürülerin denetimsel kontrolü.

Paydaşlar:
Sanayi ve Teknoloji Bakanlığı, Sivil Havacılık Genel Müdürlüğü, TÜBİTAK, Savunma Sanayi Başkanlığı, Savunma sanayi firmaları, KOBİ’ler, TGB’ler/Teknoparklar, Üniversiteler.

İHA sürüleri için yazılım ve donanım bileşenleri yönüyle Ar-Ge çalışması yapan firmalara finansal destekler sağlanmalıdır.

İHA sürü uygulamaları için gereksinimler tanımlanarak çözüm önerileri toplanmalıdır. Bakanlıkların sivil İHA sürü uygulama gereksinimleri için planlama, koordinasyon, izleme süreçleri yürütülmelidir.

İHA sürü problemlerine yönelik çevik geliştirme için KOBİ’ler/Start-up firmalar desteklenmelidir. Büyük firmalar hantal yapıda olabilmektedir bu nedenle projeler alt projelere bölünerek KOBİ’ler/Start-up firmalar tarafından bu alt projelere çevik çözümler geliştirilebilir. Firmalar koordinasyon ve entegrasyon rolünü yerine getirmelidir.

İHA sürüleri için gerekli regülasyon yol haritaları hazırlanmalı ve uygulanmaya başlanmalıdır.

İHA sürülerine yönelik yazılım ve donanım gereksinimlerine yönelik çağrılı Ar-Ge projeleri gerçekleştirilmelidir.

Çalışmaların ilerlemesini ve değişen gereksinimleri izleyerek koordinasyon ve oryantasyon çalışmaları yürütülmelidir.

Firmaların endüstriye katılımını cesaretlendiren proje yarışmaları düzenlenmelidir.

Büyük firmalar tarafından ürünlere odaklanılmalı, alt sistemler alt yüklenicilere yönlendirilmeli ve projelerde paydaşlar entegre edilmelidir.

KOBİ’ler/Start-up firmalar tarafından kritik teknolojilere ve alt sistemlere odaklanılmalıdır.

TGB’ler/Teknoparklar KOBİ’ler/Start-up firmalar arasından iletişim ve işbirliğini sağlamalıdır.

Üniversitelerde müfredatlar endüstriyel ve teknolojik gereksinimlere uygun şekilde düzenlenmeli ve gözden geçirilmelidir.

Akademi ve endüstri koordine edilmeli, İHA sürüleri üzerine çalışmalar Üniversite-Sanayi işbirliği bağlamında yürütülmelidir. Üniversitelerdeki araştırma potansiyeli endüstrinin ihtiyaçlarını karşılayacak yönde gerçekleştirilmelidir. Üniversitelerdeki çalışmaların endüstrinin ihtiyaçlarından uzak, akademik çevrelerdeki eğilimler doğrultusunda, yayın üretme odağında gerçekleştirildiği söylenebilir. Endüstrideki çalışmaların da bilimsel tabana uzak, tamamen pratik ve ticari kaygılarla gerçekleştirildiği görülmektedir. Uzun dönemli projeler oluşturulmalı, lisans ve lisansüstü öğrenciler görev yapmalı. Bu aynı zamanda istihdam mekanizmasını sağlayacaktır. Lisansüstü öğrenciler tezlerde endüstrinin problemleri üzerine çalışmalıdır. Bu bilimsel yaklaşımlar kullanılarak yerli teknolojilerin geliştirilmesini sağlayacaktır.

Tez kapsamında Türk İHA endüstrisi için bir olgunluk modeli geliştirilmiş ve bir uygulaması yapılmıştır. Anket yoluyla gerçekleştirilen uygulama sonucunda elde edilen veri seti analiz edilmiştir. Boyutların olgunluk düzeyini belirlerken Ortalama ve Medyan değerleri kullanılabilir. Bu çalışmada Medyan değerleri kullanılmaktadır.

Boyutların olgunluk seviyeleri; Hava Aracı Teknolojileri için 3.0 ile “Orta Yetkin”, Faydalı Yük Teknolojileri için 2.0 ile “Düşük Yetkin”, Güvenli Haberleşme Teknolojileri için 3.0 ile “Orta Yetkin”, Birlikte Çalışabilirlik için 2.0 ile “Düşük Yetkin”, Otonomi için 2.0 ile “Düşük Yetkin” ve İnsan-Makine İşbirliği için 3.0 ile “Orta Yetkin” olarak tespit edilmiştir.

Birlikte çalışabilirlik, Faydalı yük teknolojileri ve Otonomi konusundaki yetkinlikler daha geride görünmektedir. Sensör füzyonu, ortak protokoller, ortak veri tanımları, farklı türdeki faydalı yüklerin birlikte çalışabilirliğinin olmaması uygulama katılımcıları tarafından Birlikte çalışabilirlik açısından eksik görülen konulardır. Yerli olarak üretilen faydalı yüklerin boyut ve enerji tüketimi açısından kullanılabilir olmadığı ve çoğu faydalı yükün yurt dışından getirtildiği katılımcılar tarafından belirtilmektedir. Otonomi konusunda GPS-bağımsız olarak görme-temelli navigasyon, çoklu arıza durumunda otonom karar verme yeteneği, durumsal ve çevresel farkındalık, sürü zekası katılımcılar tarafından eksik olduğu belirtilen konuların bazılarıdır.

Hava Aracı Teknolojileri için itki, batarya, hafif ve dayanıklı malzeme, aerodinamik, multi-disipliner analiz, simülasyon ve optimizasyon araçları, test platformları katılımcılar tarafından görülen eksikliklerin bazılarıdır. Güvenli Haberleşme Teknolojileri konusunda spektrum verimliliği, karıştırmaya karşı dayanıklılık, yüksek düzeyde şifreleme, güç tüketimi ve boyut yönlerinden optimize edilmiş yerli haberleşme sistemlerinin geliştirilmesi (çoğu cihazın yurt dışından getirildiği), sağlamlık (robustness) çözümleri gerekli görülmektedir. Katılımcılar tarafından İnsan-Makine İşbirliği açısından gelişmiş İnsan-Makine Arayüzleri (ör. joystick, eldiven, ses, sinyal), giyilebilir bilgisayarlar öncelikli gereksinimler olarak görülmektedir.

Olgunluk düzeyinin artırılması için geliştirilmesi gereken teknolojiler araştırmacı tarafından modelin sunulduğu bölümde tanımlanmaktadır. Burada destekleyici faaliyetler olarak neler yapılmalıdır konuları tartışılmaktadır.

Araştırma altyapısı taban niteliğinde olup güçlü bir araştırma altyapısı oluşturmadan gerekli teknolojilerin geliştirilmesi mümkün olmaz. Araştırma altyapısı kapsamında Üniversiteler, Arayüzler ve Firmalar düşünülmelidir. Üniversiteler laboratuvarlar, Araştırma-Uygulama Merkezleri ile büyük bir potansiyel sunabilmektedir. Türkiye'de Araştırma-Uygulama Merkezleri konusunda başarılı örnekler vardır. Bu doğrultuda üniversitelerde İHA teknolojileri üzerine Araştırma-Uygulama Merkezlerine önem verilmelidir. Firmaların Ar-Ge ve tasarım merkezleri Türk İHA endüstrisinin gelişimi için önemlidir. Firmaların Ar-Ge ve tasarım merkezi kurmaları teşvik edilmeli, finansal olarak da desteklenmeli ve üretkenlikleri sağlanmalıdır. Yenilik Aktarım Merkezleri, Kuluçkalık Merkezleri, Ağ Yapılar, Üniversite-Sanayi İşbirliği platformları, Teknoloji Transfer Ofisleri gibi arayüzler yerli İHA teknolojilerinin geliştirilmesi için etkin bir şekilde kullanılmalıdır.

Teknoloji Geliştirme Bölgeleri (ihtisaslaşma), KOBİ erişimi, Bilgi tabanları, iletişim platformları gibi değer zincirleri zenginleştirilmelidir.

İHA endüstrisinde Ar-Ge ve ürün geliştirme projelerinde, proje yönetimi tekniklerinin kullanılması İHA teknolojilerinde başarı düzeyini artıracaktır.

Türk İHA endüstrisindeki aktörlerle yapılan görüşmelerde işbirliği ve bilgi paylaşımının yok denecek düzeyde olduğu tespit edilmiştir. Türk İHA endüstrisinde bir bilgi yönetimi çerçevesinin oluşturulması bilgi, tecrübe ve anlayışların paylaşılarak kaynak verimliliği sağlaması ve teknolojik ilerlemede başarı düzeyinin artırılması yönleriyle önem taşımaktadır.

Çok paydaşlı ürün geliştirme projelerinde ve sistemlerin birlikte çalışabilirliliğinde sistem mühendisliği teknikleri ön plana çıkmaktadır, bu nedenle sistem mühendisliği tekniklerinin kullanılması büyük yarar sağlayacaktır.

Daha detaylı olarak kurumsal yapılanma ve kapasite geliştirme için teknoloji yönetimi faaliyetleri, işbirliği yönetimi, fikri mülkiyet hakları yönetimi, bilgi yönetimi, proje yönetimi, sistem mühendisliği, stratejik yönetim faaliyetleri gerçekleştirilmelidir.

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