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**Federal Railroad
Administration**

Unmanned Aircraft System Applications in International Railroads

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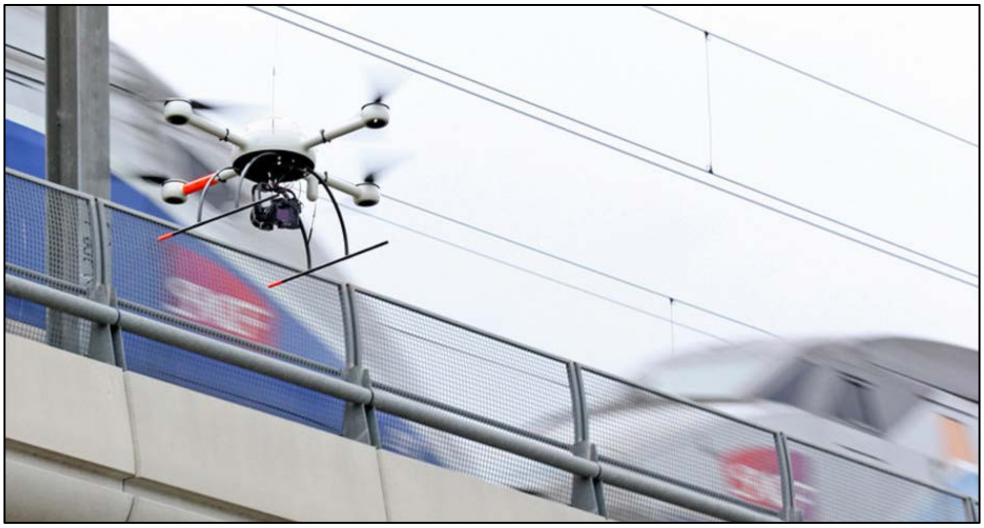
Washington, DC 20590



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13. ABSTRACT (Maximum 200 words)

This report summarizes the current uses and issues associated with Unmanned Aircraft Systems (UAS) in railroad applications, and provides the use cases employed by railroads. The report highlights global UAS market outlooks as well as regulations that influence the use of this technology around the world. The report also provides an overview of issues related to Beyond Visual Line of Sight operations that will affect the use of UAS in railroad applications internationally.

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ENGLISH TO METRIC			METRIC TO ENGLISH		
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1 inch (in)	=	2.5 centimeters (cm)	1 millimeter (mm)	=	0.04 inch (in)
1 foot (ft)	=	30 centimeters (cm)	1 centimeter (cm)	=	0.4 inch (in)
1 yard (yd)	=	0.9 meter (m)	1 meter (m)	=	3.3 feet (ft)
1 mile (mi)	=	1.6 kilometers (km)	1 meter (m)	=	1.1 yards (yd)
			1 kilometer (km)	=	0.6 mile (mi)
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1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)	10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)			
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1 pound (lb)	=	0.45 kilogram (kg)	1 kilogram (kg)	=	2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)	1 tonne (t)	=	1,000 kg (kg)
				=	1.1 short tons
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1 tablespoon (tbsp)	=	15 milliliters (ml)	1 liter (l)	=	2.1 pints (pt)
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1 cup (c)	=	0.24 liter (l)	1 liter (l)	=	0.26 gallon (gal)
1 pint (pt)	=	0.47 liter (l)			
1 quart (qt)	=	0.96 liter (l)			
1 gallon (gal)	=	3.8 liters (l)			
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)	1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)	1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)			**TEMPERATURE** (EXACT)		
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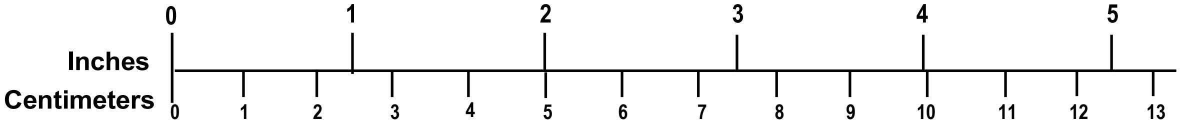

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

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Executive Summary

This report is a survey of international Unmanned Aircraft System (UAS) applications, regulations, and technology issues specific to railroads. This was sponsored by the Federal Railroad Administration's Office of Research, Development and Technology and performed by ENSCO, Inc. in 2017. This report summarizes the current uses and issues associated with UAS in railroad applications, and presents use cases employed by railroads outside of the United States.

The global market for UAS has grown exponentially in the past decade, driven by the needs of civil commercial operations in a variety of industry sectors. Enabling this growth has been the accelerated development of UAS technology. UAS capabilities that were unachievable only 3 to 4 years ago are now possible. Emerging global markets include emergency services, agriculture, insurance, energy product mining, and security with a wide range of data capture and infrastructure inspection activities being used in construction, utilities and transportation, including railroads.

UAS technology is particularly appealing to the railroad industry. Benefits include enhancing inspection capabilities to improve safety and increasing inspection frequencies and efficiencies. Railroads in North America are beginning to use UAS to identify track problems, survey bridges, examine earthworks and rail yards, and to assess rights-of-way following storms and natural disasters [20]. Unmanned Aerial Vehicles (UAV) are also being used by railroads around the world to perform large scale operations, such as aerial photography, surveying and maintenance assessment [28].

This report summarizes current uses of UAS in railroad applications with details provided on use cases from Europe and Israel. Based on a literature review and interviews with several larger agencies, it was determined that UAS operations in international railroads are generally focused on similar use cases as those focused on in North America:

As a backdrop to uses by international railroads, the report highlights the global UAS market outlook, as well as regulations that influence the use of this technology around the world. Finally, the report provides an overview of issues related to Beyond Visual Line of Sight operations that will affect the use of UAS in railroad applications.

1. Introduction

This investigation was performed by ENSCO, Inc. in 2017. The work was sponsored by the Federal Railroad Administration's (FRA) Office of Research, Development and Technology.

1.1 Background

Unmanned Aircraft System (UAS) technology, conceived for military and security applications, is currently transforming commercial markets. There is an increasing interest in the use of UAS for monitoring a variety of infrastructures. Infrastructure monitoring systems are widely adopted to detect potential issues that could lead to severe failures before they can lead to severe failures. Monitoring systems can be found in many civil structures, including bridges and viaducts, as well as many other applications in maintenance, prognostics, as well as health and security monitoring.

UAS are rapidly expanding worldwide and are used in various areas, such as precision agriculture, infrastructure inspection and monitoring, natural resources monitoring, environmental compliance, atmospheric research, media and entertainment, sport photos, filming, wildlife protection and research, disaster relief, etc. The size, configuration and complexity of Unmanned Aerial Vehicles (UAV), also referred to as drones, and the overall flight system varies based on the application and users. UASs are designed and manufactured not only by classical aviation companies, but by small and medium-sized enterprises as well [9].

The development of UAS started many decades ago, but was limited by the technology of the time. In recent years, advances in UAS technology have facilitated an increasingly rapid expansion of UAS use. As the benefits of UAS becomes clearer, organizations across the commercial spectrum seek to leverage the technology to improve their business models and offer a safer, cleaner and more cost-effective alternative to traditional data capture methods. These organizations include global railway companies.

In North America, railroads are beginning to use UAS to inspect track conditions, to conduct surveys of bridges, surrounding earthworks and rail yards, as well as to assess rights-of-way following storms and natural disasters. Burlington Northern Santa Fe Railway (BNSF) is a lead UAS user in the rail industry, and participates in the Federal Aviation Administration's (FAA) Pathfinder Program to explore Beyond Visual Line of Sight (BVLOS) operations [20]. BVLOS refers to UAV flights performed beyond the pilot's line of sight. Flights that allow the pilot to observe the aircraft without visual aids are termed Visual Line of Sight (VLOS) flights.

1.2 Objective

This report provides an overview of the recent emergence of UAS in the international railroad community and provides a summary of how railroads in Europe, the Netherlands, and Israel are applying UAS for railway surveillance and infrastructure monitoring in ways that differ from US rail applications.

1.3 Overall Approach

ENSCO's approach to this research included informal interviews, discussions and email exchanges with experts and practitioners in the rail and UAV industry internationally. Additional information was obtained through internet-based searches of publicly available records. The objective was to capture the most current data available to ensure the research results reflected new and emerging trends in the application of UAVs to the rail industry.

1.4 Scope

The scope of this effort was limited to publicly available information and direct communication with railroad organizations, regulatory agencies, and suppliers.

1.5 Organization of Report

The report is organized as follows:

- Section 2 outlines the typical application of UAS in the railway industry.
- Section 3 describes the UAS global market outlook and anticipated growth over the next years.
- Section 4 summarizes current regulations and policies affecting UAS use abroad.
- Section 5 provides an overview of UAS uses in international railroads with highlights of use cases that focus on different issues than those currently considered in North America.
- Section 6 highlights several issues associated with BVLOS operations and how they impact UAS use by railroads.
- Section 7 provides conclusions drawn from this study.

2. UAS for Railway Applications

UAS technology is having a powerful and transformative impact on the rail industry. In railroad environments, UAS are particularly suitable for:

- Structural monitoring, especially for critical assets like bridges and tunnels, and for fault detection (i.e. diagnostics/prognostics).
- Environmental security monitoring such as assessments of fire, explosions, earthquakes, floods and landslides along the track.
- Physical security monitoring. Detection of intrusions, objects stolen or moved, graffiti, etc.
- Safety monitoring, e.g., to early detect failures on track elements/devices or obstacles on the track.
- Situation assessment and emergency/crisis management. To monitor accident scenarios and coordinate the intervention of first responders.

The use of UAS technology offers the following direct benefits for routine inspection activities:

- Reduction of risk to staff and people and infrastructure in the project area
- Reduced planning cycle
- More efficient work processes
- More flexible, affordable verification tools
- Higher quality data available in larger quantities at lower costs

When natural disasters strike, many railroad assets can be at risk. In such situations, it is critical to determine which part of the railroad needs repair prior to the movement of trains. UAS can gather information regarding the condition of the track or bridges, as well as the presence of debris on the right-of-way.

The aging of European rail infrastructure network faces many condition assessment challenges. Visual condition assessment of the rail system remains the predominate input to the decision-making process. Many railroads use machine-vision technology installed on rail-bound vehicles, but there are situations in which inspectors on foot or in hi-rail vehicles assess the track's surroundings. In the case of high or steep slope embankments, UAS can collect detailed information that could be missed by inspectors.

2.1 UAV Suitable for Railway Applications

Two primary UAV types are available for railway operations: "rotary wing" shown in the top portion of Figure 1, and "fixed wing" aircraft shown in the lower portion of Figure 1 [19].

Figure 1. Rotary Wing and Fixed Wing UAVs [4]

Rotary wing UAVs share many characteristics with manned helicopters. Rather than a continuous forward movement to generate airflow, these units rely on lift from the constant rotation of the rotor blades. There is no limit on how many blades an aircraft has, but the average is between four and eight. Unlike fixed wing units, rotary wing units have the ability of vertical take-off and landing, meaning they can be deployed virtually anywhere. This enables the aircraft to lift vertically, and hover at a specific location. These UAVs can move in any direction, hovering over important areas, collecting the most intricate data. It is this ability that makes them so well suited for inspections where precision maneuvering is critical to the operation.

Fixed wing UAVs are designed for higher speeds and longer flight distances. This type of UAV is ideal for coverage of large areas, such as aerial mapping and surveillance applications. This type of UAV can often carry heavier payloads than rotary UAVs. They glide efficiently and the single fixed wing drastically reduces the risk of mechanical failure. The maintenance and repair requirements for these units is often minimal, saving time and money. However, the current BVLOS regulations limit the utility of fixed wing UAVs. Several railways are predominantly using multi-rotor or hybrid vehicles that employ multiple rotors along with fixed wings to facilitate short takeoffs. Among the various types of UAVs, the one with the highest number of units worldwide is the rotary wing followed by fixed wing UAVs.

The nano-type UAV is becoming prevalent in the UAS market space. The nano-type UAV is a palm-sized platform with a maximum takeoff mass of less than 30 g (approximately 1 oz). They utilize advanced navigation systems, full-authority autopilot technology, digital data links and multi-sensor payloads. The operational radius for this type of platform is more than 1.5 km and can be flown safely in strong wind. Future development is anticipated to yield even smaller and more advanced nano-type UAVs with high levels of autonomy [10].

2.2 Sensors Employed for Railway Applications

Cameras are still the most common sensor used on a UAV. However, dynamic sensor technologies created for use with UAVs provide essential situational awareness and a level of detail often missed by the human eye and standard cameras. Light Detection and Ranging (LiDAR) sensors on UAVs, such as that shown in Figure 2, capture imagery which only a few years ago required an aircraft and a crew to collect [19]. A LiDAR sensor mounted on a UAV, along with sophisticated software, can produce accurate three-dimensional images very quickly.

Figure 2. Various UAV-Mounted Sensors [19]

UAV payloads can integrate sensors of a different nature, such as temperature sensors or multispectral cameras to provide diverse functionalities, depending on energy consumption and maximum allowed weight. Self-powered chemical sensors can be mounted on the aerial platform to provide quick and safe analyses of chemical or air samples near a derailment.

Current standard UAS technology allows the registration and tracking of position with Global Positioning Systems (GPS), or Inertial Navigation Systems (INS), and orientation of the implemented sensors in a local or global coordinate system. UAS-based photogrammetry, or the practice of making measurements from imagery, now allows for the collection of information from platforms that are remotely controlled or operated in a semi-autonomous or autonomous manner, therefore, eliminating the need for a pilot sitting in the vehicle [14]. As described by the Croatian Association of Civil Engineers, UAS photogrammetry can be understood as a newer photogrammetric measurement tool with applications in the close-range domain that combines aerial and terrestrial photogrammetry to provide a real-time application and low-cost alternatives to the classical manned aerial photogrammetry. This approach can provide both an overview of a situation as well as detailed area documentation [19].

The collection of three-dimensional data by conventional surveying methods can be quite time-consuming, expensive and even dangerous for the field operator, especially on steep slopes and cuts where there are potential rockfalls, landslides or mudslides. Visual inspection of the terrain in such locations, just as geodetic data collection with classical methods, can result in incomplete and insufficiently detailed data, thus posing a risk to the railroad. The use of UAVs in such locations can greatly complement, enhance and even completely replace the classical methods of mapping, determining the volume, cross-sections, contours and other parameters that are necessary for the remediation measures as illustrated in Figure 3 [19].

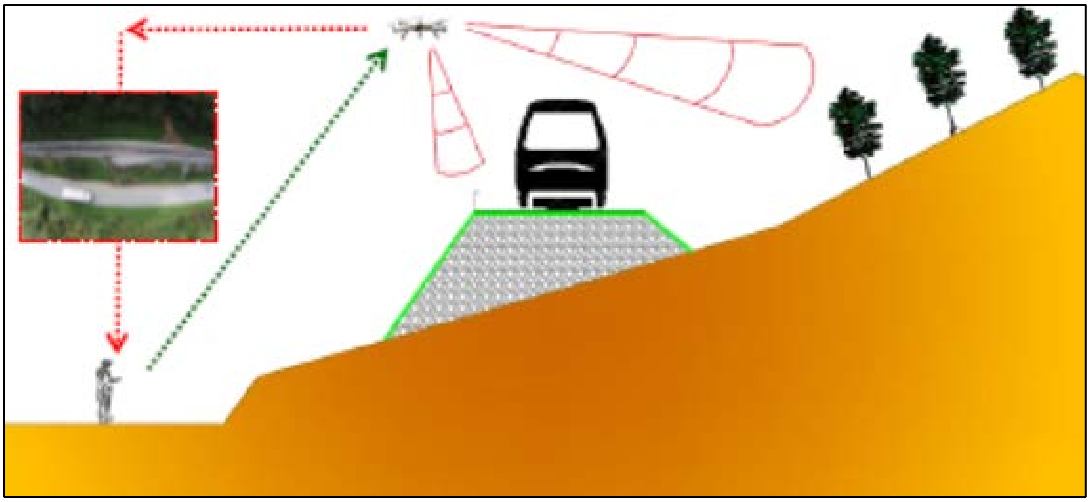


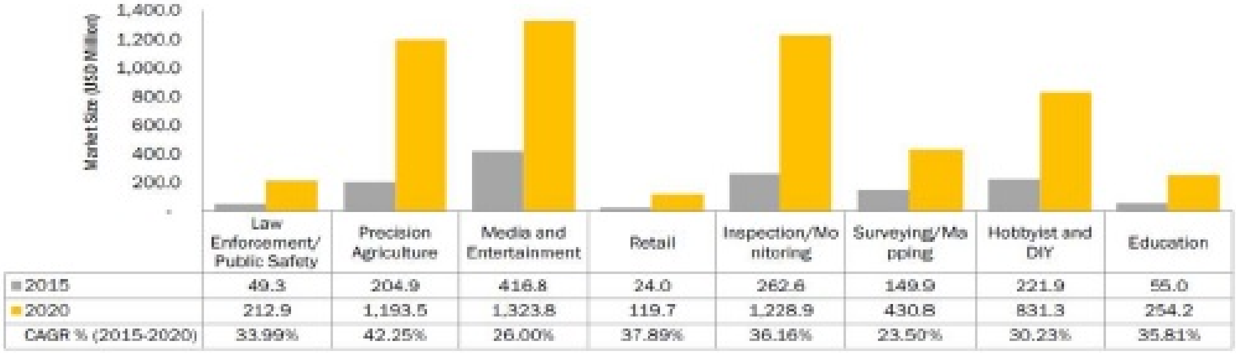
Figure 3. UAV Mapping Steep Slopes and Contours [19]

The challenge will be to increase the level of automation to reduce the need for human interventions with the ongoing enhancement of UAV endurance and payloads, even in critical situations. The number of scenarios in which railway UAVs would be useful will be proportional to UAS performance growth.

3. UAS Global Market Outlook

The UAS industry is well positioned to exploit burgeoning commercial markets with the rapidly expanding proliferation and advancement of UAS technology. By 2025, such commercial expansion will increase the momentum of economic growth toward the forecast $81 billion-dollar global impact [1]. Consequently, there has been an increasing interest to adopt this technology within several contexts and an emerging interest to research new areas of applications.

The European UAS market is expected to directly employ more than 100,000 people and economic impact will exceed €10 billion per year, mainly in services, within the next 20 years. According to a report by Markets and Markets cited by the European Aviation Safety Agency's (EASA) Notice of Proposed Amendment 2017-05 (B), the global UAS market size is expected to increase to $21.23 billion by 2022 at a compound annual growth rate (CAGR) of 19.99 percent between 2016 and 2022 [10]. As illustrated in Figure 4 produced by Markets and Markets, industries employing UAS for inspection and monitoring are projected to grow by a CAGR of 36.2 percent between 2015 and 2020.



	Law Enforcement/ Public Safety	Precision Agriculture	Media and Entertainment	Retail	Inspection/Monitoring	Surveying/Mapping	Hobbyist and DIY	Education
■ 2015	49.3	204.9	416.8	24.0	262.6	149.9	221.9	55.0
■ 2020	212.9	1,193.5	1,323.8	119.7	1,228.9	430.8	831.3	254.2
CAGR % (2015-2020)	33.99%	42.25%	26.00%	37.89%	36.16%	23.50%	30.23%	35.81%

Figure 4. Projected Global UAS Market Size by Application, 2015–2020 [10]

UAS are also employed within a variety of infrastructure systems for structural health monitoring applications to evaluate repair or retirement needs. Modern railway security systems used in infrastructure protection applications include a set of different sensing technologies integrated by appropriate management systems. However, such systems are still highly dependent on human operators for supervision and intervention. One of the challenging goals in this field is the automatic detection of both natural and malicious threats scenarios.

As shown in Table 1, the Americas (United States, Canada, Mexico, and Brazil) has been and is forecasted to be the largest share of the global commercial UAS market through 2020. The Americas' market share of UAS operations is forecasted to be followed by markets in the Asia-Pacific (APAC), Europe, and the rest of the world (RoW), respectively, in 2018 [10].

Table 1. Global UAS Market Size ($M) by Region, 2014–2020 [10]

Region	2014	2015	2016	2017	2018	2019	2020	CAGR (2015-2020)
Americas	467.4	896.9	1,449.4	2,026.6	2,580.0	3,134.6	3,744.6	33.09%
Europe	129.3	234.1	355.7	465.9	553.4	624.5	689.5	24.12%
APAC	85.9	172.9	291.6	423.6	558.0	698.7	857.2	37.74%
RoW	42.6	80.6	128.2	176.0	219.5	260.7	303.9	30.39%
Total	725.2	1,384.5	2,224.9	3,092.1	3,910.9	4,718.5	5,595.2	32.22%

In November 2016, the Single European Sky ATM Research (SESAR) Joint Undertaking (SJU) issued “European Drones Outlook Study: Unlocking the Value for Europe,” providing insights into the use of UAS. The forecast extends to 2050 and focuses on UAS operation within European skies, including economic indicators reflective of European demand [32]. The study concluded:

- European demand may exceed €10 billion on an annual basis by 2035 and €15 billion by 2050.
- Indirect macroeconomics and societal externalities of a potential UAS industry to be considered:
  - increasing the success of search and rescue missions
  - preventing chemicals impacting natural environments through precision agriculture
  - software developers creating applications for UAS
- The UAS industry impact on the labor market could be the creation of an additional 250,000–400,000 jobs.
- Some 7 million leisure UAVs are expected to be operating across Europe and a fleet of 400,000 is expected to be used for commercial and government missions in 2050.
- Potential UAS applications include provision of communication access or wind energy using UAVs attached to the ground.
- In the long term, larger commercial UAS are gradually expected to be equipped with initial versions of optionally piloted systems, a hybrid between a conventional aircraft system and an unmanned system. Anticipated for proliferation after 2030, this type of system is expected to initially impact cargo transport prior to expansion to the transport of passengers. The study noted, however, that the feasibility of such solutions will require significant societal acceptance, as well as critical advancements in technology and regulations.

4. International Regulations and Policies

Technology often advances at a faster pace than regulations. The global UAS industry is exploding, providing a challenge for policy makers, while some countries like the United States, have clear, established laws, as many others do not. Regarding international UAS operators, it is very difficult to meet all the requirements of a patchwork of local regulations and policies and several countries have identified the need for unified laws and flight regulations [25]. Many countries belong to the International Civil Aviation Organization (ICAO). The ICAO has yet to issue a final UAS rule and is not scheduled to do so until 2018. Over the last several years, many countries led by France, Japan, New Zealand, South Africa, and the United Kingdom have set the pace internationally on introducing UAS technology in their airspace [6]. Although most countries are establishing legislation to address UAS operations, other countries such as Saudi Arabia, Dubai, and Morocco have simply banned UAS operations outright [16].

The following sections summarize regulations governing UAS operations in the United States, as well as several countries leading the world in use of UAS technology.

4.1 U.S. Regulations

In the United States, UAS are considered aircrafts subject to FAA regulations. By law, any aircraft operation in the national airspace requires a certified and registered aircraft, a licensed pilot, and some type of operational approval. Model aircraft for recreational purposes are generally unregulated, with a few exceptions.

UAS under 55 lbs flown for commercial purposes are regulated under Title 14 Code of Federal Regulations (CFR) Part 107 [12]. 14 CFR Part 107 is a framework of regulations allowing routine use of UAS under 55lbs in today's aviation system while maintaining flexibility to accommodate future technological innovations. Highlights of 14 CFR Part 107 include the following requirements:

- The UAV must remain within VLOS of the remote pilot in command, and the person manipulating the flight controls of the small UAS. Alternatively, the unmanned aircraft must remain within VLOS of the visual observer. The person manipulating the flight controls of the small UAS and observers must be capable of seeing the aircraft with vision unaided by any device other than corrective lenses.
- Daylight-only operations, or civil twilight (30 minutes before official sunrise to 30 minutes after official sunset, local time) with appropriate anti-collision lighting.
- First-person view camera cannot satisfy “see-and-avoid” requirement, but can be used if requirement is satisfied in other ways.
- Maximum groundspeed of 100 mph; maximum altitude of 400 feet above ground level (AGL) or, if higher than 400 feet AGL, remain within 400 feet of a structure.
- Minimum weather visibility of 3 miles from control station.
- Operations in Class B, C, D and E airspace are allowed with the required air traffic control permission, while operations in Class G airspace are allowed without air traffic control permission.

- No person may act as a remote pilot in command or Visual Observer (VO) for more than one unmanned aircraft operation at one time.
- No operations from a moving vehicle unless the operation is over a sparsely populated area.
- UAS operator must either hold a remote pilot airman certificate with a small UAS rating or be under the direct supervision of a person who does hold such a certificate.

Many of the restrictions in 14 CFR Part 107 are waivable if the applicant demonstrates that safe operations can be achieved under the terms of a certificate of waiver. 14 CFR Part 107 does not allow for BVLOS operations.

Commercial operations with vehicles exceeding 55 lbs require a Section 333 exemption, an authority leveraged to grant case-by-case authorization to operate certain unmanned aircraft over 55 pounds. Prior to commencing operations, the operator is also required to obtain a civil Certificate of Authorization (COA) from FAA. The COA application process, separate from the petition for exemption process, makes applicable FAA Air Traffic Control facilities aware of proposed UAS operations and gives FAA the ability to consider airspace issues unique to the specific operations.

4.2 European Regulations

In 2008, the European Parliament and Council of the European Union (EU) issued Regulation No. 216/2008 to establish the EASA and give it regulatory authority for civil aviation including UAS weighing more than 150 kg (331 pounds). EASA has left it to individual countries in the EU to develop their own regulations for smaller UAS.

In 2014, the European Commission adopted a strategy to support the progressive development of civil UAV markets in Europe [11]. In its communication entitled “A New Era for Aviation Opening the Aviation Market to the Civil Use of Remotely Piloted Aircraft Systems in a Safe and Sustainable Manner,” the European Commission acknowledged that the growth of the European UAV market had stalled due to the absence of an adequate regulatory framework in the majority of EU Member States and the need to get individual authorizations from national governments. Consequently, some European countries started to develop national rules to facilitate the use of UAS in local industries.

Operators and manufacturers of UAS have pleaded for a harmonization of rules to create a viable European market for UAS, but it is still left to each member State to make its own laws. The following sections provide a high-level summary of UAS regulations in key European countries.

4.2.1 United Kingdom

The UK subjects UAS that weigh between 20 kg–150 kg (331 lbs) to all articles of its Air Navigation Order, while generally exempting the operation of UAS weighing 20 kg (44 lbs) or less from airworthiness and flight-crew licensing requirements. Operators of these aircraft are required, among other things, to obtain a certificate of airworthiness, have a permit to fly, and have a licensed flight crew. All commercial operations of UAS must be approved by the UK’s Civilian Aviation Authority (CAA).

Regulations for use of small UAVs with a mass not more than 20 kg (44 lbs) without fuel, but including payload are governed by Air Navigation Order 2016 [42]. The regulations are highlighted by the following restrictions:

- The person in charge of a small unmanned aircraft must maintain direct, unaided visual contact with the aircraft sufficient to monitor its flight path.
- If the UAV has a mass more than 7 kg (15 lbs) excluding fuel, but including payload, it may not be flown in UK Class A, C, D or E airspace unless the permission of the appropriate air traffic control unit has been obtained.
- The vehicle may not fly at a height of more than 400 feet above the surface unless it is flying in approved airspace in accordance with the requirements for that airspace.
- The operator of the aircraft must not fly the aircraft over or within 150 meters of any congested area or organized open-air assembly of more than 1,000 persons, within 50 meters of any vessel, vehicle or structure not under the operator's control or within 50 meters of any person unless permission is provided by the CAA.

UAVs with an operating mass of more than 20 kg are subject to all UK CAA regulations, although, operations may be exempt from certain requirements by the CAA. UAVs with a mass of more than 150 kg may also be subject to additional certification requirements as determined by EASA. Due to this, any operator of a UAV with a mass of more than 20 kg within the UK must obtain a specific approval, in the form of an exemption, before any flight can take place. full details and requirements for operations of this nature are contained within the CAA's UAS guidance document, CAP 722.

Commercial BVLOS operations of vehicles of any size are not currently permitted in the UK.

4.2.2 Germany

On April 7, 2017, Germany implemented an amendment to its Air Traffic Licensing Regulation and the Air Traffic Regulation that introduced stricter rules for the operation of commercial drones and model aircraft. The regulations include the following requirements [15]:

- All drones and model aircraft weighing more than 0.25 kg must be marked with a permanent and fireproof label indicating the name and address of the owner.
- Starting October 1, 2017, operators of drones and model aircraft that weigh more than 2 kg (4.5 lbs) need a certification to demonstrate that the operator has specialized knowledge of the operation of UAS and the appropriate restrictions. This certification can be a pilot's license or a similar certificate from an agency recognized by the German Federal Aviation Office in the case of UAS. The certificates are valid for 5 years.
- Operation of the following aircraft requires an authorization to fly, usually valid for 2 years, granted by the relevant State aviation authority:
    - Aircraft weighing more than 5 kg (11 lbs)
    - Rocket-powered UAV whose propellant mass exceeds 20 grams
    - UAV with a combustion engine, if they are flown within 1.5 km (0.9 miles) of a residential area

  - All UAV flown within 1.5 km of an airport. Flight at airports require an additional clearance from German Aviation Control
  - All nighttime UAV flights.

A general authorization is only issued for a specific State, but may be recognized by other States. Other restrictions include:

- Operation of drones and model aircraft weighing more than 25 kg is prohibited.
- UAV weighing less than 5 kg (11 lbs) must be kept within the operator's VLOS at all times. BVLOS operations of vehicles of any size are not currently permitted in Germany.
- UAVs cannot be operated above 100 meters or within 100 meters of:
  - People and public gatherings, the scene of an accident, disaster zones, other sites of operation of police or other organizations with security-related duties, and military drill sites
  - Federal highways, Federal waterways, and railway systems
  - Correctional facilities, military complexes, industrial complexes, power plants, and power generation and distribution facilities
  - Property of Federal or State governments, diplomatic or consular missions, international organizations, and law enforcement and security agencies.

The aviation authority may grant exceptions to general prohibitions in justified cases.

4.2.3 France

The use of civilian UAS in France is largely governed by the Airspace Order (Order of December 17, 2015, Regarding the Use of Airspace by Unmanned Aircraft) and the Creation and Use Order (Order of December 17, 2015, Regarding the Creation of Unmanned Civil Aircraft, the Conditions of Their Use, and the Required Aptitudes of the Persons That Use Them) that took effect on January 1, 2016. Key aspects of the orders include [3]:

- Within authorized areas, UAVs must not fly higher than 150 meters (492 feet) above the ground, or higher than 50 meters (164 feet) above any artificial object more than 100 meters (328 feet) in height. UAVs are limited to an altitude of 50 meters (164 feet) within areas where military training exercises are taking place.
- UAVs are prohibited from certain areas, such as military installations, nuclear power plants, historical monuments, hospitals, prisons, and certain national parks or natural reserves without authorization. UAVs are not allowed to fly in the immediate vicinity of an airfield, and must adhere to strict altitude limits in the surrounding zone without authorization from the airfield's operator. UAVs are not allowed to fly near fires or accident zones to avoid interfering with emergency services.
- UAVs may not be flown at night unless the operator obtains special permissions from local authorities.
- UAVs weighing no more than 25 kg (55 lbs) powered by engines under specific power thresholds, considered Category A platforms, do not require prior certification of the pilot. Vehicles that are not in Category A must have authorization to fly from the civilian

aviation ministry and can only be flown by operators identified within the authorization, which addresses both the aircraft and the operators' ability to fly the aircraft. The authorization is considered to last indefinitely if the conditions under which the authorization was granted remain unchanged.

- UAVs may be flown outside of the pilot's line of sight if a second person keeps it in view and either person is able to take control of the drone if necessary. If the UAV weighs no more than 2 kg (4.4 lbs), travels no more than 200 meters (656 feet) from its pilot, and flies no higher than 50 meters (164 feet), it is permissible to fly outside of the pilot's line of sight if another person keeps it in view and can warn the pilot of dangers in real time. French regulations allow the flight of drones that can fly autonomously by following atmospheric movements if they weigh less than 1 kilogram (2.2 lbs) and fly for less than 8 minutes.
- Special allocations are made for experimental UAVs that are being flown to advance UAS technology in Annex II of the Creation and Use Order.
- French regulations establish four scenarios for establishing limitations on the commercial use of drones. These scenarios are defined by proximity to populated areas and distance from the pilot. These scenarios are then used to limit the weight of the UAV and the altitude at which it operates. There are also safety requirements that apply to each scenario. These requirements include the need for a system to prevent a UAV from going beyond range limits, the ability to have the UAV's propulsion stopped if necessary and the presence of an on-board system to record flight parameters and the quality of the control signal to allow analysis of the last 20 minutes of flight.

BVLOS is generally prohibited in France. However, efforts in France are directed at fostering BVLOS operations. In June 2017, Reseau de Transport d'Electricite (RTE), the French electricity transmission system operator, and Delair-Tech flew a UAV 30 miles to inspect power lines by remote cameras and collected associated data. The UAV was equipped to allow for a 3G communication network to guide the UAV, while two pilots were used for takeoff and two pilots were used for landing [39].

4.3 Canada

In June 2017, Canada's Minister of Transport issued Interim Order No. 8 Respecting the Use of Model Aircraft to govern use of recreational UAV that do not exceed 35 kg (77.2 lbs). When flying a non-recreational UAV in Canada for any type of work or research, or if it weighs more than 35 kg, operators must get a Special Flight Operations Certificate as stipulated in Section 602.41–Unmanned Air Vehicles of the Canadian Aviation Regulations. The certificate dictates how and where the UAV is operated. The only exception to this requirement is for operations conducted under Transport Canada exemptions [38].

At the time of this report, Transport Canada is proposing new regulations for UAVs used for any purpose that weigh 250 g (0.55 lbs) to 25 kg (55 lbs), are operated within VLOS. The proposed rules introduce three categories of UAVs with each category based on the size of the device, the pilot and where the UAV is operated. New requirements will be specified for each category [37].

4.4 Japan

In 2015, Japan enacted two bills that impacted the use of UAV. Prior to these bills, there were no regulations in place for UAV operations. The first of these bills, the Aviation Act amendment that became effective on December 10, 2015, established the following prohibitions for use of UAVs more than 200 grams (7 ounces) without permission from the Ministry of Land, Infrastructure and Transportation [41]:

- No UAV operations where air traffic is expected, such as airports and their approach areas, areas above 150 meters (492 feet) and in densely populated residential areas.
- UAV flights may be made only between dawn and dusk.
- An operator must always monitor the UAV and its surroundings with his/her own eyes.
- In-flight UAVs must keep more than 30 meters (98 feet) from people and objects.
- UAVs must not fly over a place where an event attended by many people is being held.
- UAVs must not carry specified dangerous items, such as explosives and flammable objects, and must not drop items while in flight.

The second of the Japanese bills, the Act on Prohibition of Flying UAVs over Important Facilities and Their Peripheries, was implemented in March 2016 to prohibit UAV operations within 300 meters (984 feet) of government and imperial buildings as well as nuclear facilities [41].

4.5 New Zealand

In August 2015, New Zealand's CAA implemented new rules governing the operations of UAS. The CAA intended these rules to be an interim, permissive approach until more comprehensive international rules are established. The regulations do not make a distinction between commercial and recreational use. The rules are intended for UAVs that weigh under 55 lbs, with UAVs over 55 lbs or operations exceeding standard operating requirements requiring certification [4].

The regulations for UAVs that weigh under 55 lbs are highlighted by the following:

- Outdoor operations are limited to daylight hours and within unaided visual line of sight. New Zealand's regulations reference "shielded operations" which is defined as operations within 100 meters (328 feet) and below the top of a natural or man-made object. This allows the regulations to specify requirements around buildings or below the treetops in a forest. "Shielded operations" are allowed to take place during the evening.
- Aircraft are limited to altitudes of 120 meters (400 feet) above ground level, unless certain conditions are met.
- The operator's need to obtain consent from anyone above whom the aircraft will be flown or person in charge of the area above which the aircraft will be flown.

In New Zealand, BVLOS operations are permitted with possession of an operating certificate [27].

4.6 South Africa

South Africa's CAA regulations for UAV operations are organized by the type of operations being conducted—private, commercial, corporate and nonprofit operations.

A UAV cannot be operated for non-private purposes unless the operator has received a letter of approval and a certificate of registration from the CAA. To receive a letter of approval, the CAA must be provided with detailed information about the vehicle. A remote pilot license is required for all commercial, corporate and nonprofit operations. These licenses are issued airplanes, helicopters and multi-rotor platforms. The license also has different ratings for VLOS, extended VLOS and BVLOS operations. An operator certificate is also required for non-private operations. The holder of the operator certificate is responsible for documenting all operations and potential hazards, as well as ensuring that all parties that work with the UAV have routine background and criminal checks conducted. Operators are banned from using UAV in formation or swarm. Unless operated by a certificate holder and with the director's approval, an operator is prohibited from flying a UAV:

- Above 400 feet above ground
- Within a 10-km radius of an airfield
- Within restricted or prohibited airspace, or
- Near or above sensitive areas, including a nuclear power plant, prison, police station, crime scene, or court

BVLOS operation is permitted only for certificate holders approved for such operations by the Authority. The CAA may approve such operations only if the operator meets certain requirements, which vary depending on whether the operation is in or outside of a controlled airspace [17].

Section 6 further compares the distinctions of international BVLOS regulations and the challenges associated with BVLOS operations.

5. Railway Infrastructure Monitoring by UAS

Using UAS-based solutions for surveying and inspection is beginning to demonstrate significant advantages to rail operations. Ranging from track and overhead cable inspection to vegetation monitoring and network surveying, UAS solutions are helping to increase safety, reduce costs and speed up maintenance processes.

5.1 Utilization of UAS in the International Railroad Industry

Surveys were distributed to selected international railroad industry customers to solicit their perspectives and experiences in pursuing UAS usage for railroad applications. The surveys were provided in advance to the respective organizations and actual responses were recorded from telephone interviews or email correspondence. The results captured by the surveys have been consolidated and the most relevant responses are summarized within this section.

5.1.1 United Kingdom

Currently, the UK's main focus in the railway industry is to reduce risk through technology by remotely performing inspections, basically taking a "boots off ballast" approach. Network Rail (NR) is currently targeting or using UAS use for:

- Identifying and monitoring trespassing and suicide "hotspots"
- Identify problems with infrastructure and groundworks to prevent potential issues. NR's general approach is intended to improve efficiency through remote monitoring of assets and reducing the need for on-site inspections by field personnel.
- Surveillance of water risks such as water ponding and saturation near rivers
- Vegetation management and animal infestation monitoring

NR personnel reported that UAS technology also helps to identify problems with infrastructure and ground works to prevent potential issues, which may cause derailments and other potentially fatal incidents. The winter storms of 2014 in the UK saw extensive damage to the infrastructure on the South Coast. NR initially used a UAV known as the 'orange hornet' to monitor the rebuilding of around 100 meters of sea wall in Dawlish, Devon, which was destroyed by the storms [43].

NR's Air Operations is responsible for taking the lead in its UAS efforts. For the past 10 years, helicopters have been utilized to capture detailed photographs during inspections, which is expensive and time consuming. The use of UAS provides NR real-time monitoring coupled with predictive algorithms of track structures and associated status without deploying personnel in the field and removes the need for on-site inspections. It also allows necessary vegetation management, including determination of vegetation offsets, embankment slips/change detection and animal infestation, using hyper-spectral imaging.

NR has employed various payload technologies for their projects including electro-optical, infrared, high definition and 4K cameras, as well as LiDAR. NR has called a UAV-borne railway infrastructure measurement and monitoring system from Plowman Craven a "game-changer," due to its potential to increase the safety and cost-effectiveness of track maintenance.

NR's endorsement of the Hertfordshire company's Vogel R3D technology followed a successful trial of the product at sidings near Stoke [34].

Vogel R3D is comprised of a 100 mega-pixel camera, flown by a UAS at a height of 25 meters above track level and at a speed between 1–2 meters per second. The high-resolution images are then pieced together using computer software and converted to Point Cloud data to produce three-dimensional and virtual reality models for the end user, plus topographical surveys and track alignment data. Unlike train-borne devices or manual inspection, this system does not require physical access to the network or any possessions, apart from when placing visual markers adjacent to the track that act as control points for interpreting the data.

NR personnel noted the need for continued research into imaging technology, particularly in hyperspectral imaging, ground penetrating radar (GPR) and LiDAR. NR personnel reported that it currently operates multi-rotor platforms itself, but sees a need for a mix of aircraft, including hybrid aircraft that will offer the best endurance, as they move to BVLOS operations.

NR encountered several issues as it developed its program that can serve as warnings to others. These included:

- Regulatory issues governing operations over linear infrastructure versus current VLOS restrictions
- EU insurance requirements
- Endurance limitations of platforms
- Notification and safe system process development
- Technology obsolescence
- Lack of airworthiness/technical standards

Regarding the lessons learned, NR personnel cited managing expectations as an important realization. NR personnel also noted that one of the most expensive elements of its program is travel. NR has a limited number of operators, resulting in significant travel to sites of interest.

However, by avoiding the need for 'boots on the ground' or for closing the railway, the attractiveness of using UAS technology is obvious to NR personnel.

5.1.2 Germany

Germany's Deutsche Bahn (DB), Europe's largest railway and rail infrastructure operator, began using UAS in 2013 to combat graffiti-spraying gangs. Removing graffiti costs DB €7.6 million a year and they hoped UAS would help lower this annual cost by equipping UAVs with infrared cameras to identify individual vandals during the night [18]. The UAVs used by DB cost €60,000 each and were manufactured by the German firm Microdrones, which also markets the machines for landscape photography, analyzing traffic accidents and monitoring crops. The UAVs were a meter wide, from the tip of one rotor arm to another, and could fly for up to 80 minutes at a speed of 33 mph. They can operate autonomously or be remotely controlled by a human operator. The UAVs, which fly at an altitude of 150 yards, were used at graffiti 'hotspots' such as the cities of Berlin, Leipzig, Cologne and Hamburg [44].

Interviews with DB Systemtechnik (DBST), the leading center for railway research in Europe, highlighted additional UAS applications that Germany is targeting:

- Environmental monitoring to minimize interference with natural habitats
- Geotechnical monitoring to get quick and repeatable information on dangerous sites at risk for landslides, etc.
- Gathering of surveying information for railroad designers
- Supervision of construction projects to achieve better control on the progress of work

DBST's surveying department, which is the group taking the lead on UAS issues within the organization, is currently focused on establishing workflows to improve the processing of data collected with the platforms. Its operations to date have employed multi-rotor platforms employing cameras. DBST noted the need for research in the areas of laser scanners and high-resolution infrared cameras to achieve its long-term objectives.

Regarding the issues encountered, DBST noted that in addition to issues created by laws and regulations by operators, it has had to deal with concerns from the unions that the technology could be used for performance monitoring. Lessons learned by DBST include:

- The need to focus on a few pilots as operators rather than a large group of operators
- Focusing on which hardware and software to use for the given application

5.1.3 Israel

Pertaining to the light rail network in Jerusalem, UAVs have been deployed to act as extra surveillance following previous riots which saw stations and tracks of the line destroyed. "We in the city had made use of UAS for various purposes and we thought this would be an excellent opportunity to make use of the technology," Mayor Nir Barkat told The Times of Israel. "With UAS, you get great high-resolution images taken from a birds-eye perspective, giving you the flexibility to zero in on any potential trouble spots in a way that ground level cameras cannot accomplish." Video images recorded with the UAVs were analyzed by the police to help in identifying vandals [43].

5.1.4 Netherlands

ProRail, a Dutch railway company, uses UAVs equipped with infrared sensors to determine if switch point heating systems are operating correctly. Checking the switch points manually is labor-intensive and dangerous for employees, so the company has found that UAS can offer several advantages to traditional evaluation methods [43].

5.1.5 France

Société Nationale des Chemins de Fer Français (SNCF) is France's national State-owned railway company and manages the rail traffic in France and the Principality of Monaco. SNCF is now a major innovator for UAS applications in France. SNCF invested in the capabilities to integrate vehicles, sensors, operating systems, data acquisition and processing, and to adapt the resulting system to the specific needs of the railway in the fields of maintenance and security.

SNCF experimented with UAS on its network from early 2013. After inspection of the structures, the railway company wanted to generalize the use of UAS to monitor its 30,000 km of railways. One use case centered on the identification of thieves targeting copper cables, while cable theft disrupts train movements and is a significant cost to SNCF [40].

Within the SNCF Group, SNCF Réseau develops and modernizes its railway network which includes 2,000 km of high-speed lines. Pertaining to maintenance efforts, SNCF Réseau currently uses UAS for:

- Close inspection of rock faces, as required by law. These inspections, which aim to ascertain the risk of rockfalls onto the railway, usually take place on foot or sometimes using cradles or rope access, but can be complicated to conduct. UAVs are flexible and agile, and can collect detailed information with no risk to staff safety and without disrupting operations, allowing decisions on the maintenance measures needed to be taken quickly. Around 30 such structures were inspected by UAS in 2015 alone with more expected to follow.
- Creating vegetation maintenance plans. These plans involve pinpointing trees which may compromise traffic safety or punctuality. Prior to the introduction of UAS, the information was collected exclusively by foot patrols or by observation from the driver's cab. UAVs enable detailed mapping of vegetation with a view to defining at-risk areas, resources required for specific tasks and calculation of the biomass volumes involved to pay vegetation-removal companies for the exact number of trees felled.
- Inspection of station roofing and structures: inspecting station roofs requires rope access, whilst inspecting the supporting structures requires scaffolding. UAVs can perform an assessment without the need for costly resources, reducing the duration of the work (and the unavailability of the facilities affected) and providing a fuller, more detailed diagnosis [40].

In March 2017, SNCF Réseau created a subsidiary named ALTAMETRIS dedicated to providing complete UAS solutions to companies outside the railroad [33]. The subsidiary provides customized solutions with a focus on sensors, the designing of innovative solutions and data processing. Scientific and regulatory partnerships have also been established with a wide range of organizations and companies such as:

- Office National d'Etudes et Recherches Aérospatiales (ONERA), a French aerospace research laboratory
- France's civil aviation authority, Direction générale de l'aviation civile (DGAC)
- Delair-Tech, a firm specializing in UAV design and data analysis
- The French agency for personal data protection, Commission nationale de l'informatique et des libertés (CNIL), and Autorité de régulation des communications électroniques et des postes (ARCEP), France's telecommunications regulator

ALTAMETRIS specializes in large-scale projects including topography and cartography, inspections of linear assets, infrastructure and industrial installations, as well as security/safety applications and creation of media for advertising.

5.2 Proposed Application of UAS in Mobile Network

This section contains examples of UAS applications, the majority of which involve direct assessment of conditions on and around rail networks using information collected with sensors mounted to UAVs. However, it is important to note that applications to rail networks are not limited to direct assessment with UAS.

In 2016, Italian researchers described the benefits of overall railway monitoring using UAS solutions. Researchers noted that conventional methods for railway infrastructure surveillance employs tools such as analog or internet protocol (IP) cameras, wired intrusion detection and other structural monitoring sensors such as piezoelectric accelerometers. As each sensor/camera cost thousands of Euros, extensive surveillance of very large geographical areas, as in the case of railways, can be impractical. The researchers suggested that instead of using analog or IP cameras, interconnected UAVs and their payloads could be used as mobile terminals to communicate events to remote control centers [14].

Figure 5 shows the concept and implementations of an overall hardware architecture of UAV-based surveillance. Distributed smart-sensors are installed along the railway line, both in fixed (e.g., bridges, tunnels, stations, etc.) and mobile (e.g., passenger trains, freight cars, etc.) locations. They are integrated locally using local wireless infrastructures and then data is collected by gateway nodes to be transmitted remotely by means of wide-area network (WAN) infrastructures, like 3G and 4G cellular networks, satellite links, or fiber optic geographic networks along the line. Given the availability of large bandwidth (in the Gb/s range) provided by fiber optics links, for example, it is possible to transmit high-resolution videos at very high frame-rates for a superior situational awareness at the control rooms. In the case of UAVs, those links could be leveraged by fixed UAV stations to quickly download large amounts of recorded data.

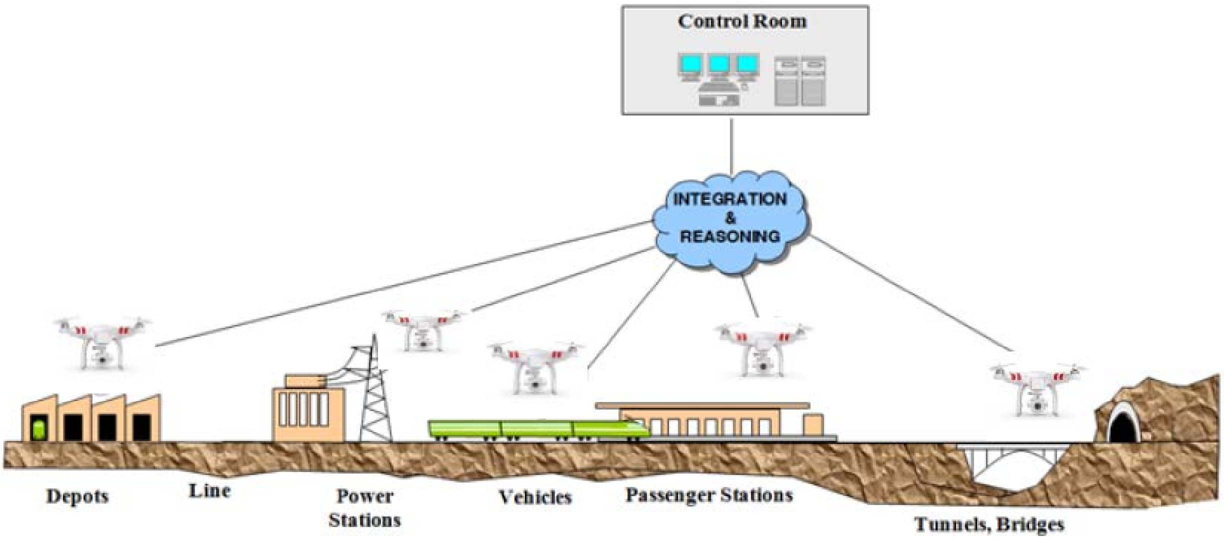


Figure 5. Communication Events Using UAV-Based Mobile Terminals [14]

Railways face challenges with the integration of UAS into their rail fleet for long endurance and forward-looking inspections. All railroad industry members surveyed for this study have cited BVLOS-related issues as one of the most significant issues impacting UAS operations for linear infrastructure. BVLOS will be required to accomplish such tasks as long distance track inspection operations. The next section provides a brief overview of the BVLOS issue.

6. Beyond Visual Line of Sight Operations

Railroad industry members surveyed for this study have cited BVLOS-related issues as one of the most significant issues impacting UAS operations for long distance surveying and track inspections, environmental applications, and geotechnical applications for quick and repeatable information on dangerous sites (e.g., landslides). It is generally accepted that operating UAVs outside of the operator's ability to see the aircraft increases the chances of an incident due to the operators' inability to visually observe the vehicle and its surroundings. Some of the issues that are associated with BVLOS operations includes [26]:

- The lack of ability for an operator to see the terrain and how it changes.
- The inability to see other incoming aerial vehicles.
- The operators' inability to determine local weather conditions.
- The potential for the vehicle to progress beyond the reach of telemetry, thereby, eliminating the ability to control the vehicle.

BVLOS is hypothetically possible with technology that is currently available. As railroads continue to employ UAS technology, the industry is beginning to develop its own set of standards and requirements for what is necessary to achieve its objectives for monitoring, assessment and inspection.

In the United States, the FAA's Small Unmanned Aircraft Regulations, or 14 CFR Part 107, does not allow for BVLOS operations. In most countries, it is either not allowed at all or highly restricted. This does not mean BVLOS will never be permitted, simply that regulators around the world want to proceed with caution. Should BVLOS eventually be allowed on a wide scale, an increase in UAS usage above the current explosion of applications and growth currently in the UAS industry can be expected.

6.1 BVLOS Technologies

Within the United States, Rockwell Collins and BNSF have been successfully flying UAS in BVLOS for long linear operations. During the test flights, which were completed over a 200 mile stretch in BNSF's Clovis, NM, subdivision, BNSF controlled the UAV via a control radio data link network supplied by Rockwell Collins. The CNPC-1000 data link employing Rockwell Collins' Control and Non-Payload Communications waveform is deployed throughout the subdivision to automatically detect the best tower-to-aircraft communication link to manage tower handoffs. "The towers along the rail lines are in constant communication with all vehicles," said Boe Svatek, Director of Advanced Airborne Programs Government Systems for Rockwell Collins. "All big railroads have their own power towers and private networks that keep everything connected. The link determines the right tower to talk to the aircraft. You don't have eyes on the UAS, so you need a management tool to maintain position and positive control of the UAS" added Svatek. These operations were an important milestone in U.S. railway safety research and the FAA's Pathfinder Program at BNSF [8].

In February 2017, the Harris Corporation was selected to develop a network to enable BVLOS operations for UAS under a Research North Dakota grant awarded by the North Dakota Centers of Excellence Commission. The University of North Dakota and the Northern Plains UAS Test

Site will also work on the project. Under a previous grant, work was carried out that included development as well as a risk and safety assessment of UAS detect-and-avoid technology. Harris is now working to create a regional infrastructure to support BVLOS operations that is scalable to the State of North Dakota and eventually to the entire United States. It is expected that developing this high-performance networked infrastructure will help accelerate regulatory approval of BVLOS UAS operations. Harris is looking to partner with end users, such as railroads and electric utility companies in the area, to create UAS test scenarios. As the project continues, Harris expects to test scenarios including railway inspection, roadway inspection, transmission line inspection, precision agriculture, public safety and emergency services, and expanded flight operations [36].

6.2 International BVLOS Regulations and Approvals

BVLOS operations are being considered throughout the international UAS industry. As early as 2013, China began trials of BVLOS through package delivery UAVs in the City of Dongguan in southeast China. As of 2015, SF Express expanded their parcel deliveries to southern and eastern China where demands for same-day couriers were high [7]. In 2016, Zipline, a San Francisco-based robotics company, began operating UAVs commercially beyond-line-of-site in Rwanda, delivering blood by UAV to almost half of all Rwanda's blood transfusion centers [29]. Efforts in France to employ 3G communications to guide the UAV between takeoff and landing during power line inspections illustrates how the international community is exploring technology to facilitate BVLOS in infrastructure assessments [39].

Regulations are perhaps the most challenging part of BVLOS operations, with few global standards established, the UAS industry and users of the technology often take the lead in showing decision makers that there is a plan on how to enable BVLOS flights.

Below is a summary of the existing BVLOS regulations of 13 countries and the approvals they have made for BVLOS flights as of the time of this report.

- **Australia** – BVLOS are allowed with prior approval. The operation of any type of UAS in Australia usually requires that the operator maintain a VLOS unless prior approval is granted. Although BVLOS is not generally allowed, the Association of Certified UAV Operators (ACUO) in Australia is calling for the creation of a continent-wide unmanned traffic management system (UTM) to facilitate transparent and harmonized integration of all forms of UAVs into Australian skies, resolving already significant and growing safety problems posed by unsafe and noncompliant operators. The creation of a UTM would allow for BVLOS flights, and make Australia one of the most UAS-friendly places to operate in the world [27].
- **Canada** – BVLOS operations are allowed with prior approval from Transport Canada. On February 24, 2017, Transport Canada issued its first BVLOS permission to Ventus Geospatial for testing in Foremost, Alberta [29]. Testing focused on demonstrating the safe operations of a vertical takeoff and landing quadcopter, as well as a fixed-wing aircraft [5].

  Transport Canada provided insight into the requirements for future BVLOS operations when a published denial of a request for approval of BVLOS operations quoted Transport Canada as stating:

> *The way ahead for BVLOS operations will include a need for UAV operators to conduct modeling and simulation tests and/or conduct BVLOS testing and evaluation under an SFOC at the UAV "test ranges" (e.g. restricted airspace) being developed at Foremost, AB, and Alma, QC. In other words, the UAV operator will need to have demonstrated their sense and avoid capability at one of the test sites before being considered for a BVLOS commercial operations* [27].

- **China** – BVLOS operations are allowed with restrictions. Flight requirements for VLOS and BVLOS are different within China. UAS operations within VLOS must be conducted in the daytime and route priority must be ceded to other aircraft. Under the Chinese rules, these prohibitions only apply to UAS operating within VLOS, and not to UAS operating BVLOS [27].
- **Denmark** – BVLOS operations are allowed with prior approval from the Danish Transport Authority. In January 2017, the Danish Authority began running a series of test flights focused on demonstration of safe operations in power line inspections. Testing was conducted in collaboration with inspection software developer Scopito, at the University of Aalborg and the University of Southern Denmark. Results of the test are expected to lead Scopito to being granted the first permanent civilian BVLOS permit in Denmark, one of the first approvals of this nature in the world [13].
- **Germany** – BVLOS operations are not currently allowed. In Germany, civilian UAS cannot weigh more than 25 kg and must always be kept within VLOS [27].
- **Japan** – BVLOS are not currently allowed. Japan regulations require operators of all UAS that weigh over 200 grams to always monitor the UAS and its surroundings with their own eyes [27].
- **New Zealand** – BVLOS operations are permitted with a UAV operating certificate. In New Zealand, UAS may be flown without the need for an operating certificate if the vehicle weighs less than 25 kg and does not exceed certain operating limits including maintenance of unaided VLOS with the aircraft.

  On February 27, 2017, New Zealand authorities announced that they had given Transpower, a New Zealand-based aerial inspection company, permission to conduct the first BVLOS flight. Transpower used the flight to conduct aerial inspections of transmission lines and towers in the Rimutaka mountain ranges [27].
- **Poland** – BVLOS operations are allowed with UAS pilot's certificate of competency for BVLOS conditions. If the weight of the UAV exceeds 25 kg a permit to fly is required and operational restrictions, such as VLOS only or minimum distance from populated areas, people, and property may be required [27].
- **Rwanda** – In general, Rwanda limits use of UAS to VLOS operations [30]. However, through a partnership with the Rwandan government, San Francisco-based Zipline began delivering blood supplies to facilities throughout the country in October 2016. Zipline employs an autonomous fixed-wing aircraft launched from a catapult to deliver blood, plasma and coagulants to transfusion centers and hospitals. The UAVs, which fly below an altitude of 500 feet to avoid commercial air traffic, drops containers with the supplies via parachute once it has arrived at the package's destination. The vehicles are battery

powered, use GPS location data, and communicates with the Zipline base and Rwandan air traffic control via cellular connection [23]. In August 2017, Zipline launched the world's largest blood supply delivery network in neighboring Tanzania [45].

- **South Africa** – BVLOS operations are allowed with prior special approval based on certain requirements, which vary depending on whether the operation is in or outside of a controlled airspace [27].
- **Sweden** – BVLOS operations are not currently allowed. Swedish rules generally require UAS lighter than 7 kg that do not create more than a specified level of kinetic energy to be flown within visual sight of the operator [27].
- **Switzerland** – BVLOS operations are allowed with prior approval. Special permission for the BVLOS operation of the UAV can be granted if other users of airspace and third parties on the ground are not endangered. Applicants must meet strict requirements [27].

  SenseFly was given permanent, as opposed to mission-by-mission, permission to operate BVLOS flights in Switzerland on February 9, 2017, by Switzerland's Federal Office of Civil Aviation for mapping efforts. SenseFly's BVLOS approval was granted under strict specific conditions. They included the company's eBee UAVs being operated at a maximum flight height of 500 feet above ground level or 1,000 feet over urban areas and the use of visual observers. These observers monitored each section of airspace with a radius of 2 kilometers for other aircraft and were required to communicate instantly with the UAV's operator in the case of any potential issues [31].
- **United Kingdom** – BVLOS are not currently allowed in the official regulations. In the UK, UAVs weighing less than 20 kg are required to be operated such that direct, unaided, visual contact sufficient to monitor the flight path of the aircraft is always maintained [27].

  Although the official regulations in the UK do not allow BVLOS flights, Amazon.com, Inc. made headlines around the world in December 2016 with the first trials of UAS-based package delivery during daylight hours to customers close to distribution centers in the UK [35]. To date, Amazon's service is not widespread.
- **United States** – BVLOS operations are not currently allowed under FAA regulations. In May 2015, the FAA Pathfinder Program's Focus Area Initiative allowed BNSF to team with UAV manufacturer Insitu to experiment with BVLOS for railroad inspections. The first flight of this nature occurred on October 25, 2015 [2]. BNSF has continued to participate in the FAA' Pathfinder Program and has demonstrated to railroads around the world how UAS' can be used with traditional methods of track monitoring, unmanned aircraft can not only improve inspections, but keep employees out of harm's way and harsh conditions.

  Although the FAA has started to work on draft regulations to issue rules for BVLOS operations, there are a variety of tests that need to take place to ensure BVLOS flights are safe and reliable. That testing is already being conducted, and the number of test sites and testing parties continues to grow. The National Aeronautics and Space Administration (NASA) started conducting BVLOS tests in Reno, NV, as part of its independent research into low altitude airspace management suitable for UAV applications in October 2016 [24], [22]. In February 2017, Harris Corporation announced its work under a Research North Dakota grant to develop a scalable infrastructure to support BVLOS operations [36].

6.3 Current State of Technical Issues

The following sections describe technical issues associated with BVLOS operations and some of the ways that the UAS industry is addressing those issues.

6.3.1 Telemetry Issues

Today there are several cellular modems on the market that can extend the range of UAV operations far beyond the current flight endurance. However, performance depends largely on the cellular network coverage. Another possibility is to use lower frequencies and directional antennas, with other challenges, such as bandwidth degradation, spectrum availability and power consumption, emerging as a result.

Flying BVLOS requires altitude awareness. This is something that sensors added to the UAV could address. However, the flight planning tool that would be used with the UAV would have to be able to calculate the flight path. A better approach might be to implement a terrain-following feature in the flight planning and flight control software. However, such a solution comes with its own challenges such as the source of sufficiently accurate terrain data and the reliability of the positioning system onboard the vehicle. Real time kinematic (RTK) global navigation satellite systems (GNSS) positioning solutions are available, but most RTK solutions need to stay within 10 km (6 miles) from a baseline to receive strong corrections, which is not consistent with the range that most railroads would desire.

Corridor flight planning capability is also a requirement. Flying long distances using waypoints does not provide information in sufficient detail to ensure that UAVs avoid flying over people or restricted zones or that the aircraft avoids steep altitude changes. Corridor flight planning is likely to rely on geofences to ensure that the vehicle remains in the intended area.

6.3.2 Infrastructure

Currently, there is no universal established infrastructure to safely mange the use of BVLOS with UAS. NASA is working with a large group of UAS industry members and researchers to investigate prototype technologies for a UAS UTM system that could meet airspace integration requirements for enabling safe, efficient low-altitude operation within the national airspace system [24]. UTM will include universal UAV registration standards, open identification systems, tamper-proof flight data recorders, accurate and trustworthy three-dimensional mapping data, dynamic weather information, and vehicle-to-vehicle communication.

According to NASA, a UTM system would enable safe and efficient low-altitude airspace operations by providing services such as airspace design, corridors, dynamic geofencing, severe weather and wind avoidance, congestion management, terrain avoidance, route planning and re-routing, separation management, sequencing and spacing, and contingency management. In the future, these features are likely to be extended to higher altitudes as well. Such UTM systems would also require the UAS to be equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) transponders, providing GPS altitude, airspeed and location information.

In Canada, Kongsberg Geospatial, an Ottawa-based developer of geospatial software technology, was awarded a contract to produce an Emergency Operations Airspace Management System

(EOAMS) for evaluation by Canadian government agencies for safely managing UAS at emergency and disaster scenes [22]. The EOAMS is a portable display that interfaces with a variety of local sensors, including radar and ADS-B receivers to give a clear picture of the airspace around disaster areas. It is intended to allow first responders to safely use unmanned aerial vehicles to survey the area without risking collision with another emergency aircraft. The new EOAMS is based on Kongsberg Geospatial's IRIS™ UAS airspace visualization system. The IRIS™ spatial awareness system evolved from technology originally developed for air traffic management display systems, and for supporting flight operations for military UAV systems like the US Navy Triton Global Hawk. The system has been developed for safely operating UAVs BVLOS, and has been adopted by the FAA Alliance for System Safety of UAS through Research Excellence, or ASSURE, group for use in research toward developing regulations for commercial BVLOS operations in the United States. The Government of Canada is expected to begin flight operations testing with the new EOAMS in the summer of 2018.

7. Conclusion

This study was undertaken by ENSCO, Inc. in 2017 under contract with the Federal Railroad Administration's Office of Research, Development and Technology. Based on literature reviews and interviews with several larger agencies outside of the U.S, it was determined that UAS operations in international railroads are generally focused on similar use cases as those focused on in North America, such as:

- Infrastructure inspection—including track, bridges and buildings—to identify potential issues
- Monitoring of geotechnical formations to assess retaining structures or sites that pose risk for landslides
- Gathering of survey information for railroad designers
- Monitoring of trespassing, vandalism and suicide "hotspots"
- Managing vegetation

Several unique use cases were identified to the rail industry outside the U.S, including:

- Proposed use of UAVs for mobile terminals for monitoring sensor networks (Italy)
- Use of infrared sensors to check the switch point heating systems (Netherlands)
- Supervision of construction projects to manage progress (Germany)

Several railroads interviewed and offered lessons learned during their implementation of UAS operations:

- NR personnel cited the importance of managing expectations
- DBST noted the need to address concerns from the unions that the technology could be used for performance monitoring

Pertaining to advancing technology, researchers from DBST noted the need for more research in imaging sensors to advance UAS operations in the railroad environment. Sensors with higher resolutions will likely be needed to capture the details necessary for automated processing of railway infrastructure images captured at higher altitudes.

Regulatory inconsistencies for UAS operations were cited by two companies surveyed, but this was a recurring theme in several other articles. The overriding concern was that governments are becoming increasingly active in this area, and are recognizing the need for standardization, but the inconsistent current patchwork of standards presents a threat to the growth of the industry. For example, the United States and many other countries around the world permit limited use of BVLOS operations, but the requirements for securing approvals can vary amongst the various countries. It is likely that as BVLOS operations expand in the future, requirements based on best practices and proven safety protocols will be adopted globally, leading to more consistent international regulations.

Railroad industry members surveyed for this study cited BVLOS-related issues as one of the most significant issues limiting the advancement of UAS operations for long distance surveying and track inspections. Currently, there is no established infrastructure to enable and safely manage the widespread use of low-altitude airspace and UAS operations, regardless of the type of UAS. NASA is currently working with UAS industry members to develop technologies to support a UTM system for low-altitude airspace. A system of this nature may be needed to continue the expansion of UAS usage around the world.

Ultimately, integrating UAS into railway system is a continuous innovation process, and not a goal with a finite endpoint. The uses of this technology will evolve and grow. EASA and other governing bodies in the international transportation sector will need to adapt and adjust their rules and procedures to accommodate expanding operations. While several international organizations have made substantial progress to meet these challenges, the regulatory framework will need to be reinvented with the new reality presented by UAS. These issues will not become less challenging or less resource-intensive as the UAS industry rapidly expands over the next decade.

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Abbreviations and Acronyms

AGL	Above Ground Level
APAC	Asia-Pacific
ACUO	Association of Certified UAV Operators
ADS-B	Automatic Dependence Surveillance—Broadcast
BVLOS	Beyond Visual Line of Sight
BNSF	Burlington Northern Santa Fe Railway
COA	Certificate of Authorization
CAA	Civilian Aviation Authority
CAGR	Compound Annual Growth Rate
DBST	DB Systemtechnik
DB	Germany's Deutsche Bahn
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
EOAMS	Emergency Operations Airspace Management System
EASA	European Aviation Safety Agency
EU	European Union
FAA	Federal Aviation Administration
INS	Inertial Navigation Systems
ICAO	International Civil Aviation Organization
IP	Internet Protocol
SJU	Joint Undertaking
NASA	National Aeronautics and Space Administration
NR	Network Rail
RTK	Real Time Kinematic
RoW	Rest of the World
SESAR	Single European Sky ATM Research
SNCF	Société Nationale des Chemins de Fer Français
UAV	Unmanned Aerial Vehicle
UAS	Unmanned Aircraft Systems
UTM	Unmanned Traffic Management
VLOS	Visual Line of Sight

WAN	Wide-Area Network