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Inspection and monitoring of railway infrastructure using aerial drones

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Note by the secretariat

Summary

The secretariat of the Economic and Social Commission for Asia and the Pacific, in accordance with its mandate to carry out activities to enhance the planning, design, implementation and operationalization of policies, systems, programmes and measures on transport-related technologies,[a] initiated research in collaboration with the Institute of Railway Technology of Monash University, Australia, in September 2018. The objective was to explore the applications of aerial drones, a rapidly expanding technology sector, in the inspection and monitoring of railway infrastructure, with a view to developing a better understanding of this technology's long-term sustainability benefits for railways, as well as its regulatory and technical implications.

The present document contains an outline of the key findings of that joint research, namely the technical capacities, risks and limitations of aerial drones as they relate to the measuring and monitoring of railway infrastructure. These findings form the basis from which conclusions can be drawn regarding the legal and regulatory conditions that could or should apply to the use of drones and the ways that public policy could incentivize or support drone-powered innovation in the railway sector and in the transport sector at large. Against this background, the Working Group on the Trans-Asian Railway Network may wish to consider the issues highlighted in the document, exchange views and experiences, and provide further guidance to the secretariat on the ways in which the use of aerial drones can provide cost-effective and sustainable solutions for the maintenance of the Trans-Asian Railway network.

[a] See Commission resolution 73/4, E/ESCAP/MCT(3)/11 and E/ESCAP/73/33.

[*] ESCAP/TARN/WG/2019/L.1.

I. Introduction and background

1. The 2030 Agenda for Sustainable Development and the Sustainable Development Goals call for ambitious, cross-sectoral and concerted actions at the national, regional and global levels to ensure sustainable development as defined by the World Commission on Environment and Development, namely development that meets the needs of the present without compromising the ability of future generations to meet their own needs.[1] The importance of providing and having access to appropriate levels of infrastructure and transport that ensure national and regional sustainable development has been extensively acknowledged, including with regard to the contribution the transport sector can make towards achieving the Sustainable Development Goals.

2. In recent years, particularly with the introduction of sustainability concepts related to transport, infrastructure has received renewed attention. As highlighted in the Sustainable Development Goals, quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, is needed to support economic development and human well-being, with a focus on affordable and equitable access for all. This raises new questions about how to approach infrastructure planning and investment in a way that takes into account what it means to have sustainable and resilient infrastructure and about the policy decisions needed to facilitate that approach.

3. Against this background, it is often considered that the advent of new transport solutions or radically different technologies could profoundly transform transport and address the increasing requirements for the capacity and overall performance of transport systems. Indeed, advances in technology are significantly changing modern transport networks and revolutionizing the sector, thus creating greater efficiency in the way systems are maintained and managed while enabling the sustainable and safe movement of people and freight from origins to destinations.

4. In that regard, it is worth examining the current and future applications of aerial drones for the improved efficiency and sustainability of railway systems. Business Insider Intelligence defines drones as aerial vehicles that can fly autonomously or be piloted by a remote individual. On the basis of this definition, the same service estimated that sales of drones were likely to exceed $12 billion in 2021. That would be an increase by a compound annual growth rate of 7.6 per cent compared to $8.5 billion in 2016.[2] Gartner produced a 2016 report in which it projected that by 2020, there will be 10 times more commercial drones than physically piloted aircraft, or roughly 230,480 commercially operated drones around the globe. Furthermore, the same report estimated that the labour cost per drone flight in 2017 was already less than $300.[3]

5. There are several current examples of how aerial drones are being deployed in railway networks today. Drones equipped with high-resolution cameras, sensors and scanners enable remote yet precise infrastructure inspections and carry out hazardous activities previously performed by human staff. This includes working at heights, accessing dangerous locations, and monitoring and inspecting operational network assets from a safe location. It is

[1] A/42/427, annex.

[2] Andrew Meola, “Drone market shows positive outlook with strong industry growth and trends”, Business Insider Intelligence, 13 July 2017.

[3] Gartner, “Gartner says almost 3 million personal and commercial drones will be shipped in 2017”, 9 February 2017.

estimated that a few hundred fixed-wing drones could monitor approximately 200,000 km of railway tracks.[4]

6. In 2017, PwC estimated that the total global addressable market for drone technology aimed at infrastructure maintenance in the road and railway sectors was worth approximately $4 billion.[5] In Singapore, the Land Transport Authority aims to deploy drones for maintenance inspection of urban mass rapid transit and to enhance underground tunnel inspections in order to gradually replace manual efforts within the next few years.[6] In India, Zonal Railways is set to procure drones for project monitoring and maintenance of rail infrastructure.[7] Drones have also been deployed in railway environments for structural monitoring, including the following: monitoring of critical assets like bridges and tunnels; environmental security monitoring along the tracks (for example, fires, explosions, earthquakes, floods and landslides); physical security monitoring (including detection of intrusions, objects stolen or moved, graffiti and vandalism); and safety monitoring (for example, early detection of track element/device failures and obstacles on the track, and situation assessment, including line of sight assessment at level crossings and emergency/crisis management).

7. However, despite offering economic and safety benefits at a cost significantly lower than that of conventional methods, aerial drones pose deployment challenges that remain to be addressed, such as aviation risks, flight management, training and expertise, and privacy and cyber-security concerns, all of which warrant further consideration and research. As a first step in that direction, the present document has been developed jointly by the Transport Division of the Economic and Social Commission for Asia and the Pacific (ESCAP) and the Institute of Railway Technology of Monash University, Australia, to outline the applications of aerial drones in the inspection and monitoring of railway infrastructure, with a view to developing a better understanding of the regulatory and technical implications of this technology.

8. While policy discussions are often focused on expanding infrastructure and building missing links, the present document is intended to provide a basis for addressing questions about the maintenance of railway infrastructure, an often underrated yet critical aspect of the transport system. Against this background, Australia has been selected as a central example of aerial drone applications in the railway environment, owing to (a) the expertise of the Institute of Railway Technology of Monash University; (b) the country's experience with aerial drones, the relatively advanced state of the country's legal and regulatory environment as it relates to aerial drones, and the scope that it offers for reviewing lessons learned and persisting challenges; and (c) the diversity of examples that can be reviewed in Australia on account of its more than 40,000 km of rail network operated in different types of terrain and weather conditions, and the availability of examples of aerial drone use in urban and light

[4] Single European Sky Air Traffic Management Research Joint Undertaking, *European Drones Outlook Study: Unlocking the Value for Europe* (n.p., 2016).

[5] PwC, "Clarity from above: transport infrastructure, the commercial applications of drone technology in the road and rail sectors", January 2017.

[6] Singapore, Land Transport Authority, "Drones: the future of rail maintenance", April 20, 2018. Available at www.lta.gov.sg/content/dam/ltaweb/corp/PublicationsResearch/files/ReportNewsletter/Connect/Apr%202018/03%20Drone%20(On%20The%20Go)%20.pdf.

[7] Press Trust of India, "Railways to deploy drones to monitor projects", *The Economic Times*, 8 January 2018.

rail settings. It is deemed that the case of Australia, a country with the world's sixth longest railway network, could provide valuable insight for the Asia-Pacific region at large. In particular, it could provide insight in connection with the Trans-Asian Railway network, large parts of which could benefit from accessible and affordable methods of inspection, monitoring and proactive maintenance. To this end, other examples from the region are also referred to in the course of the analysis.

9. Technology often advances at a faster pace than regulation. The global drone industry is burgeoning, creating a challenge for policymakers. The regulation of commercial drones at the national level has typically begun with extending regulatory frameworks already in force for the aviation sector to encompass commercial drone operations, given the similarities between physically piloted and remotely piloted aircraft.[8] Australia was the first country in which drone regulations were established, as early as 2002. As of 2016, its legislation had been modified to include rules for non-recreational drones.

10. The technical capacities, risks and limitations of aerial drones as they relate to the measuring and monitoring of railway infrastructure are outlined in the present document. These findings form the basis from which conclusions can be drawn with regard to the legal and regulatory conditions that could or should apply to the use of aerial drones and the ways in which public policy could incentivize or support drone-powered innovation in the railway sector and in the transport sector at large.

II. Technical capacities and benefits of aerial drones in the context of railway infrastructure

11. Regular maintenance and inspection procedures often require personnel to be within the rail corridor to perform visual inspections. A range of safety protocols has been introduced to minimize risks, but they can involve costly track possession or occupation to inspect track sections, which sometimes lack clear accessible safety zones. Other assets such as culverts are designated as confined spaces, and additional safety training and human resource requirements need to be met before inspections can take place. This can often make culvert inspections both time-consuming and costly.

12. Aerial drones provide a remote alternative for railway track inspection and remove the requirement of additional safety training and human resources. They are increasingly recognized as having an important role in assisting governments, the rail industry and related organizations, and their deployment is changing and challenging traditional paradigms and operating procedures for all involved. Some examples of the current use of aerial drones are briefly outlined below.

A. Track-side vegetation management

13. The presence of track-side vegetation of a height exceeding that of the rail and/or in the ballast section may result in damage to track and locomotive components or increased risk of derailment. Slippery conditions from excess vegetation require an increased use of traction sand by the locomotive, which further contaminates the ballast. Excessive vegetation can also increase the potential for collisions between railway equipment and vehicular and/or

[8] Organization for Economic Cooperation and Development, International Transport Forum, *Corporate Partnership Board, (Un)certain Skies? Drones in the World of Tomorrow* (Paris, 2018).

pedestrian traffic at public road crossings, owing to decreased braking ability. Furthermore, there are many possible sources of ignition in railway operations, including sparks from brakes, diesel engines, wheels, overheated bearings and the operation of rail-grinding equipment. These sources of ignition combined with dry brush and weeds in hot, dry conditions are a fire hazard, with the potential to harm the public or damage buildings, property and the environment.

14. Against this background, aerial drones are being used effectively for selective vegetation monitoring which, in turn, facilitates proactive control within the right of way in order to achieve the following: maintain sight line visibility at road and pedestrian crossings; maintain sight line visibility at curves; provide clear visibility of railway signs and signals; maintain the integrity of railway communications and electrical distribution lines; reduce physical hazards to train crews and track maintenance personnel who must work in these areas; reduce fire hazard potential; remove woody vegetation and brush that is interfering with the normal functioning of equipment used to detect rock falls and slides; and remove vegetation that is impacting railway site security, by providing easier access to the right of way behind security fencing.

B. Infrastructure and asset inspections

15. At present, the vast majority of open-air track has to be monitored by security guards and maintenance operatives, as it would be prohibitively expensive to deploy fixed cameras along hundreds of kilometres of railway lines. Using aerial drones to carry out the arduous work of physically checking the tracks and fencing for trespassers or security breaches could improve the efficiency of monitoring operations while freeing up staff to look after higher-value critical assets.

16. The estimated cost savings that would result from the deployment of drones for this purpose have yet to be properly explored. Experience with aerial drones in other sectors has shown that the costs of inspecting an onshore wind turbine can be reduced by 50 per cent per turbine, assessments of large cargo oil storage tanks can be completed several days faster than with manual methods, and chimney flue inspections, which traditionally require days of shut-down, can be performed in hours, with cost savings of up to 90 per cent.[9]

17. It is reasonable, then, to hypothesize that the use of aerial drones could have cost-saving potential for the railways as well, while also supporting a longer-term strategy of reducing “boots on ballast” or human intervention. The ability to allow services to continue during surveys prevents the costly network closures required to permit people to access the track. Drone surveying reduces the number of specially trained staff required to conduct surveys in difficult-to-access areas that might call for abseiling or climbing.

18. At the same time, aerial drones are able to capture data from areas previously inaccessible by traditional methods. This opens up the possibility of gathering data easily and more frequently. However, the ability to increase inspections of multiple assets presents a different problem. The more frequently a structure is inspected, the more data are captured. These data ultimately need analysing, which can be expected to lead to an increase in the demand for specialists to review the data. This could lead to a gradual transformation of the traditional railway workforce, with corresponding implications for the sector in terms of training and recruitment.

[9] Uwe Weichenhain and Sascha Schuster, “Drones: the future of asset inspection”, Roland Berger, 29 January 2019.

19. In addition, the use of aerial drones raises new ethical and legal questions about how drone-controlled data are used, including how to ensure that the right to privacy is upheld and how to delineate data that are relevant to the purpose for which the drone was deployed as separate from incidentally collected data that may be of relevance to other authorities. In Australia, for example, people residing in the vicinity of drone-inspected sites have expressed privacy concerns. Currently, the approach to addressing these complaints is to inform residents and businesses of any aerial drone operations that may affect them and to be transparent about exactly what information is being collected. These and other concerns underscore the need to address questions of data ownership, especially when the infrastructure inspected is privately owned, and to expressly identify whether and under what conditions data can be shared with governmental authorities (such as law enforcement) for purposes other than those for which the data were collected. Caution should be applied to any commercially sensitive infrastructure that may be present along railway lines.

Box 1

Railway applications of aerial drones in Australia

- In Australia, the state-level agency Transport for New South Wales has noted that aerial drones are being used across the state's transport cluster to deliver a range of operational benefits, including monitoring and surveillance of the natural environment. The agency has also noted that the use of drones in ensuring compliance with Environment Protection Authority regulations is envisaged and that there is potential for the use of aerial drones to be further expanded in the future.[a] For example, it has identified security concerns that could be better controlled with the use of drones, including the following: (1) vandalism and graffiti; (2) theft; (3) trespassing and suicide attempts; and (4) assault of staff and customers.

- Aurizon, one of the country's largest rail freight operators, used aerial drones to capture data to assess damage and plan recovery efforts after a cyclone hit central Queensland. The damage caused by the cyclone was estimated at $2.4 billion, including significant damage to Aurizon's central Queensland coal network. The damage to infrastructure included severed access routes, which proved to be an impediment to Aurizon's recovery efforts. Aurizon has also used drones to inspect rail assets, and notes that aerial drones could have additional uses, including conducting surveys and inspecting telecommunications towers, bridges and other structures. Aerial drones also allow for the acquisition of high-definition inspection information about assets without having any impact on train operations.[b]

- Queensland Rail has used drones to provide detailed high-resolution imagery of 13 steel truss bridges between Cairns and Rockhampton in Queensland, ranging from 100 m single-span bridges to 700 m 8-span bridges. The data were captured in the field using Telstra fourth generation wireless system (4G) Internet and uploaded to the cloud, where they were immediately geotagged and processed for delivery to the engineers without anybody having had to climb, traverse or access dangerous areas within the rail corridor.[c]

- Drones are also being used by the Australian Rail Track Corporation for track inspections ahead of rail shut-downs. The company employed drones that film in 4K video to complete technical bridge inspections in the lead-up to the first major rail maintenance shut-down of 2018.[d]

- Metro Trains Melbourne uses drones to spot vandals and trespassers. The drones are equipped with cameras, including thermal imaging cameras, and are deployed on specific sections of the network to respond to incidents. Data are fed back to the company's control centre and passed on to police. The company owns three drones, which have already been used for major public events.
- Trials were carried out in a Yarra Valley railway tunnel in Melbourne to test a prototype drone capable of flying safely in confined spaces. The drone is equipped with a laser sensor to enable both measurement of confined spaces and the positioning of the drone within the confined space.

[a] Engineers Australia, "The buzz about drones: how it could benefit transport in the future", 7 June 2018.

[b] Allie Coyne, "Aurizon uses drones to inspect rail assets: safer for workers, better for data", iTnews, 31 October 2014.

[c] Airsight Australia, "Case study – bridge inspections" (accessed on 3 May 2019).

[d] Sage Swinton, "Drones used by Australian Rail Track Corporation for track inspections ahead of rail shutdown", The Maitland Mercury, 19 February 2018.

III. Technical limitations and risks

20. Deploying an aerial drone over a railway line can entail significant safety risks and operational challenges. The aerial drone would, in the first instance, need to be navigated over huge linear stretches of track. This is a challenge in itself, given current regulations on maintaining line of sight, namely the requirement to observe and control the drone without visual aids. Many countries have regulations on maximum distances that a pilot may fly aerial drones. To exceed these maximum distances frequently requires regulatory approval, additional training and further risk assessment. From an operational perspective, a camera failure or loss of video link forces the pilot to control the aircraft by sight and manoeuvring, which can be difficult or sometimes impossible beyond a distance of 600 m. The aerial drone pilot would have to contend with the ever-present risk posed by live overhead lines, overhanging vegetation and passing trains.

21. Furthermore, confined spaces are common across rail networks and are frequently the target of aerial drone inspection. However, certain risks are associated with the use of aerial drones, such as satellite positioning system-denied environments. These present numerous challenges for aerial drones as they mostly rely on satellite systems for position reporting and autonomous navigation. Such environments include bridges, tunnels and deep cuttings with limited view of the sky. Particular attention needs to be paid to unexpected loss of signal, which may trigger unpredictable behaviour in some aerial drones. Confined spaces also present strong airflows that must be accounted for when operating aerial drones. The selected system should be capable of maintaining its position in the strongest gusting airflow to prevent flyaway situations.

22. Furthermore, most aerial drones are not tolerant of physical collisions, and collision risks must therefore be managed appropriately to avoid damage to both aerial drones and infrastructure. One common collision risk involves overhead lines and track-side equipment. Management of these risks is difficult. Flight below live overhead power lines can cause interference with the compass on-board most aerial drones and places the drones inside the rail corridor where they present a collision risk with rolling stock. Collision risks are also increased when operating an aerial drone beyond visual line of sight. In the railway context, such operations could arguably be one of the major benefits of using aerial drones across long stretches of track, provided the related risks can be mitigated. Traditional aviation concepts rely on the see-and-avoid principle, which is contingent on the pilot being physically on-board and in control of the aircraft. With aerial drones, this principle can only be adhered to during operations conducted within visual line of sight or, with the right technology, by extending the line of sight. Even then, however, collision risks are not entirely eliminated.

23. In that context, both the pre-planning of flight activities and the on-site evaluation should be conducted to account for any unforeseen risk. The competing interests between rapid deployment and rigorous flight planning must be managed. Adequate safety systems need to be implemented to ensure that operations strike the fine balance between risk aversion and operational efficiency. Often, due to the changing hazards associated with rail corridors, the best flight planning is done immediately prior to operations. Having a complete understanding of train movements near operations is of the utmost importance. Additionally, awareness of blind corners and areas with limited visibility is key to avoiding collisions between aerial drones and rolling stock.

IV. Visual line-of-sight restrictions

24. Issues related to the requirement to maintain visual line of sight are often cited as the most significant matters affecting aerial drone operations for linear infrastructure such as railway tracks. Aerial drone flights would inevitably be required to go beyond visual line of sight to accomplish tasks such as long-distance track inspection. Regulations are perhaps the most challenging part of conducting operations beyond visual line of sight.

25. It is generally accepted that an operator's inability to visually observe an aerial drone and its surroundings increases the likelihood that an incident will occur. Some of the issues associated with such operations include the inability to see the terrain and how it changes; the inability to see other incoming aerial vehicles; the inability to determine local weather conditions; and the potential for the aerial drone to progress beyond the reach of telemetry, thereby eliminating the ability to control the drone.[10]

26. Drone operations beyond visual line of sight are hypothetically possible with technology that is currently available. As railroads continue to employ aerial drone technology, the industry is beginning to develop its own set of standards and requirements to achieve its objectives for monitoring, assessment and inspection.

27. Such operations, however, require altitude awareness. This could be addressed by adding sensors to the aerial drone. However, the flight planning tool used with the aerial drone would have to be able to calculate the flight path. A better approach might be to integrate a terrain-following feature into the flight

[10] United States of America, Department of Transportation, *Unmanned Aircraft System Applications in International Railroads* (Washington, D.C., 2018).

planning and flight control software. Still, such a solution comes with its own challenges, such as ensuring access to sufficiently accurate terrain data and the reliability of the positioning system on-board the drone. Real-time kinematic solutions for satellite positioning systems are available, but most require remaining within 10 km of a baseline to receive strong corrections, which is not consistent with the range that most railways would desire.

28. Corridor flight planning capabilities are also a requirement. Flying long distances using waypoints does not provide information in sufficient detail to ensure that aerial drones avoid flying over people or restricted zones or executing steep altitude changes. Corridor flight planning is likely to rely on geofences to ensure that the vehicle remains in the intended area.[11]

Box 2

Selected national regulations on operations beyond visual line of sight

Australia

Operations beyond visual line of sight are allowed with prior approval. The Association of Australian Certified Unmanned Aerial Vehicle Operators is calling for the creation of a continent-wide unmanned traffic management system to facilitate the transparent and harmonized integration of all forms of aerial drones into national airspace. It is argued that such an approach would resolve significant and growing safety problems posed by unsafe and non-compliant operators. The creation of an unmanned traffic management system would facilitate the necessary conditions to conduct operations beyond visual line of sight.

China

Operations beyond visual line of sight are allowed with restrictions. Aerial drone operations within visual line of sight must be conducted in the daytime and route priority must be ceded to other aircraft.

Japan

Operations beyond visual line of sight are currently allowed over areas unlikely to be entered by a third party (for example, mountains, rivers, lakes and forests), while more permissive regulation is scheduled to be enacted by 2025. Regulations require operators of all aerial drones weighing more than 200 g to always monitor the drones and their surroundings with their own eyes.

India

Operations beyond visual line of sight may only be carried out in designated drone corridors, on the following conditions: the aerial drone must be certified as airworthy to be flown in that particular drone corridor; the aerial drone must be flown for the purpose specified in the relevant authorization; and the aerial drone must not carry any unauthorized payload that is not incidental to the purpose of the operation. Furthermore, aerial drones may only take off from and land in designated drone ports authorized to handle operations of pre-approved aerial drone types.

[11] Ibid.

V. Legal and regulatory environment

29. The regulation of commercial drones at the national level has typically been approached as an extension of existing regulatory frameworks for the aviation sector. In that regard, drones are essentially aircraft with special characteristics,[12] the most notable of which is that a pilot is not on-board. The drone thus operates with a remote link to a control station, or autonomously via computerization. While drones are not new technology per se, the recent upsurge in their availability, capability and affordability poses difficulties for traditional models of national regulation and enforcement.

30. From an international law perspective, it is generally accepted that drones fall within the scope of article 8 of the Convention on International Civil Aviation, in which pilotless aircraft are addressed. The article stipulates that pilotless aircraft can be flown over the territory of a State only with special authorization by that State, and that they must be operated in accordance with the terms of that authorization. In addition, each State must ensure that the flight of such aircraft shall be so controlled as to obviate danger to civil aircraft. In article 8, therefore, the duty of States to eliminate risks to other aircraft within their jurisdiction is formalized. In addition, under the article, States are by default prohibited from allowing their pilotless aircraft to operate beyond their jurisdiction. Therefore, international drone operations are not currently in practice. Consistent with this Convention, and in line with the international airspace standards established by the International Civil Aviation Organization, national regulatory responses to drones have been centred on concepts of segregated and non-segregated airspace. If treated as aircraft, drones are unable to comply with the traditional rules of the air and technical standards issued by the International Civil Aviation Organization and are therefore unsuited to non-segregated airspace.[13]

31. Thus, drones are generally only permitted to operate in segregated airspace, invariably below 500 feet, where they are separated from the bulk of air traffic. Certain other conditions typically apply, most notably those concerning proximity to built-up areas, such as protected zones near airports and military installations, and requirements on maintaining line of sight. Dedicated regulations have been implemented in approximately 20 jurisdictions to counter these concerns. Australia, Canada, New Zealand, the United Kingdom of Great Britain and Northern Ireland and the United States of America are some of the earlier archetypes to include such regulations.

32. The most commonly cited concerns with regard to drone use are that (a) national legislation is not adapted to deal specifically with drones, (b) enforcement mechanisms are inadequate and (c) current regulation is too restrictive and presents impediments to the further development of drone technology and innovation. Other concerns that have been identified by the industry are those relating to safety, security, airspace access, the radio communications spectrum and regulatory considerations.[14]

33. With regard to security, it is becoming increasingly evident that new safeguards are required for the screening and clearance of drone operators including, but not limited to, ground station security, control of physical access

[12] David Hodgkinson and Rebecca Johnston, *Aviation Law and Drones: Unmanned Aircraft and the Future of Aviation* (London, Routledge, 2018).

[13] Ibid.

[14] Ibid.

to drones at ground facilities and appropriate encryption or cybersecurity protocols for control links.[15]

34. The growing use of aerial drones is also putting pressure on a limited radio communications spectrum. Like airspace access, an expanding demand for limited allocations on the spectrum will necessitate rationing and prioritization.[16] Other considerations include authorization and permits for operations, personnel and operator licensing, and liability issues.

35. Drone regulations were in force in Australia as early as 2002, making it the first country to establish such regulations; as at 2016, Australian legislation has been modified to include rules for non-recreational drones.[17] Australia regulates drone operations according to weight and type of use. Pilots are required to be licensed, complete training, have a minimum number of flying hours and have procedures for flight safety. Pilots flying a heavy drone are required to obtain an airworthiness certificate for their aircraft.

36. In China, guidelines and provisions for drone operations have been issued since 2015.[18] A dynamic database system (known as the Drone Cloud) was also created to monitor drone operations. This system triggers alarms to notify operators when they are flying in close proximity to restricted zones. Users that are not connected to the Drone Cloud must consult the authorities before flying. Two operating regimes are stipulated: flying within visual line of sight and flying beyond visual line of sight. Flying within visual line of sight must occur during the daytime. Regulations for drones weighing between 1.5 kg and 150 kg limit their speed to 100 km per hour. Drone operations require a designated pilot who will be held liable for all incidents. According to the country's "Interim provisions for low-level operation of light and small unmanned aircraft systems", aerial drones are divided into seven categories. Drones weighing less than 1.5 kg are not regulated but must operate in a safe manner to avoid injury to third parties.

37. Until recently, drone regulations were absent in India.[19] However, legislation is now being drafted for consideration. In India, aerial drones are defined as consisting of a remotely piloted aircraft, a remote pilot and a command-and-control link. This definition is important and paves the way for the regulation and imposition of restrictions of drone operations. Civilian use of drones is allowed and includes activities such as monitoring, disaster management, surveys, commercial photography and mapping. For all drone operations in India, a unique identification number is required and issued by the country's Directorate General of Civil Aviation. Upon receipt of the unique identification number, an identification plate inscribed with the number must be affixed to the drone. Only citizens of India or companies registered in India can

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15 Ibid.

16 United States, *Unmanned Aircraft System Applications in International Railroads*.

17 Australia, Parliament of Australia, Rural and Regional Affairs and Transport References Committee, *Current and future regulatory requirements that impact on the safe commercial and recreational use of Remotely Piloted Aircraft Systems (RPAS), Unmanned Aerial Systems (UAS) and associated systems* (Canberra, 2018).

18 Droneregulations.info, "China", Global Drone Regulations Database. Available at https://droneregulations.info/China/CN.html (accessed on 9 July 2019).

19 UAV Coach, "Drone Laws in India", available at https://uavcoach.com/drone-laws-in-india/; and India, Ministry of Civil Aviation, "Civil aviation requirements", Directorate General of Civil Aviation website, available at http://dgca.nic.in/rules/car-ind.htm (both accessed on 10 July 2019).

acquire a unique identification number. Ownership of the drone is registered and is transferable under certain procedures. Liability insurance is mandatory in case of damages to a third party, and the operator is responsible for notifying the Air Safety Directorate, the Directorate General of Civil Aviation and the Bureau of Civil Aviation Security of any incident or accident within 24 hours. All flights above an altitude of 61 m require a permit, also issued on a case by case basis by the Directorate General of Civil Aviation. Drones must be operated during daylight in good visual meteorological conditions, with ground visibility over 5 km and wind speed less than 37 km per hour. Pilots of drones heavier than 2 kg must be at least 18 years of age. The pilots complete practical training and must demonstrate satisfactory control of a drone throughout its operation. Dropping or discharging substances is prohibited unless specifically cleared in the operation permit.

38. In Japan, in April 2015, amendments were made to the Civil Aeronautics Act to include drone regulation.[20] An inter-agency council involving several ministries and public authorities was established and, in 2018, it developed a road map on the industrial revolution in the air, to regulate the commercial use of aerial drones. According to the road map, all drones are to be operated within visual line of sight. Limited applications beyond visual line of sight are currently permitted, and wider deployment of drones by 2025, including for logistics services, is envisaged in the road map. Drones cannot carry dangerous objects such as flammable materials and must avoid dropping anything.

39. In the Russian Federation, the first draft legislation concerning drone operation, outlining standards on certification and drone registration, was introduced in 2015 and entered into force in March 2016.[21] According to the legislation, each flight must have a crew comprising a pilot and an observer, both of whom are present throughout the flight and responsible for the flight. The crew must have a flight plan, similar to a conventional aircraft. The flight plan information should include the drone model, the purpose of the flight, the flight time and the estimated area or zone of flight. Drones must be operated during the daytime and have documentation on-board.

40. In general, the legal frameworks in most of these countries are aimed at protecting property and securing the safety of people on the ground and of other airspace users. However, the approach to issues such as insurance, privacy, licensing and other flight restrictions varies greatly from country to country.

41. In particular, issues related to liability and insurance for aerial drone operations constitute uncharted territory in many countries, since the nature of drone operations makes it difficult to allocate liability among manufacturers, operators, pilots, software providers or any other entity involved in drone operations. In aviation, liability typically includes the damage caused to people and property (third parties) either on the ground or in mid-air collisions. There is no common international regime for third-party liability in aviation (whether piloted physically or remotely). While a global legal instrument exists (the Convention on Damage Caused by Foreign Aircraft to Third Parties on the Surface), very few countries have ratified it. It follows that rules governing liability for third-party damage are based on domestic law. Liability can be

[20] Hiromi Hayashi and Kohi Toshima, "Regulations on Drone Flights in Japan", in *The International Comprehensive Legal Guide to Aviation Law 2019*, Alan D. Meneghetti and Philip Perrotta, eds. (London, Global Legal Group, 2019).

[21] Russian Federation, Office of the Mayor of Moscow, "Let's fly: rules to follow when flying a drone", Official Portal of the Moscow Mayor and Moscow Government, 27 September 2017.

limited by a cap on the potential level of compensation, or unlimited, with no cap on the amount of damages for which defendants are potentially liable. In practice, compensation will be limited by the value of the insurance policy purchased. Hence, regulations exist to establish minimum insurance requirements. On the premise that the regulation of aerial drones is primarily based on the basic notions of aviation, further consideration may be required to incorporate the specificities of aerial drones into traditional insurance policy calculations.

VI. Select policy considerations

42. In considering policy aspects, the overriding concern appears to be the need for standardization and effective regulation. However, the current patchwork of inconsistent standards presents difficulties for the growth of the industry. In that regard, a distinction should eventually be made between what could be considered risk-mitigated, routine drone activities in the railway environment and special, higher-risk operations requiring additional risk assessment. The fact of the matter is that commercial drone applications are not only already under way in the railway environment, but are also expanding alongside this rapidly progressing technology. In that respect, fundamental issues to consider include the extent to which operational standards and safety protocols are to be set by the industry and the identification of the appropriate policy space in which Governments can intervene and regulate the safe and lawful deployment of drones.

43. For example, many countries around the world permit limited operations beyond visual line of sight, but the requirements for securing approvals can vary significantly. As operations beyond visual line of sight will expand in the future, it is likely that harmonized requirements based on best practices and proven safety protocols will be adopted across different jurisdictions, leading to greater consistency of international and national regulations.

44. The emergence of aerial drones as a distinct segment of aviation gives rise to clear challenges for other airspace users. The safe separation of air traffic is a key safety principle in physically piloted aviation that led to the development of air traffic control systems. These systems operate at both the national and international levels to provide a common operating environment based on the fundamental rules of the air as laid out in the annexes to the Convention on International Civil Aviation.

45. The low altitude and traffic density challenge of using aerial drones is recognized by several countries as being far from hypothetical. Since 2014, the National Aeronautics and Space Administration and the Federal Aviation Administration of the United States have been conducting parallel major research programmes tasked with developing unmanned aircraft system traffic management architectures intended to provide air traffic control services for aerial drones operating at altitudes between 100 ft and 400 ft.[22] Likewise, the European Commission announced, at the end of November 2016, the launch of a research programme on unmanned airspace, or "U-space", also addressing

[22] Parimal Kopardekar and others, "Unmanned aircraft system traffic management (UTM) concept of operations", paper presented at the Sixteenth American Institute of Aeronautics and Astronautics Aviation Technology, Integration, and Operations Conference, Washington, D.C., June 2016.

aerial drone operations in the 100 ft to 400 ft airspace category.[23] In December 2016, the Civil Aviation Authority of Singapore and Nanyang Technological University launched a four-year research programme aimed at developing a complete national unmanned traffic management system.[24] While such a development would have implications stretching far beyond the use of drones for railways, it will likely have clear benefits for that use case as well.

Box 3

National unmanned traffic management research initiative in Singapore

Commercial drone operations were adopted early in Singapore, but the country faces the fundamental challenge of extremely limited availability of airspace[a]. In addition, airspace access is an important economic and security consideration. The emergence of the commercial aerial drone industry has exacerbated those pressures, producing a situation where applications to fly in Singaporean airspace are all-too-often rejected as a result of conflicting user needs, even where the proposed operations would otherwise comply with national regulatory requirements. That restriction on airspace access for aerial drones, in turn, is seen to present obstacles to the development of the commercial drone industry as a whole, including secondary impacts on the country's significant information technology base.

In December 2016, the Civil Aviation Authority of Singapore and Nanyang Technological University announced a four-year joint research and development programme intended to create a national unmanned traffic management system as a means of overcoming this airspace access challenge. The proposed architecture will include the following features: designated air corridors for aerial drones; defined no-fly zones around sensitive areas such as airports and other critical infrastructure, enforced using geofencing; detect-and-avoid systems integrated into aerial drones to assist in collision prevention; and a national network of ground coordination stations that can schedule drone traffic flows, monitor aircraft speed and ensure safe separation. The development programme is expected to draw upon a wide variety of technological and research disciplines, including automation, robotics, sensor processing and data fusion. Initial development activity will rely primarily on laboratory-based work, using simulation to test concepts.

[a] For more information, see Singapore, "CAAS and NTU extend partnership in air traffic management research", Civil Aviation Authority of Singapore website, 8 February 2018.

46. Another consideration is the basic notion that the operator of a drone is responsible for its use. When a drone service is delivered in prohibited airspace, in an unsafe manner or for illegal purposes, the authorities should be able to act and hold the operator or operators accountable. Where lacking, this principle will need to be clarified in national law. Moreover, it will be necessary for drones to have an identifiable owner or operator at all times, so that responsibility can be enforced.

47. In that regard, competent authorities should clarify the applicable insurance and third-party liability regime and monitor the compensation mechanisms for potential victims and damages. The establishment of

[23] Single European Sky Air Traffic Management Research Joint Undertaking, *U-space: Blueprint* (Luxembourg, Publications Office of the European Union, 2017).

[24] Innovation Toronto, "Singapore developing drone air traffic control systems", 30 December 2016.

compensation funds to cover victims of accidents caused by uninsured drone users, similar to the system used in the motor insurance sector, could be envisaged. Reporting on drone incidents should be integrated into overall incident reporting requirements, drawing from the example of India. Systematic and coherent incident reporting will improve safety and be instrumental for insurance companies in carrying out risk analysis, which forms the basis for third-party liability insurance premiums.

48. Ultimately, integrating aerial drones into railway systems can only be approached as a continuous innovation process, not as a goal with a finite end point. The uses of this technology will evolve and grow. Governments and other competent authorities and sector organizations will need to adapt and adjust their rules and procedures to accommodate expanding operations. While several international organizations have made substantial progress towards meeting these challenges, the regulatory framework will need to be reinvented to accommodate the new reality presented by aerial drones. These issues will not become less challenging or less resource-intensive as the drone industry rapidly expands over the next decade.

49. The discussion of the benefits, challenges and policy considerations regarding drones is summarized in the annex to the present document.

VII. Issues for consideration by the Working Group

50. Among the strategic transport priorities of ESCAP is the pursuit of quality, reliable, sustainable and resilient infrastructure through, among others, the integration of science, technology and innovation. Against this background, the Working Group may wish to consider its potential role in supporting a contemporary and forward-looking approach to transport infrastructure planning, investment, maintenance and operation.

51. In this context, it could be beneficial to consider whether, and under what circumstances, a regional approach could be developed. Indeed, international commercial drone operations are effectively omitted from the current international legal framework, leaving it to national jurisdictions to formulate the frameworks most appropriate for their purposes. At the same time, the use of various technologies and tools is increasingly being codified in international instruments on the basis of technological neutrality and functional equivalence. The question then arises as to whether technological neutrality and functional equivalence could be combined to formulate a so-called soft approach (for example, guidelines, best practices and models) whereby international commercial drone operations would be introduced into regional and subregional legal frameworks, and whether that could conceivably facilitate the alignment of the policy cycle with the speed of technological development.

52. In this connection, the Working Group may wish to take the following actions:

(a) Consider the issues highlighted in the present document, including in the annex;

(b) Exchange views and experiences;

(c) Consider the ways in which the use of aerial drones can provide cost-effective and sustainable solutions for the maintenance of the Trans-Asian Railway network and provide further guidance to the secretariat on the matter.

Annex

Key benefits, challenges and policy responses related to the deployment of aerial drones for railway infrastructure inspection and monitoring

Benefit	*Challenges*	*Possible policy responses*
Increased efficiency and reduced costs	1. Training and licensing of staff for rail-related drone operations/flights 2. Ensuring the availability of secure ground facilities, with access to drones and related equipment limited to authorized personnel 3. Mitigating the risks associated with drone operations beyond visual line of sight to such a degree that lawmakers could be satisfied with their safety and enact more flexible legislation in order to authorize them, thus enabling inspection of long linear sections of rail track, culverts, tunnels and bridges	1. Inclusion of the special case of infrastructure in the regulation and definition of reasonable training and licensing requirements tailored to the infrastructure sector 2. National framework legislation for commercial drone operators, including for railways 3. Formulation of policy addressing operations beyond visual line of sight in special categories such as railways, including consideration of unmanned air traffic control systems for drone corridors along the right of way
Increased frequency and level of detail of data collection	1. Increase in the data to be analysed will require additional expertise or technology 2. Staffing requirements of railways may begin to change 3. There will be difficulties in separating the data that are collected for the purposes of the operation from incidentally collected data (data ownership issues) 4. Caution should be applied in the case of commercially sensitive infrastructure or other restricted installations	1. Incorporation of drone operations into national data-related policies 2. Updating and adaptation of railway training and education, as well as recruitment incentives for highly qualified engineers and data analysts 3. Clear and enforceable legislation on the ownership and management of data collected by commercial drone use 4. Application and enforceability of airspace regulation concerning sensitive locations accessible by railway lines
Increased safety for railway personnel in the inspection of assets in remote or dangerous locations	Increased risks associated with flight planning and operations, including the following: (a) Collisions with other drones, rolling stock or overhead lines, or in confined spaces (b) Liabilities associated with drone accidents	1. Identification and codification of industry best practices for safe flight planning and operation, and incorporation of best practices into national guidelines 2. Formulation of a clear and enforceable liability and insurance regime