State of the art in RTM technology for phase 2 trials

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https://doi.org/10.4224/40002683

National Research Council Canada

Conseil national de recherches Canada

Technical Report:

State of the Art in RTM Technology for Phase 2 Trials

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Limited Distribution

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1 Abstract

This report provides a survey of a number of key enabling technologies for implementation of RTM Services. It continues on an earlier work and report by the authors in 2020, which covered the following capabilities: 1) E-Identification and Situational Awareness, and 2) Flight Planning and Strategic Flight De-confliction. In that report, first performance requirements of these services were discussed in details and examples from literature and other jurisdictions were provided. The second part of that document presented several examples of commercial technologies related to these services.

The present report continues on the earlier work and explains the state of the art of the key enabling technologies for RTM essential services, including:

1) Geo-fencing
2) Collision Avoidance and Detect and Avoid
3) Surveillance and Tracking
4) Communications and Cybersecurity
5) Navigation

While the RTM architecture and services have been defined in recent Transport Canada documents, there is little published work related to the problem of characterization of the performance requirements and effectiveness of the services themselves. In this report, the authors first adapt a model initially introduced by NASA and propose a framework and description for the performances of the RTM services. Then, the performance requirements and proposed measures of performance, specifically for each services are described in Table 3.

2 Introduction

National Research Council Canada is contracted by Transport Canadas's RPAS Task Force to provide technical and scientific input in support of the design and implementation of nation-wide RTM (RPAS Traffic Management) services and network in Canada. The NRC team, represented by the first author, has participated in the regular RTM Action Team since 2019 and also has been a member of the Trial Executive Steering Committee (TESC) since its inception, and has recently joined the TESC's System Engineering Sub-Working Group. Through these participation we have maximized our interactions with the TC team and the opportunities to learn from the on-going activities in order to be able to provide effective contributions to the discussion and work of the Action Team (e.g., NRC Technology Matrix for trial selection). NRC has effectively taken a leading role for assessments and gap analysis of the candidate RTM technologies.

The underlying project aims to: a) provide background information and technical guidance for defining performance requirements related to the RTM services, and b) assist in the assessment of the RTM trials (as selected by the TESC) from the perspective of technology performance and capability. The goal is to understand and analyze the state of the technologies and evaluate their potential for wider adoption in a RTM network by the RPAS ecosystem in Canada.

An earlier project report by the authors in 2020, titled "Background Study and Performance Requirements for Selected RTM Phase 1 Essential Services" dealt with the following capabilities:

1) E-Identification and Situational Awareness
2) Flight Planning and Strategic Flight De-confliction

In that report, first performance requirements of the above services were discussed in details and examples from literature and other jurisdictions were provided. The second part presented several examples of commercial technologies related to these services.

The present report continues on the latter part and explains the state of the art of the key enabling technologies for RTM essential services. It also includes a section on the technical requirements and performance measures of RTM services. The report is structured as follows. Section 2 is a brief background of the RTM services and their performance levels as a reference to this document. Section 3 will dive deeper in the state of enabling technologies and will bring recent examples of technology trials performed in other jurisdictions (US and EU). It will start with a functional-level grouping of the technologies involved in RTM services as related to urban flight scenarios (Phase 2) and will present the state of art for those technology groups. Section 4 presents a proposed framework for defining technology requirements and performance measures from the perspective of RPAP operator. This framework has been originally delivered to TESC's Systems Engineering Sub-Working Group in January 24, 2021 and was discussed by the members for additional refinements.

3 Background

A recent UTM (UAV Traffic Management) market study, forecasts that the global market for commercial UAV will reach to 6 million units sold in 2021 and then grow at a CAGR of 10.75% in the proceeding ten years (2021-2031) [1] . UTM or RPAS Traffic Management (RTM) systems are generally understood to be key enablers to support the expected growth of the UAV industry and foster new applications that will come with emergence of e-VTOL platforms.

Canada's RTM services are Illustrated in Figure 1. This report focuses on RTM technologies that can impact urban flight applications, as the second phase of the RTM trials.

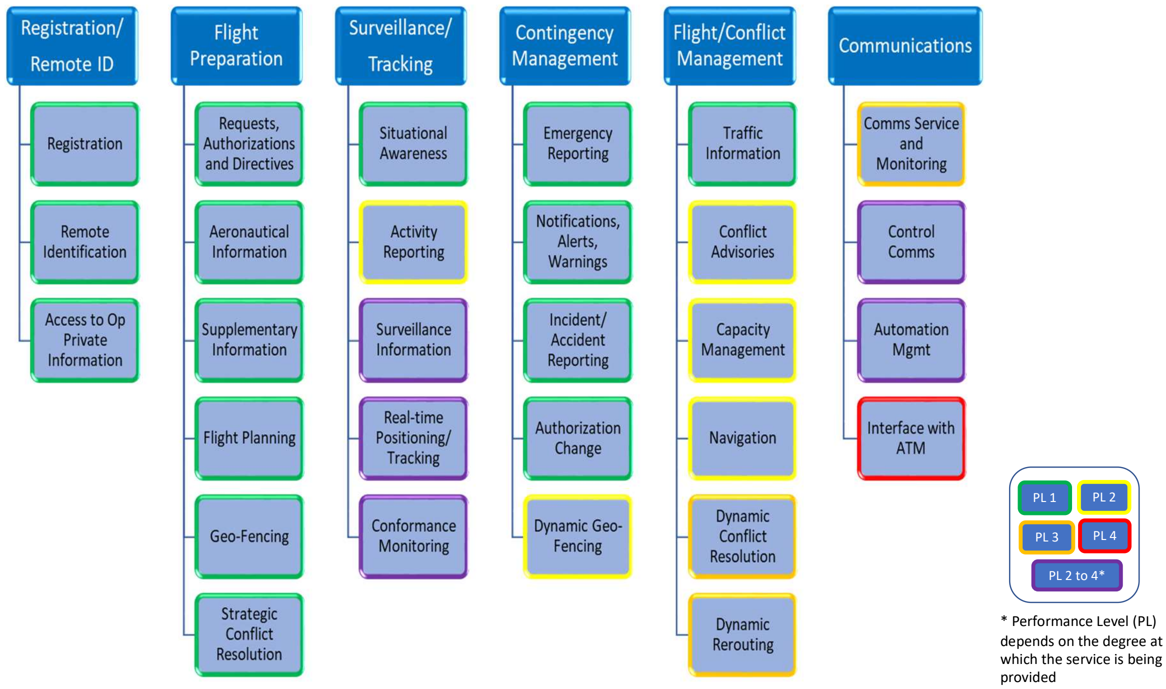


Figure 1 : Canada RTM Services (Courtesy of TC RTMAT)

4 Enabling Technologies

Technology is critical for effective implementation and deployment of RTM systems. The key enabling technologies for UTM/RTM may be summarized in Table 1. They cover key RTM services that are essential for managed urban flight operations.

Key Technology	Core Functions
UAS Identification and Registration	UAS needs to register in accordance with the rules and regulations provided by the regulator (TC) prior to operating in the airspace. Airspace managers (ANSP) have the responsibility to identify each UAS operating in the airspace. There should be a direct communication between the pilot and airspace managers in case the UAS operation is aborted or airspace is not available.
Pre-flight planning management tool	ANSP and (Secondary) RTM Service Providers provide operators with accurate, up-to-date pictures of the airspace for the operation that is going to be carried out. The data supplied will mostly be on weather, terrain, and other obstacles hindering the operation. Other data information includes different UAS, no-go areas, etc. This system needs to be dynamically organized. Therefore, the operator needs flight approvals instantaneously before starting the operation. Geo-fencing as well as geo-caging will be implemented with other automated approval by the pilot in case of any flight rerouting in the airspace.
Collision Avoidance	Dynamic conflict resolution is required for safe operations. A detect and avoid system is needed to maintain separation and to avoid dynamic and static obstacles.
Surveillance and Tracking	Situational awareness through tracking cooperative and non-cooperative traffic has to be maintained during the operations in the airspace. Operators has to be provided with the tools to report their activities to the ANSP and UAS Service Providers
Communications	The means of (real-time) communication between operators, TC, ANSP, and other stakeholders has to be provided. In case of emergencies, the operator/manager can dynamically alter the change in operation.
Navigation	The RPAS needs to be able to navigate itself with sufficient precision in all conditions. In case of failure of the operation, it needs to come back to base or a nearby safe area, complying with all RTM standards.

Table 1 Key Enabling Technology Groups

The stat of the art for UAS Identification has been covered in the first project report, hence the following sections will discuss and present that for the other groups in this table.

4.1 Geofencing

Geofencing is essential to ensuring that drones comply with airspace restrictions. Geofences prevent drones from entering no-fly zones and keep them away from protected areas and critical infrastructure. Geo-caging, by contrast, does not allow drones to fly beyond a set boundary. Both measures are critical to keeping complex low-altitude airspace safe for all.

Geofence will allow that an area of airspace be reserved to inhibit a UAS from entering in during a defined time. For practical purposes, it provides a digital barrier to UAS operations and traffic management. Following are the essential functions of geofencing.

- Provide updated information on airspace limitations and requirements where the unmanned aircraft operates, and,
- Ensure the integrity and validity of this data.

Commercial UAS manufacturers, including DJI, have included geo-fencing capabilities in autopilot and control of their RPAS platforms. Some RTM software developers such as UniFly and OneSky also provide this functionality through geo-zoning or similar functions on their flight planning platforms. NAV Canada has partnered with Unifly in 2020 to develop and provide a situational awareness App, namely NAV Drone Mobile App [2] for the airspace users. Goe-zoning is among the functions that the App will feature.

NASA has also tested and demonstrated geofencing technologies, starting at its UTM Technology Capability Level (TCL) 1 (see Figure 2) demonstration [3]. During TCL 2 demonstrations in 2017, the separation was successfully maintained by geo-fencing and at TCL 4 in 2019 that included flight in urban environment. Geo-fence boundaries were defined to restrict the flight volumes.

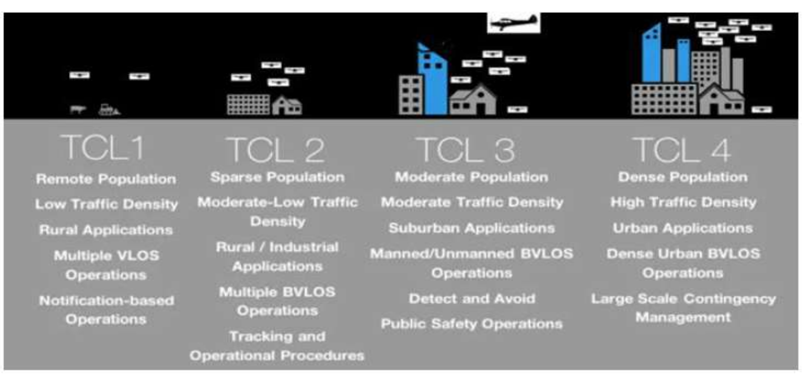


Figure 2: NASA UTM Technical Capability Level structure [3].

A more recent development and demonstration activity regarding Geo-fencing can be attributed to SESAR and U-space. As part of the European U-space project, SESAR launched GOESAFE 2018

(Figure 3) with the objective of "enabling establishing the state-of-the art (in) geofencing solutions". It conducted more than 280 flight tests with 16 different drones to gather data and propose improvements and recommendations for the geofencing system definition in the U-space system. The project concluded in October 2019 with a successful demonstration of geofencing technologies in simulated search and rescue operations. The project demonstrated three tiers of geofencing technologies and capabilities aligned with U-space architecture and capability levels.

The partners first demonstrated pre-tactical geofencing in order to visualize airspace restrictions, including the presence of a no-fly zone, prior to take-off. This allowed the drone operator to create a flight plan that did not conflict with the no-fly zone. As the drone entered the restricted search area, the system used provided a real-time notification to the drone operator, alerting the operator to the presence of the no-fly zone. In addition to notifying operators via real-time geofencing alerts, a pilot application also offered an opt-in function that enables operators to actively prevent a connected drone from entering prohibited airspace.

During the simulation, firefighters employed a drone to assist with the operation and created a temporary restricted airspace around the search vicinity. Two drones hovered outside the restricted airspace boundary, while the search-and-rescue drone and a participating helicopter hovered inside. Firefighters' goal: to contain the search-and-rescue drone to the restricted airspace so it could execute its mission, and to keep other civilian drones out.

Figure 3 U-space GEOSAFE demonstration [4].

4.2 Collision Avoidance and Detect-and-Avoid (DAA)

The ability to detect and avoid other drones in the airspace is crucial for BVLOS flight. There has been several recent progress in utilizing on-board sensor, such as LiDar, radar, and 3D imaging coupled with machine learning for detection and classification of intruders.

In March 2021 [5], NASA reported completion of a simulated aerial inspections demonstration as part of *Systems Integration and Operationalization* (SIO) program. SIO aims to accelerate the safe integration of UAS for commercial applications into the national airspace system. In that demonstration NASA partnered with FAA and American Aerospace Technologies Inc (AATI) and Echodyne to survey miles of petroleum pipeline using an installed detection system to find faults or hazardous conditions in the pipes.

In this demonstration, OneSky System provided real time UTM function, such as drone tracking, integration of telemetry, ADS-B integration, and weather data for situational awareness. AATI' AiRanger UAS platform used an Echodyne radar for detect and avoid. The radar, shown in Figure 4, is a solid state (Electronically Scanned Array) radar designed and developed for airborne detect and avoid.

Figure 4 UAS platform (and Echodyne radar) used for NASA BVLOS aerial inspection demonstration [5].

4.2.1 ICAROUS & FLARM [6]

NASA LangleyResearch Center (LaRC) has conducted a series of flight tests referred to as Pathfinder 1 to demonstrate the use of onboard autonomy-enabling technologies [5,6]. Two test vehicles were equipped with an onboard autonomy software developed at NASA LaRC referred to as ICAROUS (*Independent Configurable Architecture for Reliable Operation of Unmanned Systems*).

The paragraphs below are based on excerpts from NASA's publication on these flight tests:

"ICAROUS's autonomous detect and avoid and geofence conformance capabilities were tested and demonstrated in the Pathfinder 1 flight tests. In these flight tests, the two aircraft initially follow flight plans that have been previously approved by a USS [UAS Service Supplier] and determined to be conflict-free (strategic de-confliction). During the flight, a scripted emergency scenario is triggered, requiring one vehicle to make an emergency landing using an onboard application named Safe2Ditch to select the best landing site. A straight-line path to the landing site would cause the UAS to become non-conforming and cross directly through the airspace of the other UAS, creating an elevated risk of collision. Two methods of autonomous onboard conflict resolution were tested to resolve this scenario and prevent collision. In the first method, the non-conforming vehicle flew directly to the landing site, passing through the airspace of the conforming vehicle. The conforming vehicle used ICAROUS's SAA [DAA] capability to autonomously deviate from its flight plan to maintain a well-clear distance of 500 feet then returned to the flight plan once the conflict had passed. In the second resolution method, a keep-out geofence was placed 500 feet around the flight plan of the conforming vehicle. The non-conforming vehicle used ICAROUS to plan a route to the landing site that respected the geofence and thus maintained a safe separation from the airspace of the conforming vehicle. This paper also reports on the use of FLARM (Flight Alarm), a vehicle-to-vehicle position communication technology that transmits on 915 MHz, to provide traffic vehicle position data for onboard SAA [DAA]."

"These flight tests demonstrated the use of FLARM technology [(see section below)] as a traffic surveillance source for onboard SAA. Because FLARM operates in the 900 MHz band, there is no concern of oversaturating the ADS-B frequencies, but the 900MHzrange may experience interference from common UAS telemetry radios and communication methods. FLARM reception during the Pathfinder flight tests was adequate to enable SAA in these particular scenarios but was less reliable than similar tests using ADS-B.A full FLARM installation with the recommended two antennae is expected to improve performance. It would also be beneficial to SAA systems if FLARM could guarantee reporting of all detected traffic vehicles and directly provide absolute position instead of relative position. Future work should evaluate FLARM with a full two antenna installation and determine the extent to which interference from common 900MHz transmitters affects FLARM reception."

Figure 5 UAS platform used by NASA for DAA demonstration using FLARM [7]

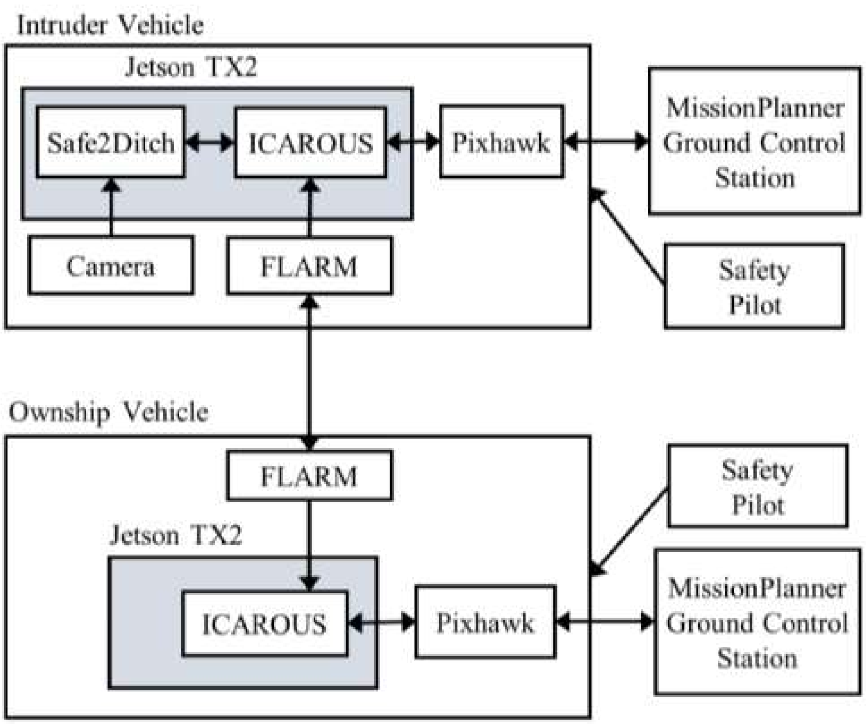


Figure 6 System diagram of the test vehicles in NASA DAA demonstration [7]

4.3 Surveillance and Tracking

Surveillance is another key enabling technology. It can provide complete tracking and identification of cooperative and can be achieved through automatic dependent surveillance - broadcast (ADS-B) and other transponder solutions, such as FLARM (as referred to in the previous section) and Unifly's Broadcast Location & Identification Platform (BLIP.) [8].

However, the industry is presently in its early stages to determine a suitable form of technology for the surveillance of drones. Historically, the large size of the ADS-B systems is one of the major constraints for its deployment in drones. However, certain companies have come up with ADS-B solutions for drones specific to commercial applications. For instance, DJI's Matrice 200 (M200) series drone has built-in ADS-B, which can be used for firefighting, aerial inspections, precision agriculture, and search-and-rescue applications.

For surveillance of non-cooperative a number of technologies have been developed that are based on Radio Frequency (RF) detection, radar, Electo Optical (including Infra-red) and Sonic sensors. Ground radars and more recently airborne radars (such as recent models developed by Echodyne and Fortem Technologies) can be used for airspace surveillance.

DJI has developed and marketed a RF-based drone detection platform, namely DJI Aeroscope [9] that identifies UAV communication links and tracks in real-time telemetry data from DJI aircraft up to a range of 50 km for stationary unit and 5km for the mobile. It can identify the following information from a detected drone

- UAV serial code
- Make and model
- UAV position
- Speed
- Latitude
- Ground controller location
- Take-off position

FLARM was developed to give recreational sail plane pilots warnings about conflicts with other aircraft in the airspace. It can also be used by UAS to detect transmitting aircraft and other UAS. In addition to communicating with other FLARM units, FLARM is capable of receiving1090MHzADS-B, giving even more awareness of the airspace. FLARM transmits data on 915MHz, while ADS-B operates on 978or 1090MHz. There is concern that if many UAS began transmitting ADS-B, the frequency would become saturated and GA applications of ADS-B would be degraded. Unlike ADS-B, the FLARM system uses an undedicated (Industrial, Scientific, and Medical) radio band so that operational practices to ensure signal continuity are appropriate. FLARM offers multiple products.

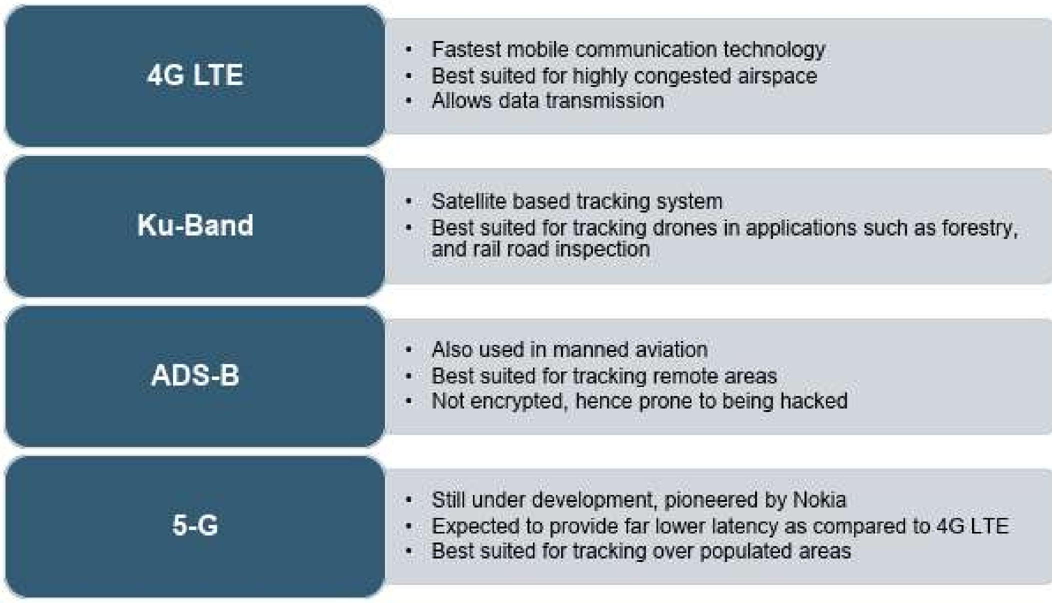
4.4 Communications

Communication is a top priority technology to enable RTM. An effective communication system helps in effective drone-to-RTM and drone to drone communication. It is important for command and control (C2) as well as wireless exchange of data among systems. For short-range missions, Wi-Fi, and other technologies like Bluetooth 5 may work, however, at farther distances (BVLOS), a reliable transmission is required for smooth communication with drones.

Presently, there is no established infrastructure to support drone operations. However, a number of communication technologies are under testing to support RTM C2 communications. These communications are likely to rely on 4G/LTE (long-term evolution) systems. NASA's UTM project is currently aimed at improving C2 communication networks to evaluate its performance to support drone operations. Figure 8 shows the various communication technologies being used for drone navigation.

One of the most important requirements of a successful UAS traffic management system is extremely low latency and an ultra-reliable communication system. The use of communication systems is to track drones and to transfer instructions between drones, operators, USS, and transfer data in case of vehicle-to-vehicle communication. For this to work smoothly, the authorities working on the concept of UAS traffic management are collaborating with communication companies to utilize their technical expertise. There are four types of communication technologies envisioned to be used in UAS traffic management systems – 4G LTE, ADS-B, Ku-Band, and 5G technology. These technologies are best suited for different drone applications. Moreover, a combination of these technologies is expected to be used in the final UAS traffic management system architecture for better safety of drones and people around them. The following figure depicts different communication technologies envisioned to be used in the UAS traffic management system:

The 5G use cases have evolved and there is a need for the safe operation of UAVs. Moreover, it is to ensure that other end users of the network do not face any loss of service due to their proximity to unmanned aerial systems. In order to focus on the needs of a new and rapidly maturing sector, there have been several activities in the 3rd Generation Partnership Project (3GPP) Working Groups to certify that the 5G system will fulfill the connectivity requirements of unmanned aerial systems (UAS), which includes drones, and UAV controllers under the surveillance of UAS traffic management (UTM).



Source: Expert Interviews and BIS Research Analysis

Figure 7 Type of Communication Technologies used in RTM

In 3GPP's Release 17, which is 5G Enhancement for UAVs, it looks into the needs of 5G connectivity of drones. In this study, new KPIs and communication needs of the UAV with a 3GPP subscription have been produced.

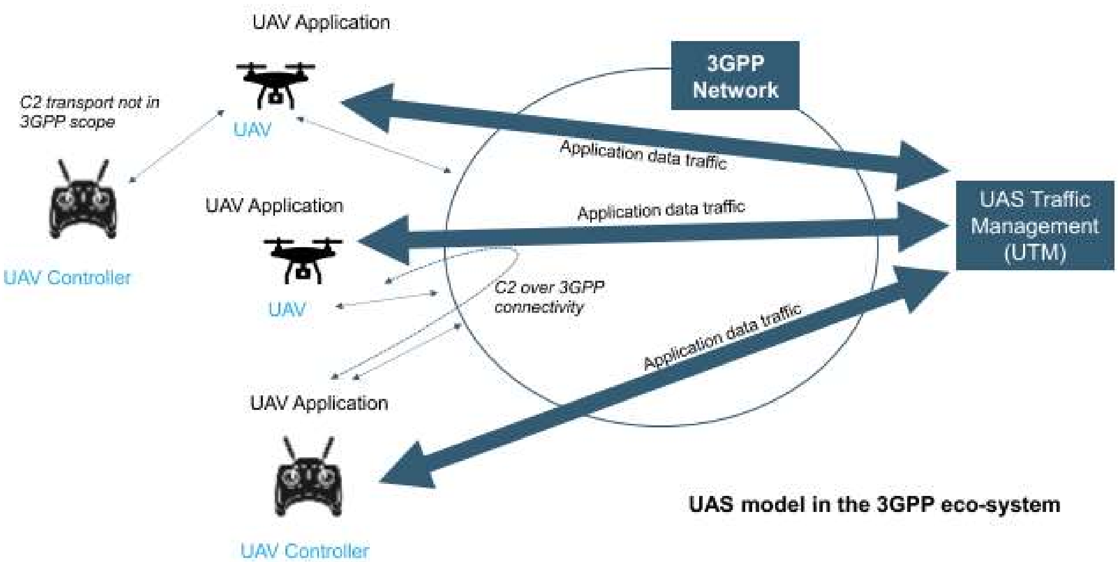


Figure 8 UAS Model in the 3GPP Ecosystem

Source: 3rd Generation Partnership Project (3GPP)

In another instance, in July 2020, CIRC Coretronic Intelligent Robotics Corp (CIRC), a Taiwan Technology and subsidiary of Coretronic Group, conducted successful operational demonstrations over 5G using its autonomous drones in Taiwan. The company collaborated with CHT to use CIRC's solutions to Chunghwa Telecom's commercial 5G network. These two companies partnered to demonstrate remote drone inspection and real-time transmission of 4K.

4.4.1 Cybersecurity and Blockchain

In simple terms, blockchain means recording transactional data in the form of blocks that are linked together using cryptography. Each block has a cryptographic hash of the previous block. Due to its design, blockchain is resistant to the modification of data, and it cannot be altered once recorded. These blocks are secure, and in order to modify or alter the data, subsequent alteration of data is required.

As drone applications are becoming significantly universal, a proper service delivery model involving new participants in this ecosystem is required. Virtualization and cloud infrastructure need to be deployed in order to deliver services quickly and in a rich manner. All the data that has been shared with the users and other parties is to be accessed through APIs for granular control and security of services. Blockchain has the potential to deliver a framework that can be used by different stakeholders and third parties in the drone ecosystem.

There are two important areas in which blockchain can be of important use:

- **• Security:**

Future drones have to be provisioned with cryptographic material that supports all the confidential, authenticated, and protected communications amongst themselves and through the gateway. The cryptographic material and services should depend on the protocols that are being used for communication, messaging, and security objectives of each drone. In addition, the solution required for communication protocols and messaging protocols also use cryptographic algorithms and key material.

For instance, in case of a logistic delivery operation, a blockchain-based vault could log information of the operations such as time, location, resources, and delivery date and make the data accessible to registered users and to other stakeholders along a package's route.

- **Identity Management**:

The blockchain identification system has its own benefits in keeping a track record of drone registration using their ID numbers, thereby protecting users' private information. It monitors and reports complaints about irregularities in drone behavior and damage to public safety as well. This concept is identical to cryptocurrency blockchain, which provides transactional data without disclosing user information.

In case of package delivery services, Walmart is looking forward to using blockchain in a process by which it could automate the logistics of delivery drones. As per Walmart, drones would be able to exchange authenticated information through blockchain keys to confirm whether they are in the same fleet. After validation, a drone then safely passes the package to another.

4.5 Navigation

Currently, a majority of UAS navigation methods rely on GPS/GNSS data for identification of path way points and tracking the position of the aircraft.

Self-piloted drone traffic may be just over the horizon. Also, the current accuracy of ordinary civil GPS data (~ 5 meters) may pose a risk for high precision navigation around crucial infrastructure. A number of methods such as RTK (Real Time Kinematics) [10] and PPK (Post Processed Kinematics) [11] have been used by the industry for accuracy improvements. The typical nominal accuracy of vertical positioning with RTK and PTK is in the 1-2 centimeters range.

GPS-denied navigation is also gaining more attention, as a mode of navigation where the GPS data is degraded substantially or not available (such as indoor flight). Several methods in research literature have been reported recently that rely on on-board sensors such as LiDAR or Stereo Vision or depth camera (RGB-D) for localization and navigation (c.f, [12]).

NASA, for example has contracted Near Earth Autonomy to build the technology for safe, self-piloted takeoff and landing without the use of GPS or maps. Using an on-board LiDAR sensor the navigation system is able to perform SLAM (Simultaneous Localization and Mapping) in real time and navigate the platform in its final stages of flight.

4.5.1 EuroDrone

Launched in 2019, EuroDRONE is an Unmanned Traffic Management (UTM) demonstration project, funded by the EU's SESAR organization and its aim is to test and validate key UTM technologies for U-Space program. The EuroDRONE architecture is made of cloud software DroNav (illustrated in Figure 9) and hardware (transponder) to be installed on drones. The proposed EuroDRONE system is a Highly Automated Air Traffic Management System for Small UAVs Operating at Low Altitudes. It is a sophisticated self-learning system based on software and hardware elements, operating in distributed computing environment, offering multiple levels of redundancy fail-safe algorithms for conflict prevention/resolution and assets management. EuroDRONE focuses its work on functionalities which involve use of new communication links, use of V2I and V2V technology to communicate information and drones for safe and effective

UTM functionality. Practical demonstrations taken place in Patras/Messolonghi in 2019 are presented and show the benefits and shortcomings for near term UTM implementation in Europe.

EuroDRONE uses a novel Vehicle to Infrastruture (V2I) system called DronAssistant (Figure 10), developed by Dronsystems [13]. Dronassistant is an end to end automated flight management system/mission planning (director) hardware and software system using V2I, V2V over 2.4/5GHz, LTE and sub-GHz communication technology. DronAssistant is used also for Vehicle to Vehicle (V2V) communication thus giving the ability for drones to communicate information to each other (among DronAssistants). The hardware also allows use of

Detect and Avoid (DAA) solutions, giving the ability for drones to detect cooperative conflicting traffic, or other hazards, and take the appropriate action to comply with the applicable rules of flight. DronAssistant is also used for real time tracking via LTE/4G transponder/mission director system. All these capabilities along with full flight planning management were demonstrated in the live demonstrations taken place in July and October 2019 in Misslonghi in multiple realistic UTM scenarios. Figure 10 shows the 200-gram DronAssistant hardware used in the practical demonstrations where autonomous operations of the system where implemented successfully using cloud-based operations over LTE for multiple and complex scenarios.

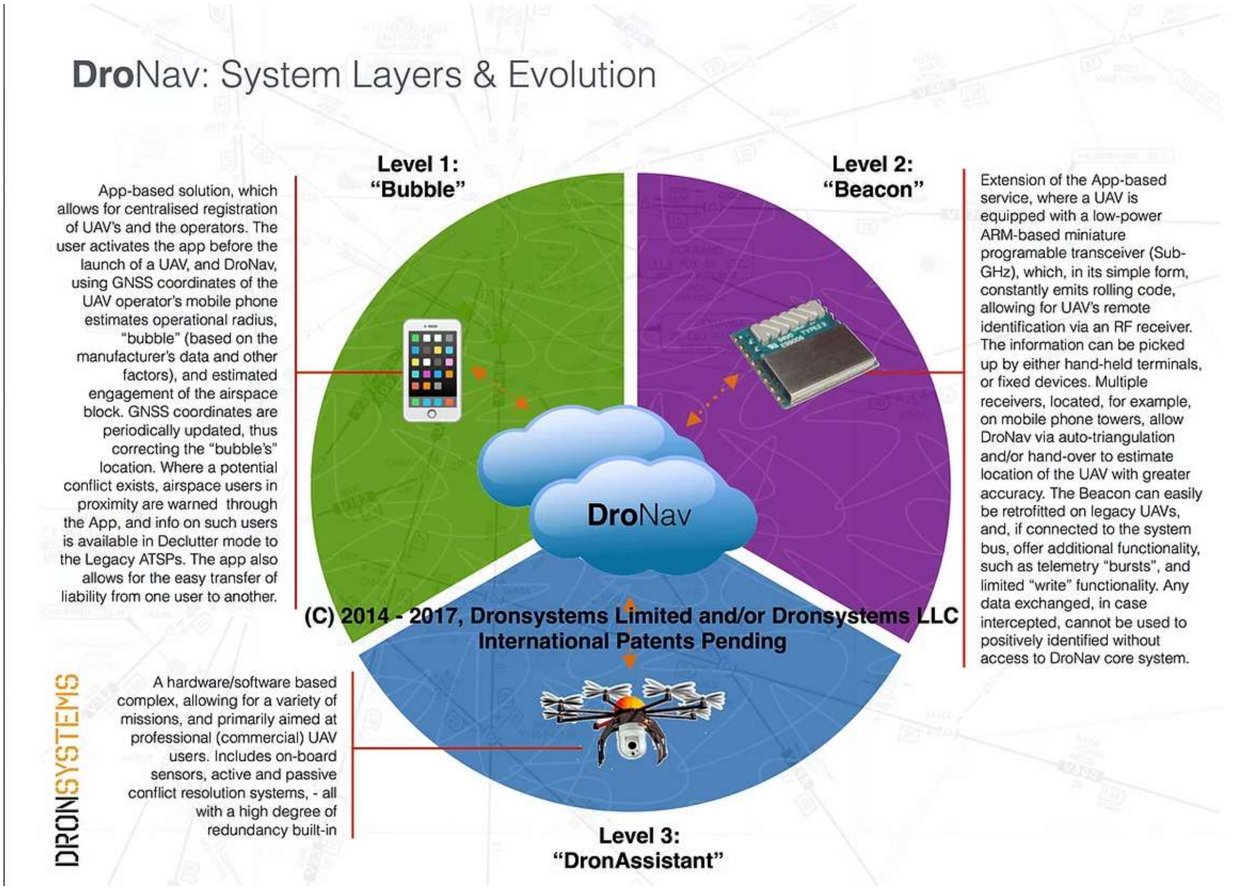


Figure 9 DroNav Cloud Service

Figure 10 DRONAsstant V2I transponder

5 RTM Trial Goals and Requirements

This section proposes a framework for definition of RTM Services requirements and definition of performance criteria of the products and solutions that may become part of the integrated RTM System. The framework and performance measures that are listed in Table 3 have been originally provided to the TESC System Engineering Sub-Working Group on January 24, 2021 and have undergone revisions and refinements as a result of the feedback and comments from the Sub-Working group members

The approach taken here is similar to the method NASA has developed for its UTM services and trials, described below, with a slight difference. Here we combine a multi-actor (client-server) view in the framework for performance of the RTM functions and define the requirements and performance on both the RPAS Operator's side of the function as well as the service provider's. The underlying assumption is that for a RTM function to perform satisfactorily each actor involved has to perform in accordance with its established criteria (individually). Also, the requirement characterization for the operator's side specifically will assist in establishing guideline for RTM Trials with a focus on the RPAS and use cases that will follow and be tested.

To provide a unified RTM System all actors have to work in concert. The RTM Service Requirements provide a comprehensive definition of "what" and "when" about the functions. The actors will carry out and execute the functions through various interactions, which makes the definition of Use Cases and scenarios important in understanding and proper definition of Measures of Performance.

This work is the first step in definition of the requirements and measures of performance for the technologies that will ultimately shape the RTM System as an integrated system. At the first step, the system requirements are defined using the descriptions provided for the services (Appendix A).

As Use Cases and actor interactions that build the RTM System are being developed the requirement and MOPs for other actors may be also defined and proposed at the subsequent steps.

5.1 Background

Since 2016, NASA UTM (**U**nmanned **T**raffic **M**anagement) project has organized four Technology Capability Level (TCL) trials with a number of industry participants. The last TCL test (TCL 4), conducted in August 2019, and focused on UAS flight in urban environment.

Given the similarity between the TCL 4 and RTMAT Phase 2 Trials in urban environment, the framework used by NASA is considered closely here.

NASA applied the following structure for linking UTM (RTM) requirements to the performance levels measures during the trials [14].

Figure 11: Performance model used for NASA/FAA trials [14]

Requirement are defined as:

> *The agreed upon need, capability, capacity, or demand for personnel, equipment, facilities, or other resources or services by specified quantities for specific periods of time or at a specified time expressed as a "shall" statement. Acceptable form for a requirement statement is individually clear, correct, feasible to obtain, unambiguous in meaning, and can be validated at the level of the system structure at which stated. In pairs of requirement statements or as a set, collectively, they are not redundant, are adequately related with respect to terms used, and are not in conflict with one another.*

Each Requirement is connected to a defined Measure of Effectiveness (MOE), as defined below:

> *A measure by which a stakeholder's expectations will be judged in assessing satisfaction with products or systems produced and delivered in accordance with the associated technical effort. An MOE is deemed to be critical to not only the acceptability of the product by the stakeholder but also critical to operational/mission usage. An MOE is typically qualitative in nature or not able to be used directly as a "design-to" requirement.*

And, a Measure of Performance is then defined as:

> *A quantitative measure that, when met by the design solution, will help ensure that an MOE for a product or system will be satisfied. MOPs are given special attention during design to ensure that the MOEs with which they are associated are met. There are generally two or more measures of performance for each MOE.*

REQ ID	Title	Description	Source
UTM-REQ-1	The UTM System SHALL aid in sUAS staying clear of each other.	A fundamental feature of an air traffic management system is to aid in keeping aircraft safe, including from each other.	[NASA 2016]
UTM-REQ-2	The UTM System SHALL aid in sUAS staying clear of traditional aviation.	Traditional aviation encompasses many forms of air vehicles and operation types. UTM needs to aid sUAS operators in staying clear of these operations.	[NASA 2016]
UTM-REQ-5	The UTM System SHALL allow for priority of Public Safety operations over other nominal operations.	Public safety operations need to perform their essential tasks safely, without interference from nominal operations. UTM protocols allow for this need.	[NASA 2016]

Table 2 NASA UTM Requirements for strategic de-confliction [14].

5.2 RTM Requirements and Measure of Performance

The NASA framework links UTM (RTM) System capabilities and services to stakeholders' expectations and performance of products or systems that will be part of RTM.

For characterization of the RTM requirements, the architecture of RTM services, below, is considered and the role of RPAS Operator is differentiated from the role of RTM Primary and Secondary Service Providers

As illustrated in the Figures 12 and 13 the RPAS Operator is considered as an actor client to the services provided by RTM System and other actors e.g., Navigation and Communication Infrastructure. The Operator is in direct contact with Regulator for Registration services but in general will rely on RTM Primary and Secondary Service Providers for the remaining of the remaining of services. Some of the services (especially those provided by Secondary Providers) may deem here as provided directly by the corresponding infrastructures, such as GPS Positioning.

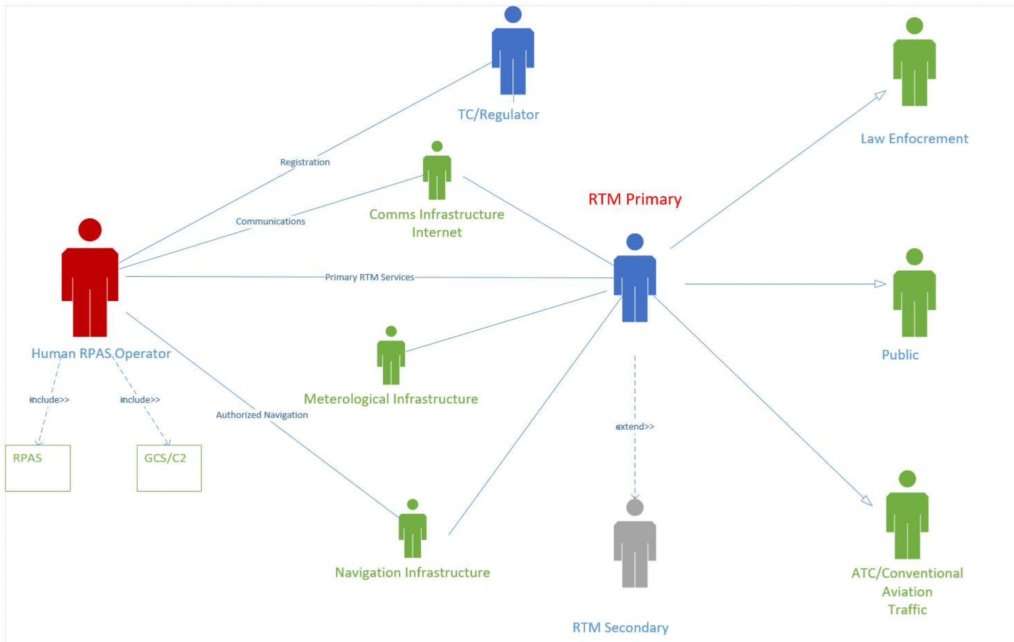


Figure 12 : Simple Use Case illustrating RPAS Operator as client to RTM Service providers

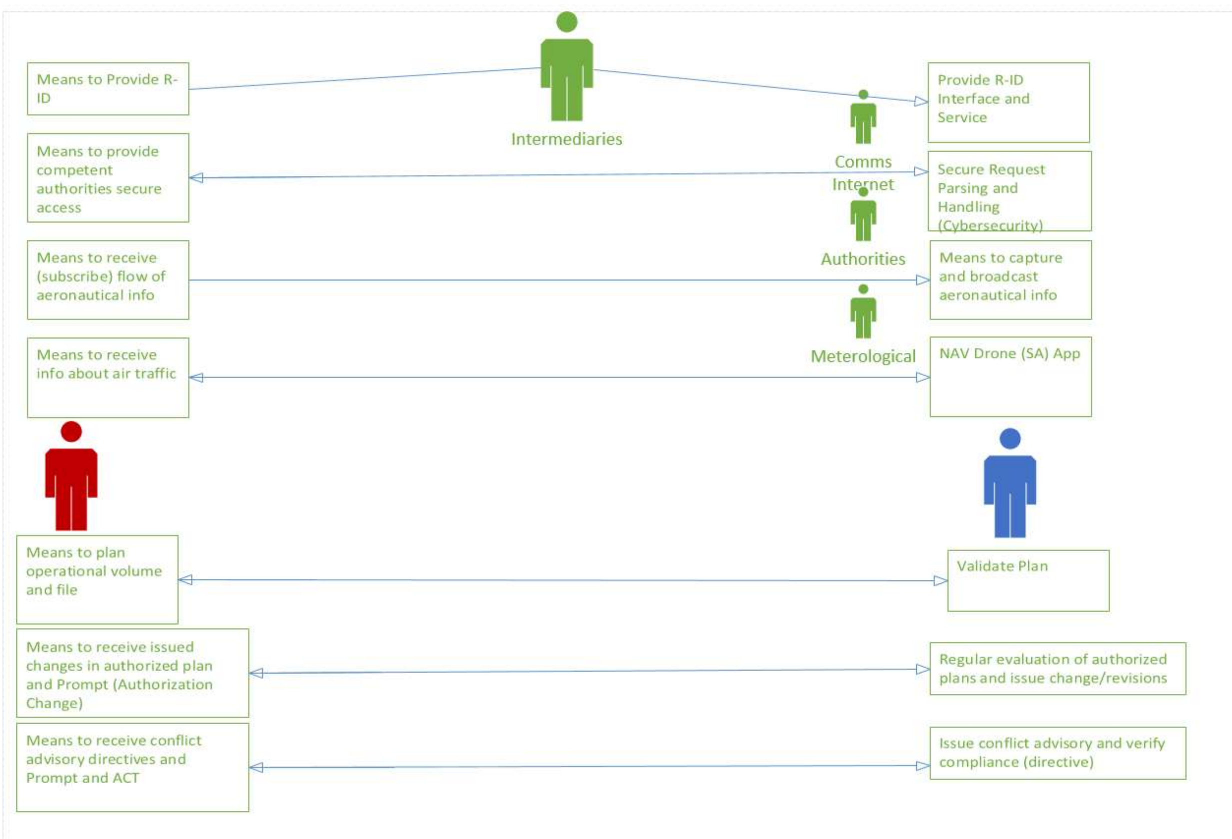


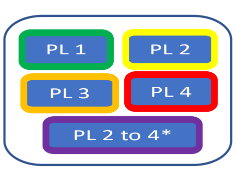
Figure 13 : Examples of RPAS Operator-RTM Provider Interactions

Table 3: RTM Service Requirements and Measures of Performance for RPAS Operators

RTM Services	RTM Requirement Definition	Urban Flight, PL1-3, Measure of Effectiveness (MOE)	Urban Flight, PL1-3, Measure of Performance (MOP)
1) Registration/ Remote ID			
Registration	Means to provide the appropriate registration info to Regulator	This operation may be performed offline a priori. Operator issues query to Regulator for registration and provides required information and receives response in advance of a flight	Rate of positive response received from Regulator
Remote ID	Means to provide identification and location information data (in broadcast or network model, if applicable) about the drone as well as other required info to authorized parties with sufficient update rate	RPAS Operator provides complete Remote ID Info (as defined by the providers) with the optimal required frequency, and if applicable receives acknowledgement in a network model.	1) Remote ID information provided is complete (as per defined requirements) 2) The Frequency complete Remote ID information is provided (in broadcast or network mode, if and where applicable) during flight
Access to Private Info	Means to provide competent authorities secure access to operator data while ensuing data protection	Query by RTM System will provide info about RPAS and Operator during flight while ensuring data privacy	1)Time delay between the receipt of a request and the generation of a response by RPAS Operator 2) Number of repeat requests received for the same flight event
2) Flight Preparation			
Request Authorization	Means to request authorization and directives from RTM System	Operator issues request to RTM System and receives authorization and directive on planned operational volume	1)Average latency to file authorization request in RTM System and receive acknowledgement 2) Rate that successful authorization received
Aeronautical Info	Means to receive flow of aeronautical info from RTM System	Operator receives aeronautical info successfully and applies if/when necessary	1) Average latency to receive complete aeronautical data transmitted during flight 2) Average latency to affect the flight plan with the received Aeronautical Info
Supplementary Info	Means to receive data as deemed necessary and appropriate by RTM System, e.g. terrain map, obstacle data, population density	Operator receives supplementary info successfully and applies if/when necessary	Average latency to receive supplementary data transmitted during flight and latency to incorporate in the flight plan
Flight Planning	Means to plan the operational volume for the RPA flight and file in the RTM System by appropriate interfacing	Operational volume for mission flight is successfully planned and filed with the RTM System	1) The session time to generate flight plan (how long it takes for a complete flight plan to be ready for filing) 2) Average latency to successfully plan flight path and file with RTM System. 3) The number of concurrent flight path that can be created and filed
Geo-Fencing (Strategic)	Means to define 3-D perimeter around a geographic point and trigger response when the perimeter is approached or breeched by RPA	These measures apply to strategic geo-fencing, i.e, prior to flight 1) Geo-fence data is successfully received prompt/provided to Operator for inclusion in flight planning. 2) Operator or RPAS will receive alert/notifications and enact if the geo-fence is approached.	1) Average latency to receive and process/incorporate Geo-fence data from RTM System 2) The No. of flight paths that approaches Geo-fence within the navigation data accuracy (e.g., GPS) 3) Average latency to alert Operator when Geo-fence is breeched within a distance lower than navigational data accuracy (e.g. GPS)
Strategic Conflict Resolution	Means to arrange and negotiate intended operational volumes with RTM System to minimize the likelihood of airborne conflicts	Operational volume of mission flight(s) is (are) defined successfully and airborne conflict with other aircrafts and ground objects currently in RTM system is avoided	1) Average latency at which flight paths are modified to avoid a conflict, after receiving new environment info such as Geo-Fence data and Aeronautical Info 2) Number of strategic conflicts detected and resolved 3) Rate at which flight paths modified successfully to minimizes or avoids airborne conflict with other traffic in the subscribed airspace and ground objects vs the number of 4) Number of events that strategic conflict resolution does not provide de-confliction prior to flight

RTM Services	RTM Requirement Definition	Urban Flight, PL1-3, Measure of Effectiveness (MOE)	Urban Flight, PL1-3, Measure of Performance (MOP)
3) Surveillance/Tracking			
Situational Awareness	Means to receive sufficient information of cooperative and non-cooperative traffic with sufficient update rate to enable tracking	Operator receives traffic info of cooperative and non-cooperative flights in the subscribed airspace in real time	1) Average latency to connect with Surveillance Infrastructure (NAV Canada SA App) 2) Average latency to provide/display Situational Awareness data to Operator
Activity Reporting	Means to receive reporting of activities in the subscribed airspace volume	Operator receives activity report issued by RTM System in real time and is able to act upon	Average latency to receive activity report from RTM System and present/provide to Operator for action
Surveillance Info	Same as Situational Awareness for other info than traffic	TBD	TBD
RT Positioning/Tracking	Means to monitor and track positional data of the RPA flights planned and/or active in the subscribed airspace		1) Average accuracy for real time positioning during flight 2) Percentage of flight duration time at which RT positioning and tracking data is available
Conformance Monitoring	Means to receive non-conformance alerts issued by RTM System or GCS during flight and prompt/provide to Operator and ANSP This service is meant to ensure an in flight RPAS does not violate airspace bounds or infringe on restricted airspace. The notifications would be both the operator, but also to the ANS		TBD
4) Contingency Mgmt.			
Emergency Reporting	Means to report and alert RTM System of an emergency and/or contingency situation	Operator issues emergency or contingency situation reports to RTM System	1) Percentage of emergency reports issued vs known emergency incidents (self reporting) 2) Average latency to issue emergency report to RTM System upon encountering the situation 3) Rate of conformance of issued reports with the messaging requirements of RTM system
Notification/Alert/Warning	Means to receive notifications and alerts from RTM System and prompt to Operator	Operator receives other notifications/alerts/warning issued by RTM System	1) Average latency to receive issued notification/alert/warning from RTM System 2) Average latency to process the notification and prompt to Operator for action
Incident/Accident Reporting	Means to provide data-secure report of incidents/accidents to RTM System	Operator is able to provide and file reports of incidents/accidents in real time to RTM System	1) Percentage of incidents reported 2) Rate of self reporting vs known incidents 3) Average latency to prepare report of incident/accident during mission (pre-flight, flight and post-flight) and file with RTM System 4) Average latency to issue and communicate report to RTM System
Authorization Change	Means to receive changes in planned flight authorizations from RTM System and prompt/provide to Operator	Operator receives notifications of authorization changes issued by RTM System and is able to act on	1) Average latency to receive authorization changes from RTM System 2) Average latency to prompt Operator for action 3) Rate at which issued authorization change is validated by RTM System (implemented within required reaction time to avoid any incident/accident)
Dynamic Geo-Fencing	Means to receive changes in Geo-fencing data and prompt/provide to Operator	Operator receives notifications of changes in geo-fence data issued by RTM System and is able to act on	1) Average latency to receive Geo-fence data changes from RTM System 2) Average latency to prompt Operator for action 3) Rate that Geo-fence data change is implemented and validated (e.g., Acknowledgement provided by Operator, No incident)

RTM Services	RTM Requirement Definition	Urban Flight, PL1-3, Measure of Effectiveness (MOE)	Urban Flight, PL1-3, Measure of Performance (MOP)
5) Flight/Conflict Mgmt.			
Traffic Info	Same as Situational Awareness, for traffic info	Operator receives traffic info of cooperative and non-cooperative flights in the subscribed airspace in real time	1) Average latency issued traffic report is received from RTM System 2) Average latency to prompt Operator for action 3) Rate at which traffic info is successfully implemented within a required time delay
Conflict Advisories	Means to receive suggestive or directive information of RPA proximity and prompt/provide to Operator	Operator receives conflict advisories in the subscribed airspace and is able to act on in real time	1) Average latency to receive conflict advisory from RTM System 2) Average latency to Operator for action 3) Rate that conflict advisory is successfully implemented within a required time delay (e.g., no incident)
Capacity Management	Means to balance traffic demand and capacity constraints	Operator is able to apply methods to balance traffic demand of planned flights in the subscribed airspace	TBD
Navigation	Means to receive navigational info from available infrastructure (e.g., GPS) and provide to Operator or GCS	Operator receives navigational info from Navigation Infrastructure in sufficient accuracy and real time	1) Average percentage of flight duration time that navigational data (e.g., GPS/GNSS) not available and/or degraded in accuracy 2) Average navigational data (GPS/GNSS) accuracy during flight. 3) Number of Geo-fence breech due to navigational data inaccuracy 2) Average percentage of flight duration time that RPAS control signal to GCS signal is lost or weak
Dynamic Conflict Resolutions	Means to receive instructions in real time to avoid possible conflicts in flight volume and prompt/provide to Operator	Operator receives conflict resolution directives issued by RTM Service in real time and is able to act on	1) Average latency to clear conflict after instructions received 2) Average rate of flight duration in loss of "Well Clear" (subject to definition to being provided)
Dynamic Re-routing	Means to receive issued changes in the authorized operational volume issued by RTM System and prompt/provide to Operator	Operator receives re-routing directives issued by RTM Service in real time and is able to act on	1) Average latency to receive re-routing instructions for flight path by Operator once issued by RTM Service 2) Average flight duration before route correction upon receipt of re-routing instructions
6) Communication			
Comms Service and Monitoring	Means to monitor communication coverage and quality of service that the mission relies on	Operator is able to monitor the signal strength and communication quality with the infrastructure it relies on (Communication, Navigation, Surveillance, Metrological, Spatial Data)	1) Received Signal Strength Indicator (RSSI) from Communication Infrastructure (including C2) during flight 2) Receivied Signal Strength Indicator (RSSI) from Navigation Infrastructure (including GPS) during flight 3) Receivied Signal Strength Indicator (RSSI) from Surveillance Infrastructure during flight 4) Received Signal Strength Indicator (RSSI) from Metrological Infrastructure during flight
Control Comms	TBD		
Automation	TBD		
ATM Interface	TBD		



* Performance Level (PL) depends on the degree at which the service is being provided

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Appendix A

Description of RTM Services

The following definitions, which have been written to fit the Canadian context, have been derived from international RTM documents from ICAO, the FAA, GUTMA, CESAR, and Swiss U-Space.

Access to Operator Private Information (OP PI)	Allowing the services and the competent authorities to access data while ensuring privacy and data protection of the participants.
Activity Reporting	A service which provides on-demand, periodic, or event driven information on RTM operations occurring within the subscribed airspace volume and time (e.g. density reports, intent information, status and monitoring information, etc.). Additional filtering may be performed as part of the service.
Aeronautical Information	A service which provides for the flow of aeronautical information/data necessary for safety, efficiency, economy and regularity of, in this case, RPAS operations.
Automation Management	Communicates the level of automation available or required in the area covered by the service.
Authorization Change	Communicate de level of automation available or required in the area covered by the service
Capacity Management	Responsible for balancing traffic demand and capacity constraints during operational plan processing.
Communications Service & Monitoring	1) A service which provides infrastructure and quality of service assurance for radio frequency (RF) Command and Control (C2) capabilities to UAS Operators. 2) Provides information about communication coverage for missions that will rely on it. This information can be specialized depending on the communication infrastructure available (e.g. ground or satellite based).
Conflict Advisories	A service which provides real-time monitoring and alerting through suggestive or directive information of RPA proximity for other airspace users.
Conformance Monitoring	A service that provides real-time alerting of non-conformance of intended operational volume to the concerned operator, to inform the operator in case the UA leaves the operational volume and inform authorities, when required, when flights deviate from intended operational volume.
Control Communications	In an automated environment provides control information or instructions to aircraft and/or operator during exchange of responsibility.

Dynamic Geo-Fencing	An enhancement of geo-awareness that allows geo-fence changes to be sent to drones immediately. The drone must have the ability to request, receive and use geo-fencing data.
Dynamic Rerouting	A real-time service which provides modifications to intended operational volumes/trajectories to minimize the likelihood of airborne conflicts and maximize the likelihood of conforming to airspace restrictions and maintaining mission objectives. This service arranges, negotiates, and prioritizes inflight operational volumes/trajectories of RPAS operations while the RPAS is aloft.
Emergency reporting	A service, which allows the operator, and possibly the RPAS itself to report a contingency and/or emergency situation to identify contingency and/or emergency situations, exchange information related to the emergency flight with all relevant stakeholders and provide the RPIC with relevant information for the management of the emergency.
Dynamic or Tactical Conflict Resolution	Checks for possible conflicts in real time and issues instructions to aircraft to change their speed, level or heading as needed.
Flight Planning	1) A service which, prior to flight, arranges and optimizes intended operational volumes, routes and trajectories for safety, dynamic airspace management, airspace restrictions, and mission needs. Note – this is not intended to refer to the existing manned aircraft flight planning services. 2) A service which, prior to flight, arranges and optimizes intended operational volumes/trajectories for safety, dynamic airspace flight rules, airspace restrictions, and mission needs. 3) A service which, prior to flight, arranges and optimizes intended operational volumes/trajectories for safety, dynamic airspace flight rules, airspace restrictions, and mission needs. It entails an interface for flight planning, all relevant information (from all other services) to plan the flight, possible conflicts/rules violation of the proposed flight, legal compliance of proposed flight according to applicable rules and the possibility to submit the flight plan to the relevant stakeholders.
Geo-fencing	A virtual three-dimensional perimeter around a geographic point, either fixed or moving, that can be predefined or dynamically generated and that enables software to trigger a response when a device approaches the perimeter (also referred to as geo-awareness or geocoding).
Incident/Accident Reporting	A secure and access-restricted system that allows drone operators and others to report incidents and accidents, maintaining reports for their entire life-cycle, post-flight.
Interface with ATM	Offers verbal or textual communication between the remote pilot and ATC when a RPA is in a controlled area. This service replaces previous ad-hoc solutions and enables flights to receive instructions and clearances in a standard and efficient manner.
Navigation	Provides information about navigation coverage for missions that will rely on it. This information can be specialized depending on the

	navigation infrastructure available. Also provides status information about navigation infrastructure during operations. This service should give warnings about loss of navigation accuracy.
Notifications/Alerts/Warnings	Notifications, alerts and warnings such as NOTAM, weather alerts, etc. shared to improve the awareness of the RPAS pilot, created if, for example, an incident occurs, and it is needed to create a temporary restricted area.
Real-Time Positioning/ Tracking	A service, which tracks position reports of the RPAs in order for other services to operate (deconfliction, flight planning and so on). It tracks RPA positions in real-time, securely stores tracked data and provides different access levels to users with different credentials for the tracking data.
Registration	The ability to provide the registration of the operator, RPAS and pilot with the appropriate information according to the Regulation. The system may also provide a query function which permits authorized stakeholders (e.g. regulator, police services, etc.) to request registration data.
Remote Identification	Enables information about the drone and other relevant information to be verified by authorized parties without physical access to the RPA in accordance with regulations and standards.
Situational Awareness	The ability to provide traffic information for user situational awareness coming from any kind of monitoring.
Strategic Conflict Resolution	A service which arranges, negotiates, and prioritizes intended operational volumes, routes or trajectories of RPAS operations with the intention of minimizing the likelihood of airborne conflicts between operations.
Supplementary Information	A service which provides data as appropriate and necessary to meet the safety and operational requirements of individual UAS operation. It provides a digital map of the terrain, obstacle data, population density and other information, to relevant stakeholders.
Surveillance Information	Information of cooperative and non-cooperative traffic provided in order to build a complete situational awareness of aircraft positioning.
Traffic Information	Information issued by a service to alert a pilot to other known or observed air traffic which may be in proximity to the position or intended route of flight and to help the pilot avoid a collision.

Note:

Transport Canada has released a new draft of the RTM services description in 2021.

The readers are referred to the new release for updated definition.

Remotely Piloted Aircraft- Traffic Management Systems (RTM), Description of Services. Released May 21, 2021