Functional Requirements for Remotely Managing Fleets of On-Demand Passenger Aircraft

Victoria Chibuogu Nneji[*], Mary L. Cummings[†], and Alexander Stimpson[‡]
Duke University, Durham, NC 27708 USA

and

Kenneth H. Goodrich[§]
NASA Langley Research Center, Hampton, VA 23681 USA

The concept of On-Demand Mobility (ODM) in aviation has gained popularity in recent years, with several manufacturers proposing vehicles for high-speed intra-city air taxis. However, less attention has been placed on how these fleets would be operationally controlled and managed. Through the development of concepts of operations for remote management of vehicles with differing levels of autonomy, this paper presents preliminary requirements for ODM air operations control centers. The centers would interface with air traffic control and be responsible for ensuring safe, efficient, and effective operations of fleets within subareas of the National Airspace System. Our effort identified key functional requirements related to vehicle safety, customer experience, and airspace integration for these futuristic concepts. Further, this work introduces a novel Remote Operations Center (ROC) concept with highly integrated human-machine systems for efficient operations with limited staffing. The ROC would support the transition from providing dispatcher-like support to supervisory control of autonomous ODM systems, including managing emergencies, which will be crucial for operational success as vehicle autonomy evolves.

I. Introduction

SINCE Uber Technologies' 2016 announcement that the company would be getting into the intra-city air taxi business[1] utilizing electric, vertical takeoff and landing (eVTOL) aircraft, a surge of interest, investment, and development has ensued. To date, the primary focus has been on the design of the vehicles, popularly referred to as "flying cars." While a critical element of such futuristic operations, other significant system components will be needed. Particularly, remote operations centers (ROCs) are needed to remotely manage aircraft for on-demand mobility (ODM). There are unique systems engineering challenges, requirements, and design considerations for these ROCs, which will integrate elements of dispatch centers, air traffic control (ATC), and customer service centers.

Our earlier work identified three ODM concepts of operations (CONOPS), each stemming from different autonomy architectures, including conventional air taxis, revolutionary vehicle autonomy, and evolutionary vehicle autonomy[2]. The conventional air taxi approach proposes single-pilot operations, which currently occur in operations with up to nine passengers (14 Code of Federal Regulations Part 135), with a pilot-in-command onboard the vehicle and in control throughout each trip. The revolutionary vehicle autonomy CONOPS envisions no onboard human pilot whatsoever. The third CONOPS is a hybrid between these two extremes.

How such operations should be supported by ROCs has not been studied in depth. The revolutionary CONOPS would require not just a drastic shift in customer expectations but also in the tasks and responsibilities currently allocated to airline dispatchers who remotely monitor flights and communicate with the pilots flying the aircraft. Moreover, as onboard autonomy increases and trained human resources onboard decrease, customer interfacing

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[*] Ph.D. Candidate, Duke Robotics, victoria.nneji@duke.edu, AIAA Member.

[†] Professor, Duke Robotics, m.cummings@duke.edu, AIAA Fellow.

[‡] Research Scientist, Duke Robotics, alexander.stimpson@duke.edu, AIAA Member.

[§] Aerospace Engineer, k.goodrich@nasa.gov, AIAA Senior Member.

requirements present a new breed of functions that will draw inspiration from call center operators, flight attendants, and captains in how to communicate with laymen helpfully, quickly, emphatically and empathetically.

ODM operations will likely introduce increasing numbers of flights over shorter distances and times that could overburden pilots and ATC[3] unless supported by newly defined remote operators. In this paper, we investigate how remote fleet management could and should occur to enable passenger-carrying, on-demand air mobility operations across the three CONOPS. We present a novel ROC architecture, its vehicle safety and customer interfacing functional requirements, and design considerations including consideration of differing and/or evolving levels of vehicle automation and autonomy.

II. System Boundary of Remote Operations Center

Defining the boundary of the ROC system is essential to identifying key functional requirements. By boundary, we consider what people, places, and subsystems the ROC must monitor and interact with to meet performance requirements. As shown in Figure 1, the primary agents are the remote operators who each supervise one or more vehicles, whether the vehicles are stationed at vertiports or in flight. In early CONOPS, these remote operators would be responsible for interactions with pilots as they do now, but in the future, they could directly interact with the aircraft and its flight systems. These personnel would act in a similar capacity as present-day dispatchers by handling weather monitoring, flight planning, and communications for conventional air taxi operations. However, under the conditions of increasing vehicle autonomy, the remote operator may directly monitor and command the vehicle at a tactical level (i.e., commanding a maneuver or modifying an immediate goal) to assure safety. A key function for futuristic ROC operators will be detecting and mitigating contingency or emergency operations

A vertiport is where eVTOL aircraft takeoff, land, park, and load/unload passengers and baggage. Such vertiports would have some customer interfacing agent who would interact with passengers during the pre-embarkation and post-debarkation process. Maintenance personnel would refuel (recharge, in the case of electric aircraft), and conduct pre- and post- flight inspections to prepare the vehicle for its next flight. Security agents would monitor personnel and passengers to maintain a secure environment, ensure cleared landing pads, and maintain surveillance of stationed vehicles. An individual could perform multiple functions but could also be an automated agent.

Increasing levels of vehicle autonomy and advancements in artificial intelligence (AI) more broadly could lead to automation of system functions, in addition to piloting, such as vertiport service and maintenance. This is a critical consideration for reaching economic viability at scale. Regardless of how automated the vehicle and vertiport become, the remote operations center will be critical for monitoring fleet operations and resolving emergent problems so these centers will likely need highly-trained humans and thoughtfully-designed AI decision support systems in the future.

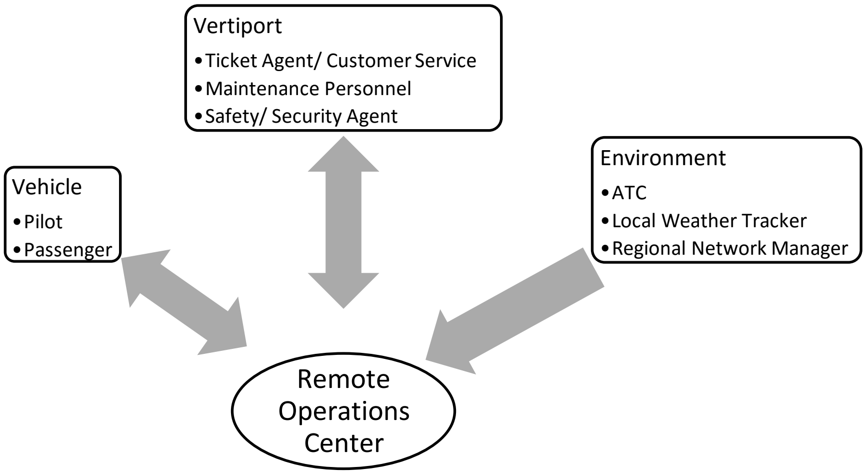

Figure 1: ROC system boundary.

There are several potential strategies for allocating different functions across remote operators or teams within the ROC system, as shown in Figure 1. For example, certain ROC teams may be specifically responsible for organizing maintenance across all vertiports. Alternatively, a divisional allocation could be used, in which each ROC operator or team could handle all potential tasks for a single vertiport. Under this architecture, an ROC operator could fill any needed role within the system. Note that collaboration and communication needs would likely differ significantly across these different strategies[4]. Such different team allocations have been shown to have positive and negative benefits[5], so further research is needed to determine optimal staffing architectures and their associated constraints.

III. Vehicle Safety Functional Requirements for ODM ROCs

For on-demand mobility air operations to be successful, the high-speed nature of this travel option will need to be realized across an environment that will be extremely dynamic. However, a safety standard must also be met at levels equivalent to or better than expected from current regulatory and operational standards. Thus, the primary purpose of an ROC will be to ensure safe operations while promoting expeditious operations. Identifying the overlapping requirements with existing systems will be useful in conceptualizing future design considerations for these ROCs.

For major commercial airline operations today, dispatchers, supported by other specialists within the operations center, develop preflight load plans that respect weight and balance constraints. Additionally, they review immediate and near-term weather predictions within the operational environment for each flight. They assist with planning flight paths by accounting for aircraft performance and loading, en route winds, forecasted weather, restricted airspace, and conditions at the takeoff and landing sites. Dispatchers continue monitoring relevant conditions once a flight has departed and if they deem conditions unsafe for operations, may divert, delay, and even cancel flights. By federal regulation, these Part 121 operations require the aircraft dispatcher and pilot-in-command (PIC) to share the responsibility of their flight's safety[6].

The following sections describe how this current role of the dispatcher will likely change in support of ODM.

A. Conventional Air Taxi

Aircraft dispatchers are not required for present day Part 135 on-demand operations (30 seats or less). Instead, in the case of unplanned flights, a designated individual who is called a "flight follower" takes on the role of following flights via a tracking interface or other process. Rather than taking on joint legal responsibility of flight operations, this individual maintains records of aircraft whereabouts in case the Federal Aviation Administration (FAA) needs to identify its location during contingencies. In these operations, the safety responsibility is allocated between the PIC and a director of operations (14 CFR Part 119). This director of operations must hold the same certificate (e.g. airline transport pilot) held by the PIC. Operations control specialists are the remote operators responsible for helicopter air ambulance services with fleets of 10 or more aircraft (14 CFR Part 135.619).

Given the set of safety functions previously outlined for ODM operations[2,7,8], Table 1 identifies what tasks would likely be the responsibility of dispatcher-like personnel in remote operations centers of ODM conventional air taxis. Just as with present-day operations, the ROCs would support pilots by developing flight plans, monitoring the flight, and presenting economical and safe solutions to deviations from the plans. However, since ODM operations would happen over shorter distances and timespans and with more potential obstructions, remote operators will need rapid, automated decision support to ensure safe separation parameters and track those factors that may affect available resources, especially in the event of contingencies. For example, if a designated emergency landing area is unexpectedly occupied, the remote operator must quickly search for the next-best-alternative, likely aided by some form of autonomy.

B. Revolutionary Vehicle Autonomy

While Table 1 suggests that safety functions for conventional air taxis will not significantly change the role of the dispatcher, revolutionary operations with "full" onboard autonomy will require significant changes in operations (both vehicle and dispatch), customer interfacing, and regulations. Communications are one significant change that will occur for ROCs of the future, since communicating with ATC is required to fulfill vehicle safety function #1 of maintaining safe separation (Table 1). To manage traffic safely, ATC needs reliable knowledge of aircraft whereabouts, receipt of notice, and intention to respond within appropriate time and space constraints. So, while dispatchers in current operations do not interface directly with en-route air traffic control except in some emergency situations (14 CFR Part 121.557), for such futuristic operations without a pilot onboard, the remote operator will communicate more directly with ATC and the volume of communication is likely to require more bandwidth than achievable through voice-based, primary pilot-controller communication methods (e.g. analog aviation radios).

As the number of aircraft in the fleet under management grows, the ROC will need to integrate artificial intelligence decision aids (AIDA) to support remote operators who need to re-route vehicles on short time scales and reassigning resources within the fleet. For example, the assignment of a vehicle to a customer request will likely incorporate recharging requirements, as the system will need to consider the relevant market supply and demand for vertiport selection. Given multiple aircraft, vertiports, and charging requirements, underlying optimization algorithms will be needed in the future to manage these demands in a time pressured setting.

Table 1: Vehicle safety functional tasks allocated to ROC in the three Concepts of Operations.

Safety Function	*Conventional ROC*	*Evolutionary ROC*	*Revolutionary ROC*
1. Maintain safe separation from other participating aircraft (A/C) & do not create excessive risk.	Establish flight plans within ATC separation requirements.	Monitor airspace, communicate with pilots if separation parameters need adjusting.	Monitor airspace status, command A/Cs to ATM traffic flow management initiatives as needed for efficient fleet operations
2. Maintain safe separation from fixed & dynamic hazards that are outside the "system" & that cannot reliably be expected to share separation responsibilities.	Establish a flight plan to account for buildings, other established obstructions, & potentially hazardous weather.	Share new information with & between pilots to ensure hazards are avoided.	Calibrate fleet maps with regional data streams to ensure hazards are avoided.
3. Maintain A/C control such that future states & trajectories can be reliably predicted & directed under all conditions	Communicate with each pilot if shall re-route A/Cs.	Monitor fleet, use artificially intelligent decision aids (AIDA) to project paths & communicate with each pilot if shall re-route A/Cs.	Monitor A/Cs sensor-actuator state, use AIDA to project paths and re-route A/Cs as needed via network supervisory control.
4. Maintain the physical & cyber security of the A/C such that it can be commanded or controlled only by authorized operators & the occupants are protected from malicious harm.	Verify pilot identity & maintain communications to be alerted in case of breach.	Verify pilot identity & maintain communications to be alerted in case of breach.	Monitor fleet, periodically review projected paths via AIDA to command against unauthorized A/C deviations from flight plans & sensor system accuracy.
5. Maintain sufficient energy to complete trip.	Compute energy requirements considering mission parameters. Provide pilot safe alternatives for the case in which energy depletes before destination landing.	Monitor fleet, provide safe landing alternatives to pilots that are approaching minimum charge.	Monitor fleet, continually compute feasibility of trips, ensure A/Cs approaching minimum charge have timely access to landing sites for recharging, command A/Cs to recharge as needed.
6. Maintain adequate navigation accuracy to safely complete the trip, including position & infrastructure awareness such that an appropriate route can be planned & followed.	Follow flights' real-time locations via tracking technologies. Maintain communication with PIC to confirm physical with digital location.	Maintain communications with pilots to verify navigation between onboard & ROC data.	Monitor fleet, use supporting data from ground stations to verify navigation of A/Cs on approach, review A/C sensors as needed.
7. Maintain adequate ride quality for passenger safety, including avoiding weather & other conditions that could create discomfort.	Project flight plans to account for poor weather & communicate with pilot accordingly. Monitor aircraft acceleration. ATC would be responsible for redirecting flights to avoid unplanned weather.	Monitor & provide new information required for pilots to ensure passenger comfort.	Monitor fleet, maintain communications with passengers as needed to provide new information required for autonomous systems to ensure passenger comfort.
8. Manage A/C systems to maintain & alter operations in case of subsystem failures such as making a precautionary landing should engine health become uncertain.	Monitor subsystem data & communicate alternatives with PIC as needed.	Monitor subsystem data, maintain communication with PIC, provide supporting information if autonomous systems fail.	Monitor subsystem data on fleet-level, redirect resources as needed in collaboration using AIDA, assume supervisory control if autonomous systems fail.

Another major change in revolutionary vehicle operations will be in emergency operations. Due to the management of multiple vehicles and limited sensory information (as compared to being in the cockpit), ROC operators may have challenges maintaining appropriate situation awareness to respond quickly to emergency situations. This requires that the onboard vehicle autonomy be capable of robustly identifying and reacting to emergencies that may arise during operations, particularly those on a timescale that may not allow ROC intervention. Examples could include redistributing propulsion during system failures, automatic collision detection and avoidance, or determining and executing an emergency landing maneuver at a suitable site.

In emergency or off-nominal cases, the ROC operator would receive all relevant data and plans generated by the vehicle, and would respond and adjust plans accordingly. While these vehicles should be able to land themselves without any external intervention in most emergencies, in some cases, command of the vehicle by a remote operator could be desirable. One such case could be the event where an external sensor fails that is critical for landing site identification and clearance, so the ROC operator must coordinate with other agents in the system and possibly position the vehicle prior to the automated landing. Additionally, the ROC operator will act as an on-scene commander and perform other functions in support of responding to emergencies, such as clearing a landing site or contacting ATC or maintenance crews to ensure they are informed and ready to address the situation.

The consideration of emergency operations in revolutionary vehicle autonomy reveals challenges in how the ultimate responsibility and authority for vehicle safety is handled under this architecture. Traditionally, this responsibility and authority is assigned to the PIC on the aircraft (e.g. CFR 14 Part 91.3). When no pilot is onboard, and the vehicle has the capacity to act independently, a question arises of whether the ROC operator supervising the vehicle should be considered the "PIC," as UAV ground operators are today. In addition, what (if any) authority the ROC operator may have over the actions of the semi-autonomous vehicle is not yet clear. In the revolutionary vehicle operations concept the ROC operator may not have the time to exert authority in rapidly evolving emergency scenarios, so the vehicle autonomy would need to make safety critical decisions until "relieved" or "overruled" if necessary by the ROC operator. In this way, it is likely that identification and initial execution of actions must be manageable by the vehicle autonomy, with later confirmation or adjustment by the authority figure (ROC operator).

Further, similar to the debates around hard versus soft flight-envelope protections[9], it may not be practical or desirable to afford the pilot the authority to command the vehicle into conditions that the vehicle interprets as assuredly and irreversibly perilous. In some respects, the situation between the ROC operator and semi-autonomous vehicle may take-on complexities like the relationship between PIC and pilot not flying (PNF). While the FARS clearly delegate final authority to the PIC, there are situations where the PNF is expected to aggressively question the PIC's actions. In extreme situations, the PNF is authorized to take control away from the PIC[10].

In addition to the technical challenges that will be introduced by high-levels of vehicle autonomy and associated human-machine interaction requirements, current federal regulations would need to be substantially revised to reflect the shift in roles, responsibilities, and authorities between the air and ground agents. The intent of revolutionary vehicle autonomy is to eliminate the need for an onboard PIC by endowing the vehicle with sufficient agency to autonomously conduct flight operations within its design conditions, including detecting, avoiding, and mitigating off-nominal situations with a level of safety equaling or exceeding onboard pilots. In this situation, it is likely that many of the current responsibilities and authorities of the PIC cannot legally be assigned to the vehicle (and its manufacturer) and will shift to the ROC and its personnel.

While dispatcher-like functions regarding flight planning and operational control may be like today, the levels of responsibility and authority assigned to the ROC for revolutionary operations will likely increase as the operators will be the sole humans involved in the authorization and conduct of flights. Further, with the ability of a remote operator to assume command of the vehicle, most likely in adverse, non-normal situations, additional PIC-like responsibilities are likely to migrate from the air to ROC personnel. Relatively esoteric concepts such as the "reasonable reliance defense"[11] applicable to the relationship between PIC and other crew members, are likely to become relevant to the vehicle-remote operator relationship and may need to be codified in regulatory requirements and guidance rather than assessed by the National Transportation Safety Board or civil-liability proceedings.

C. Evolutionary Vehicle Autonomy

The evolutionary vehicle autonomy architecture represents a bridging between conventional and revolutionary autonomy operations, in that it would allow for autonomy to be tested and implemented in supporting roles alongside the human pilot. As capabilities, experience, and trust improve with these autonomous systems, they could be phased into greater responsibilities for the functions described in Table 1. Ultimately, this could later be transitioned into full vehicle autonomy, with operations running similarly to those described in the revolutionary vehicle autonomy section.

During the initial stages of evolutionary operations, the general vehicle safety functions as outlined in Table 1 would not likely significantly change from the conventional column. In these early stages, the ROC operators will be critical for sharing information with and between pilots who may not have situational awareness of changes that other nodes in the network (fellow aircraft in the fleet) make on short timescale and within proximity to their flight paths.

Thus, these ROC operators will assume their traditional role of dispatcher but with a higher demand on quickly routing information for coordination of vehicles in the network.

However, as autonomy increases in this phase of operations, moving more responsibility out of the cockpit and into the ROC, the ROC operators will play a more active role in supporting the key vehicle safety functional tasks. Compared to conventional operations, under evolutionary vehicle autonomy, ROC operators would have access to more detailed flight paths and fleet level information that would allow them to share information between pilots, identify appropriate alternate landing sites, manage network traffic, and determine appropriate rerouting in the case of disruptions and emergencies. It is likely that in more advanced stages, ROC operators could assume some level of emergency control, but network connectivity (e.g. bandwidth, latency, and availability) concerns are a major limitation to this approach.

As discussed previously in the revolutionary vehicle operations section, the technology available to these futuristic pilots and dispatchers will also likely include layers of AIDA not seen in present day operations. Since the key objective of the evolutionary approach is to bridge into revolutionary vehicle autonomy, certain capabilities of the ROC (such as the use of AIDA to support vehicle safety function #3 in Table 1) may be integrated to support future operations, including flight planning, one of the core functions of present-day dispatchers. A parallel of this can be found in surface transportation network companies' scheduling technologies (e.g. Uber or Lyft algorithms).

Given the current regulatory structure, evolutionary air taxi operations with a pilot onboard would not, initially, require major regulatory changes relative to the ROC as the ROC personnel would effectively be dispatchers and possibly the director of operations. Initial regulatory changes of significance would primarily pertain to the vehicle and pilot as the onboard pilot is supported by, and nominally dependent on, highly automated flight systems. Over time however, as sufficient confidence and coverage in the automation's capabilities increase, the evolutionary vehicle is likely to be operated as an optionally piloted aircraft (OPA) with the onboard pilot acting primarily or solely in a safety role and the ROC interacting directly with the vehicle in a manner like the revolutionary autonomy. This approach provides a transition path from conventional to revolutionary concepts while mitigating risks and uncertainties associated with remotely-piloted and unpiloted operations.

At this stage, regulatory issues become similar to those discussed for the revolutionary concept. It should be noted however that the potential for confusion of functional responsibilities and authority between an onboard safety pilot, a semi-autonomous vehicle, and ROC personnel is elevated in this phase as compared to the conventional and revolutionary phases. This is especially the case if different companies decide on different definitions in the range of evolutionary autonomy but recruit from the same pool of potential operators. While this potential confusion entails some risk that must be identified and managed (e.g. mode confusion[12]), an OPA transition stage potentially provides a practical approach to operationally exercising autonomous systems before fully trusting them in passenger-carrying service.

IV. Possible New Roles for Remote Operators in the ROC

The nature of ODM concepts will require ROC operators to adopt new roles not seen in current dispatch centers. New ownership and operational models originating in ground transportation markets may be relevant in the realization of ODM[13]. Such models rely heavily on central handling of customer service components that must be both efficient and individualized to improve customer satisfaction. Additionally, due to airspace constraints around traditional airports and runways, to achieve higher density of operations ODM, providers will need to operate and maintain dedicated vertiports with terminals for these new vehicles, associated support personnel, and customers. Due to the proposed rapid turnaround time for the vehicles and desire for on-demand bookings, management of these facilities and related operations will probably need to be centrally managed. Some of these new types of customer interfacing and vertiport-related tasks may fall to ROC operators.

The customer experience is a key aspect of ride-hailing services that may serve as a foundation for new ODM operations. While the principal user interface is based on mobile platforms, such companies also allow for direct communication between drivers and passengers, as well as host call centers to handle issues or complaints. In ODM operations, it is possible that such mediating functions would be handled by ROC operators. This would allow a more personalized experience for the customer and help ensure expedient service, promoting customer retention. To serve these customer interfacing tasks, the remote operators would need both additional training in handling customer requests, as well as authority to be able to resolve issues quickly (e.g. re-route a vehicle to allow for a more rapid pickup of a customer after a mechanical failure of the original vehicle). Another option would be to develop parallel customer-interfacing agents that would work in parallel with the ROC operators.

As an integral part of the ODM system, management of vertiports, including scheduling of fixed infrastructure such as landing pads or hangars as well as more dynamic resources such as maintenance personnel, will be critical to ensure efficiency of the overall system. With a global perspective of all vehicles and locations, ROC operators will likely handle, at a minimum, elements of scheduling tasks. How ROCs relate to vertiport management is still an open question since to make such business models viable, reduction in human resources is desired. Thus, how to best divide tasks between operators in an ROC and local vertiport management will be informed by both technical and financial considerations.

Another important issue that arises in the ODM CONOPs is how responsibility for vehicle safety will be handled in the cases of revolutionary and evolutionary vehicle autonomy as described earlier. Since ROC operators will take a more active role in the monitoring and safety of the vehicles, it is likely that some responsibility will be assumed by the ROC operator. In the case of early evolutionary autonomy, the pilot on board will likely still act in the PIC role, with final authority on decisions related to vehicle safety. As discussed in the revolutionary vehicle autonomy section, assignment of responsibility is more challenging when no pilot is on board. One possibility is that the ROC operator would legally hold final authority with the ability to override decisions made by the autonomy, but would be reliant upon rapid analysis and execution made by the autonomy in cases where time does not allow for remote intervention. This CONOPs has little regulatory precedent, and would likely need extensive testing and certification discussions with a variety of organizations within FAA before it could be considered viable in terms of a shared understanding of the system requirements, means of compliance, and operating procedures.

V. Design Considerations

Remote operators are primarily needed in maintaining vehicle safety functions #1 and #2 in Table 1 from the conventional air taxi through evolutionary and increasingly for the revolutionary autonomous vehicle CONOPs. Remote operators do not work alone but within teams of other operators and in the future, will also work with increasingly capable machine agents that help to optimize large-scale decisions at speeds that on-demand service operations will require. At the ROC level, automated path planning, scheduling, and resource allocation decision support tools will be just some of the tools that will be needed. In addition to the onboard vehicle autonomy that will be required to achieve this future vision of ODM, more advanced systems will be required to enhance communications, including sharing information between remote operators and other vehicles in the network, as well as air traffic control.

If the advanced evolutionary and revolutionary vehicle CONOPs are to be achieved, remote operators will require an interface to monitor and command aircraft at a tactical level. Examples of tactical command include specifying a landing offset from the center of a vertiport pad, initiating a go-around and diversion to an alternative vertiport, or modifying a traffic avoidance maneuver to provide increased separation. Such an interface would need to provide operators with sensory and environmental data from the vehicles in order for them to operate in a supervisory control fashion[14] and redirect or re-task the onboard trajectory and action planning systems. It is expected that the onboard automation would continue to perform low-level vehicle control in response to re-planned trajectories as these high-bandwidth, lower-level flight control functions are ill-suited for ground-based implementations. Supervisory control would be critical since operations of this nature need to be robust against time latencies, and not subject to a reliance on perfect communications. Thus, for these highly automated operations, remote operators should be able to define envelopes of allowance within which the aircraft itself can navigate with high guarantees of safety.

As more and more vehicles are added to the fleet, ROC operators will need interfaces that present vehicle information on a network level, such as how many vehicles are headed to a vertiport with maintenance issues. This will allow remote operators to monitor overall operational conditions and quickly identify exceptional cases that warrant additional, specialized attention, either at the vehicle level or the resource level like charging stations at vertiports. ROCs may also rely on decision support tools that leverage machine learning algorithms to identify solutions for emerging network problems that share many of the same attributes as previous problems. Such an interface should be designed in a way that remote operators can quickly comprehend and act upon information with high trust in its veracity.

This design requirement will present technical challenges since sending detailed, raw video and sensor streams may require more bandwidth than is available, and the transmission of only highly-processed information may limit the ROC's ability to independently monitor the situation. Past research has shown that it is difficult to design actionable decision aids in multiple unmanned aerial vehicle (UAV) control environments based on common machine learning approaches[15]. Moreover, research also has shown that operators supervising unmanned vehicles may adopt overly conservative strategies of autonomy application due to distrust[16,17], particularly if the remote operators have high-accountability for the overall outcome. Ultimately, more research will be needed to develop decision support tools that are both robust to significant uncertainty but also utilized in the manner intended.

While automated vehicles and air traffic management may become more intelligent over time and independently able to cope with a wider range of conditions, it would be naïve to assume that these capabilities will always reduce workload for remote human managers and operators. The addition of sophisticated automation often changes workload instead of reducing it[18]. With the addition of various decision support tools that could aid future dispatchers, it will be critical to ensure that this new information is presented such that it does not add undue workload to operators who may already be overburdened with other tasks. Often such systems are designed for nominal conditions and work well within these constraints, but they often do not anticipate spikes in workload caused by emergency and unforeseen contingency events. Moreover, as companies shift from evolutionary to revolutionary vehicle operations, remote operators will likely be controlling heterogeneous systems (i.e., some vehicles piloted and some with no pilot), which would create additional workload and situation awareness challenges due to the high cognitive load of managing dissimilar systems with different requirements.

Finally, to maintain acceptable levels of operational efficiency and effectiveness as well as safety, the function allocation scheme across the multi-agent human-automation teams will need to be clearly elucidated to protect against mode confusion. This futuristic team of human and computer agents will require new paradigms in training. Operating procedures will have to fundamentally change to ensure that each agent (human or artificial) is aware of who or what is responsible for each task that arrives into the system. Retraining on how the human-machine functions are allocated will be essential to operational performance.

VI. Conclusions

Increasing autonomy on aircraft, which is fundamental to scalable ODM concepts, will result in a changing role of dispatchers such that they will be transformed into ROC operators. While “conventional” ODM operations may utilize a traditional model based on present-day operations where the ROC is primarily responsible for high-level monitoring, scheduling, and weather related activities, CONOPS incorporating evolutionary and revolutionary vehicle autonomy will require greater ROC operator involvement and greater authority related to the operations. In the case of revolutionary vehicle autonomy with no onboard pilot, the ROC operator may become solely responsible for the safety of multiple vehicles, representing a dramatic shift from current commercial airline operations. The ROC will play an integral role in realizing and assuring the key safety functions for future ODM operations.

As mentioned previously, evolutionary autonomy can be treated as a transitional architecture to ease the regulatory burdens and unknowns of certifying autonomous flight. As the autonomy improves and becomes trusted and certified, these operations could be shifted to those like the revolutionary autonomy with no pilot on board. This transition would also have marked impacts on the ROC and the operator responsibilities. Evolutionary vehicle autonomy may provide a robust pathway between conventional and revolutionary levels of vehicle autonomy, with the pilot able to fill gaps in capability. However, having the role of the pilot change over time has a high potential to introduce other issues such as role confusion in which neither the pilot nor the autonomy complete a critical task as each expects the other is responsible. For both evolutionary and revolutionary autonomy CONOPS, understanding and updating how the responsibilities and functions currently assigned to the PIC are distributed between human and machine agents, on the vehicle and at the ROC, entails significant sociotechnical challenges.

Additionally, a key aspect of evolutionary and revolutionary vehicle operations will mean that ROC operators must interact closely with ATC to ensure approval of flight plans and safety of the airspace. With the desired frequency of flights under ODM, current voice-based reporting and approval methods will be insufficient for the ROC operators to make or respond to requests. Therefore, an additional challenge will be the streamlining of communications between the ROC and ATC to not overburden either while meeting the rapid cadence expected under ODM operations.

Regardless of the CONOPS utilized, the key functionalities provided in Table 1 must be met to ensure the safety of future ODM operations. Maintaining separation from other vehicles and static obstacles, monitoring and maintaining energy for flight, ride quality, and emergency handling must all be met for ODM to be successful. However, challenges will be encountered in realizing these capabilities under the different architectures, as much of the needed technology to achieve these goals is still in research and development stages. There remain many open questions about how regulations may support, deter, or constrain different approaches for ROC operations, how remote operators be should trained to address the key safety functions, what the role of human factors for ROC human-machine interaction and interface design is to ensure operator capacity to manage both nominal and emergency operations, and how these requirements change as aspects of the fleet such as size and autonomy change.

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