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An Operator Function Taxonomy for Unmanned Aerial Vehicle Missions

Track 4: Cognitive and Social Issues

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This paper details a taxonomy generated for unmanned aerial vehicle (UAV) missions. Specifically, we examine the primary functions that a human operator would perform for a particular UAV mission within this taxonomy, including mission planning, management, and replanning. The goal is to understand what operator functions are common across different UAV missions in order to design robust and adaptable decision support systems. In addition to enumerating the operator functions required for each mission type, we also break down the information and functional requirements for each mission phase. The resulting requirements can aid in the design of interfaces that can be used for broad application between and across different mission types, and between UAV types as well.

INTRODUCTION

Unmanned aerial vehicles (UAVs) are becoming capable of performing more diverse and heterogeneous missions. These missions include military applications, as well as commercial applications such as search and rescue, border patrol, traffic control, etc. For each of these missions, UAVs are being outfitted with increasingly complex and robust automated technologies. However, despite these automated capabilities, the role of the human operator remains a critical component of these systems.

The role of the human operator in unmanned aircraft systems (UAS) varies depending on the mission being performed. As such, it is desirable to pinpoint the differences and similarities between mission types performed by UAS in order to (a) increase the usability of human-UAV interfaces across mission types and (b) leverage research from one UAV mission type to another.

UAVs are no longer single mission aircraft. For example, the MQ-1 Predator can perform both reconnaissance and weapons delivery missions. Multi-mission capable UAVs allow for increased versatility and flexibility. However, they also provide additional challenges. For instance, different missions often have distinct functional and information requirements. This, in turn, means that different mission types will require different types of decision support and user interfaces. Since the operator might have to switch functions when switching between missions, it is important to realize what operator functions are needed for each of the missions, and what commonalities may or may not exist between these missions.

Identifying similarities between mission types should also help to leverage research from one domain of UAV operations to another. UAV missions with similar operator functions will tend to require similar cognitive processes from the human operator(s). Thus, research on the cognitive steps performed in one mission type could possibly be used to help leverage research on a different mission type that requires similar operator functions.

To assist in identifying the differences across UAV mission types in terms of operator functions, we present a taxonomy of UAV missions, including those performed today as well as those that could possibly be performed in the future. As part of the taxonomy, we enumerate for each of the UAV mission types, the functional and information requirements that can serve as guidelines in robust interface design. This taxonomy and requirements can be used to inform the design of UAS decision support systems, particularly those with multi-mission capabilities.

TAXONOMY

Our proposed taxonomy for UAV mission types is shown in Figure 1. Definitions for the terms in the taxonomy can be found in the Appendix. There are three tiers or levels in the taxonomy. Mission types become more specific as one traverses the tree towards the leaves (increasing levels).

The first level contains seven different mission types. Some of these mission types, such as *Intelligence* and *Surveillance*, are standard UAS mission types, while others such as the *Drone* mission, are less common. The second level expands on the mission types in the first level by describing the exact role the UAV will be undertaking for a particular mission. The third and final level was added to further specify those mission types whose implementation can vary. For example, the *Target Acquisition* mission type can be executed when the target(s) to be acquired are either static or dynamic. This can be observed in the third level of the taxonomy, where the two variants further divide the *Target Acquisition* mission type. The distinction that the third level serves is important. Depending on the mission parameters identified in the third level, the interface functional and information requirements for the operator can vary.

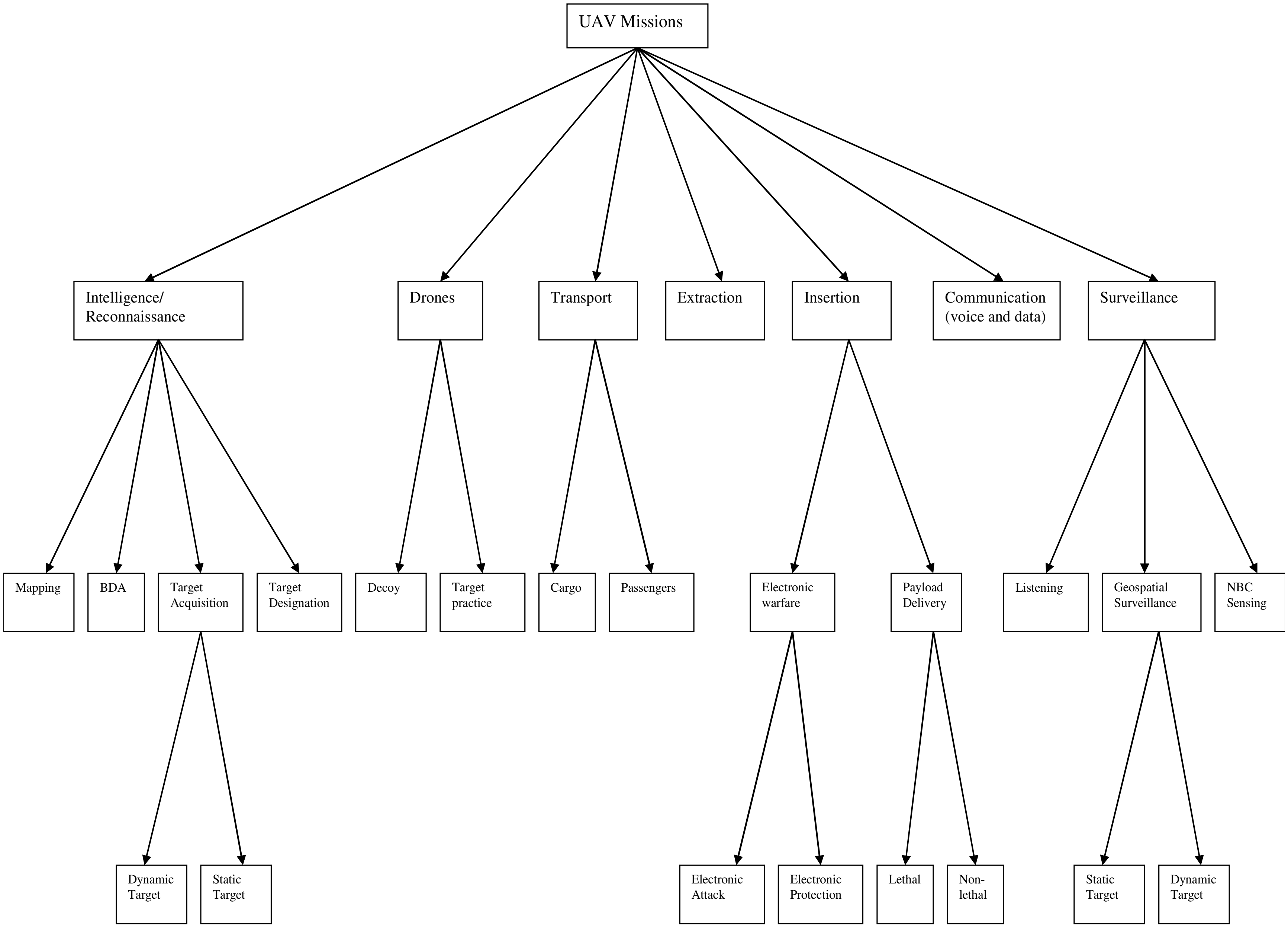

Figure 1. UAV Taxonomy

There are several properties to this taxonomy. First, the taxonomy is generic in that the nomenclature used to describe the different missions applies to both military and commercial mission types. For example, the *Transport Cargo* mission type can refer to either the transportation of military equipment when the taxonomy is used in a military context or the transportation of commercial goods when used in a commercial context. The benefits of a generic taxonomy are that it is universal, and can be used as a reference in more than one domain.

The taxonomy is also capable of being extended as mission types can easily be added to the already existing hierarchy. As new mission types become feasible, they can be placed in the taxonomy either as a subset of an already existing mission type, or as a parent node in level two of the tree. In fact several of the mission types in the taxonomy presented in Figure 1 are not currently being performed by UAVs, such as the *Transport Passengers* mission type.

The different mission types are not necessarily mutually exclusive, as one UAV can conduct multiple missions (e.g., the Predator which can conduct both surveillance and strike mission types.) In fact, it is likely that vehicles will be required to complete multiple missions in order to achieve certain objectives. For example, an objective such as target designation requires that the target first be acquired. Both of these missions could possibly be performed by the same UAV.

The mission types are also organized in a hierarchical manner which makes missions placed close together in the graph likely to have similar characteristics in terms of demands in operator functions and interface requirements. The organization of the missions in this manner also makes them more easily accessible, especially as the number of mission types in the taxonomy increase.

FUNCTIONAL / INFORMATION REQUIREMENTS

Each mission type consists of three phases: mission planning, mission management, and mission re-planning. The three phases were chosen so as to reflect the changes in operator tasking in time and delineate the three phases of planning, management, and replanning. Each phase consists of a number of steps, which we call phase goals. For example, the phase goals for the *Mapping* mission are shown in Table 1. Similar tables for all the UAV missions (those missions that form leaves in the tree) in our taxonomy are given in (Nehme et al., 2006).

The phase goals can be used to derive the functional and information requirements that would be needed for an interface to support the corresponding goals. For example, due to the resource allocation goal that might be required in the mission re-planning phase of the *Mapping* mission, the mission has the functional requirement that decision support is needed for asset coverage.

Table 2 shows the phase goals and requirements for the *Battle Damage and Assessment (BDA)* mission. The phase goals are similar to those for the *Mapping* mission, except that in the mission planning phase, the goal of path planning is replaced by the goal of assessing targets and routes. However, the functional and information requirements in the mission planning phase remain the same for both missions. This is due to the fact that the two different goals require the same functional and information requirements in terms of operator decision support, making these two mission types highly interoperable in terms of functional and information requirements.

Table 1. Functional and Information Requirements for the Mapping Mission.

Mapping		
	Phase Goals	**Functional/Information Requirements**
Mission Planning	- Planning path of area to be mapped - Scheduling of health and status reports	- Threat area information - No fly zone information - Scheduling mechanism - Decision support for path planning (including loitering)
Mission Management	- Tracking progress of UAVs and of health and status reports - Image (map) analysis	- Health and status indicators - Image analysis tools (zoom, panning, filtering)
Mission Replanning	- Resource allocation	- Asset coverage re-plan decision support
Operator Functions	- Monitoring health and status of UAV - Optimal position supervision - Path planning supervision - Analyzing images - Positive target identification	

Table 2. Functional and Information Requirements Functions for the BDA Mission.

BDA		
	Phase Goals	**Functional/Information Requirements**
Mission Planning	- Assessing targets and routes - Scheduling of order of assessments if more than one - Scheduling of health and status reports	- Threat area information - No fly zone information - Scheduling mechanism - Decision support for path planning (including loitering)
Mission Management	- Tracking progress of UAVs and of health and status reports - Analyzing BDA results	- Health and status indicators - Image analysis tools (zoom, panning, filtering)
Mission Replanning	- Resource allocation	- Asset coverage re-plan decision support
Operator Functions	- Monitoring health and status of UAV - Analyzing images - Monitoring network communications - Resource allocation & scheduling - Path planning supervision - Optimal position supervision - Notifying relevant stakeholders	

In contrast, the *Target Acquisition* mission (shown in Table 3) has many more functional and information requirements than for the *Mapping* mission. For example, unlike the

Mapping mission, the mission management phase of the *Target Acquisition* mission requires support for the viewing and storage of target acquisition results. This lack of commonality in requirements makes the *Mapping* and *Target Acquisition* missions less interoperable with each other than the *Mapping* and *BDA* combination in terms of operator information/functional requirements. Hence, it is likely that these two missions would require distinct (or at least altered) user interfaces and decision support.

Comparisons of functional and information types for other mission types can be inferred from the Tables found in the full report (Nehme et al., 2006).

Table 3. Functional and Information Requirements for the Target Acquisition Mission.

Target Acquisition (Static and Dynamic)		
	Phase Goals	**Functional/Information Requirements**
Mission Planning	- Path planning (areas to search and waypoints to the area of interest) - Scheduling of health and status reports	- Threat area information - No fly zone information - Scheduling mechanism - Decision support for path planning (including loitering)
Mission Management	- Tracking progress of UAVs and of health and status reports - Analyzing EO imagery - Image/sensor matching (e.g., ATR) - Position tracking (only for dynamic)	- Health and status indicators - Support for viewing results and storing results - Support for sensor matching - Support for tracking position of target (only for dynamic) - Signal detection - Predictive path planning (only for dynamic)
Mission Replanning	- Path Replanning - Resource allocation	- Replanning decision support - Rescheduling decision support
Operator Functions	- Monitoring health and status of UAV - Monitoring for sensor activity - Optimal position supervision - Analyzing images - Analyzing other sensor data - Positive target identification - Resource allocation & scheduling - Tracking target (only for dynamic) - Notifying relevant stakeholders	

OPERATOR FUNCTIONS

The specific functions required from the human operator can also be derived from the phase goals of each mission type. The operator functions for the *Listening* mission are shown in Table 4. For example, due to the goal of listening to transmissions in the mission management phase, the UAS must perform the function of listening for sensor activity. At least some aspect of this task will need to be performed by the human operator.

The operator functions for the *Target Acquisition* mission (Table 3) are similar to those of the *Listening* mission. The main difference is that for the *Target Acquisition* mission, the operator might be required to do target tracking when the target being acquired is dynamic. This function that is not required in the *Listening* mission.

Table 4. Functional and Information Requirements for the Listening Mission.

Listening		
	Phase Goals	**Functional/Information Requirements**
Mission Planning	-Path planning (location of target to be or area to be monitored) - Scheduling of health and status reports	- Threat area information - No fly zone information - Scheduling mechanism - Decision support for path planning (including loitering)-
Mission Management	- Track progress of UAVs and of health and status reports - Listening to transmissions - Interpreting transmissions	- Health and status indicators - Listening support - Audio Signal Detection - Alert management - Signal analysis decision support
Mission Replanning	- Maintaining flexibility for changing goal states - Resource allocation & scheduling	- Re-plan decision support for optimal position
Operator Functions	- Monitoring health and status of UAV - Optimal position supervision - Monitoring for sensor activity - Analyzing other sensor data - Positive target identification - Resource allocation & scheduling - Notifying relevant stakeholders - Tracking target	

In contrast, the *Payload Delivery* mission (Table 5) differs much more in its operator functions from the *Listening* mission. For example, the *Payload Delivery* mission requires the operator to monitor the status of the payload that is onboard the UAV, unlike the *Listening* mission for which there is no such requirement. Thus, integrating the operator functions of the *Listening* mission with those of the *Payload Delivery* mission requires more effort than doing the same for the *Listening* and *Target Acquisition* combination. Synergy in the requirements for operator functions between two different mission types can aid in the development of a decision support system for both missions.

The operator functions derived specify the responsibility of the human operator in the UAS. They do not specify how the human operator will implement these functions. Depending on the decision support tools and the level of automation aboard the UAV, the operator functions can be undertaken in several ways (Parasuraman et al., 2000; Sheridan & Verplank, 1978). For example, the operator function of monitoring the health and status of the UAV can, at one extreme, require the constant monitoring of gauges. Alternatively, in a system that is highly automated, this function can be reduced to listening for alerts. Note, however, that increased automation can introduce the need for the human to perform additional cognitive tasks (Brainbridge, 1987).

Table 4 summarizes the operator functions for all the different mission types depicted in Figure 1. An "X" in a cell implies that the mission type belonging to the corresponding column has the requirement specified by the corresponding row. From the table, it can be seen that, unlike the "monitoring health and status of UAV" operator function that is required by all the mission types, other operator functions are only required by a select few mission types.

Table 5. Functional and Information Requirements the Payload Delivery Mission.

Payload Delivery		
	Phase Goals	**Functional/Information Requirements**
Mission Planning	- Scheduling of health and status reports - Pick areas to strike - Path planning (routes to strike locations) - Scheduling of targets if multiple targets	- Threat area information - No fly zone information - Scheduling mechanism - Decision support for path planning (including loiter locations)
Mission Management	- Tracking progress of UAVs and of health and status reports - Monitoring information coming from BDAs (military only) - Payload choosing	- Health and status indicators - BDA information channels (military only) - Command interface with payload selection support
Mission Replanning	- Modifying payload order list (if multiple final destinations) - Path replanning	- Replanning decision support - Threat area information - No fly zone information - Decision support for path planning
Operator Functions	- Monitoring health and status of UAV - Path planning supervision - Monitoring payload status - Positive target identification - Optimal position Supervision - Resource allocation & scheduling - Negotiating with other stakeholders - Notifying relevant stakeholders	

Missions such as mapping and BDA with high interoperability in terms of functional and information requirements also have many operator functions in common. This stems from the fact that both the functional/information requirements as well as the operator functions are derived from the same phase goals. In any event, missions that have more of their requirements in common are likely to require the human operator to perform similar cognitive processes. This means that (a) similar interfaces and decision support is likely to be effective for both tasks and (b) knowledge about UAV operations for one mission type is more likely to carry over into the other mission type. This, in turn, means that common operator functions can also mean that similar operator training could occur for each mission type.

ANALYSIS

In this section, we discuss the most commonly represented operator functions from Table 6. Specifically, we further analyze those operator functions that exist in at least half of the UAV mission types in the taxonomy. These mission types are:

- Monitoring health and status of the UAV
- Notifying relevant stakeholders
- Optimal position supervision
- Path planning supervision
- Resource allocation and scheduling.

For each of these operator functions, we discuss the reason for their common occurrence and the manifestations of the commonality in terms of decision support design.

Monitoring health and status of UAV

The health and status of a UAV are essential attributes to the proper functioning of the vehicle. They are, therefore, fundamental in achieving the overarching objective(s) of any UAV mission. Thus, it is important that these functions be carried out accurately and with great diligence. However, the need to monitor UAV health and status should not subsume operator attention as the operator will have many other functions to perform (as indicated by Table 6). Moreover, it is well established that beyond 30 minutes, the human ability to remain vigilant for possible system anomalies is significantly degraded (Wickens & Hollands, 2000). Thus, robust decision support should be developed that allows the operator to monitor UAV health and status effortlessly and quickly. Such decision support is likely to occur through alarming systems. In general, the operator only needs to interact with vehicle health issues when there is a problem, so the alerting strategy for these events will be the crux of the decision support design. Once an event occurs, information summarizing this critical event as well as predictions for future system states (such as rising oil temperature) can be presented continuously.

Notifying relevant stakeholders

In many UAV missions, the human operator is a member of a hierarchy of stakeholders. In these missions, it is essential for the operator to be able to communicate with the relevant stakeholders in order to notify them of the success or failure of the mission objective. This operator function is especially important in those mission types where the UAV mission involves an objective that may or may not be achieved. For example, in the *Listening* mission, the operator might need to communicate with the stakeholders when substantial information is acquired. Thus, it will be important that any decision support for mission management contain activity awareness tools so that operators are aware of not only who is in their network of contacts, but how and if an interaction should occur (Carroll et al., 2003).

Optimal position supervision

Many UAV missions require one or more activities to be performed at a predetermined location. It is therefore common for mission types to require optimal position supervision, a function in which the human operator must take part since it is likely based on a mission goal. However, such precision is not easily obtained by the human operator alone, particularly in a multivariate situation when many factors affect the situation such as loiter time, fuel costs, time-on-target demands, etc. Thus robust automation and decision support should provide the operator with the ability to adequately achieve this objective without consuming her/his mental and physical resources and ensuring the best possible mission plan. This function is related to the next operator function that we discuss, path planning supervision.

Table 6. Operator Functions vs. Mission Types.

	Intelligence/ Reconnaissance				Drones		Transport		Surveillance			Comm	Extra-ction	Insertion	
	Mapping	BDA	Target acquisition	Target designation	Decoy	Target	Cargo	Passenger	Geo-spatial	Listening	NBC sensing			Electronic warfare	Payload delivery
Monitoring payload status								X							X
Monitoring network communications		X										X			
Monitoring health & status of the UAV	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Monitoring for sensor activity			X							X	X			X	
Negotiating with other stakeholders				X					X				X	X	X
Notifying relevant stakeholders		X	X						X	X	X	X	X	X	X
Optimal position supervision	X	X	X						X	X	X			X	X
Path planning supervision	X	X			X	X	X	X	X				X		X
Analyzing images	X	X	X						X				X		
Analyzing other sensor data			X							X					
Positive Target Identification	X		X	X						X			X		X
Resource allocation and scheduling		X	X	X					X	X			X	X	X
Tracking target			X						X	X					

Path planning supervision

The path taken by a UAV to reach a location is an important part of mission success, particularly in congested or dangerous operating environments. Thus, careful planning and re-planning of a UAV's path is an important operator function of many missions. Again, however, due to limited human cognitive resources, automated path planners are becoming an increasingly necessary part of a UAS. Just as in the optimal position problem, there are many variables to be taken into account in planning paths such as range, no fly zones, threat areas, times on targets, etc. Because optimal path planning represents a complex multivariate optimization problem, operators need automated decision support to quickly plan new paths and ensure that a number of vehicle and mission constraints are not violated.

Resource allocation and scheduling

Many UAV mission types involve distributing the resources of the UAV on multiple sub-objectives. For example, a UAS may need to acquire several targets (either with imagery or with weaponry), each of differing priority. Thus, resource allocation and scheduling becomes an essential element to overall mission success. Scheduling resources can be a computationally complex task, one that humans may not perform well in many instances, for the same reasons described above. Thus, automated schedulers are needed to assist the humans in these tasks.

There are several possible implications to these findings. First, for certain mission types that may be performed by the same operator(s) or for highly related mission types, designing a universal decision support aid that can span the different missions might be useful. For example, because target acquisition and designation are highly related missions that may need to be performed consecutively, developing a resource allocation and scheduling decision aid that is applicable in both of these mission types would allow a single operator to perform both of these missions using the same decision aid. A second implication is that operator training could be similar for certain mission types that share many operator functions. Finally, research in some of these mission types is less developed than for others, and this will especially be the case for the futuristic missions that will be added to the taxonomy. It would therefore be beneficial to leverage the research on a particular operator function and apply it from one mission type to another.

CONCLUSION

We have presented a taxonomy of UAV mission types. We have also enumerated the information and functional requirements including operator functions for each mission type in the taxonomy. This taxonomy could potentially be useful for identifying commonalities in user interfaces and decision support systems for UAVs across UAS missions. In this paper, the five most common operator functions were highlighted: monitoring health and status of the UAV, notifying relevant stakeholders, optimal position supervision, path planning supervision, and resource allocation and scheduling. The multivariate aspect of these operator functions was highlighted supporting the need for effective decision support for the human operator. Lastly, the implications of having commonly needed operator functions with a requirement for robust decision support were discussed.

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APPENDIX

Mission Type Definitions:

Intelligence: a military discipline that focuses on the gathering, analysis, protection, and dissemination of information about the enemy, terrain, and weather in an area of operations or area of interest.

Reconnaissance: an inspection or exploration of an area to gather information.

BDA (battle damage assessment)**:** the act of measuring, either quantitatively or qualitatively, the status of a target.

Drones: UAVs can also be used to imitate fighter aircraft for several purposes. This could include **Target Practice** (an imitation of a hostile target for training purposes) or **Decoy** (an imitation in any sense of a person, object, or phenomenon which is intended to deceive enemy surveillance devices or mislead enemy evaluation.)

Transport: the movement or transference of passengers or cargo from one location to another.

Surveillance: the process of monitoring the behavior of people, objects or processes for conformity with expected or desired norms.

NBC sensing: Nuclear, biological and chemical sensing**.**

Communications: links between units, including connections to a higher command.

Extraction: Payload extraction from a specified target. In the military, insertions typically involve cargo and/or personnel (search and rescue would fall here).

Insertion: Payload delivery to a specified target. In the military, insertions typically involve weapons (although not necessarily lethal) and can include, for example, the rendering of facilities inoperable (electronic jamming), and the elimination of targets. Commercial applications of strike would include crop dusting and emergency supplies drops.

Electronic Attack (EA)**:** the active use of the electromagnetic spectrum to deny its use by an adversary. Most EA activity is in the form of jamming or electromagnetic deception. EA can also include the use of devices that employ electromagnetic or directed energy weapons in order to destroy enemy vehicles and incapacitate or kill opposing infantry forces. An older term for EA is Electronic countermeasures (ECM).

Electronic Protection (EP)**:** all activities related to making enemy EA activities less successful by means of protecting friendly personnel, facilities, equipment or objectives. EP can also be implemented to prevent friendly forces from being affected by their own EA. Active EP includes technical modifications to radio equipment (such as frequency-hopping spread spectrum), while passive EP includes education of operators (enforcing strict discipline) and modified battlefield tactics or operations. Older terms for EP are Electronic protective measures (EPM) and Electronic Counter Counter Measures (ECCM).

<u>Operator Function Definitions:</u>

Monitoring Payload Status: A function that requires the operator to have knowledge of the current status of the payload (humans, sensors, weapons) on board the unmanned vehicle.

Monitoring Network Communications: A function that requires the operator to have knowledge of the existence or lack of communication signals between the different unmanned vehicles and ground stations in the listening range of the vehicle.

Monitoring Health and Status of the UAV: A function that requires the operator to have knowledge of the current health and status of the unmanned vehicle.

Monitoring for sensor activity: A function that requires the operator to have knowledge of the presence of sensor data.

Negotiating with other stake holders: A function that requires the operator to communicate with other personnel for replanning considerations.

Notifying relevant stake holders: A function that requires the operator to notify relevant personnel of information on relevant tasks.

Optimal position supervision: A function that requires the operator to specify a specific region of space were the unmanned vehicle needs to be, likely in a loiter patter or a hover (perch and stare) position.

Path planning supervision: A function that requires the operator to specify the path that a vehicle must take.

Analyzing Images: A function that requires the operator to perceive and analyze an image in search for certain information or the lack there of.

Analyzing other sensor data: A function that requires the operator to perceive, interpret, and analyze sensor data other than imagery in order to search for certain information or the lack thereof.

Positive target identification: A function that requires the operator to identify whether or not a specific target (possibly found in imagery data) matches a specific target the operator is looking for.

Resource allocation and planning: A function that requires the operator to share a limited resource among multiple targets.

Tracking target: A function that requires the operator to track the motion of a target.