A Comprehensive Matrix of Unmanned Aerial Systems Requirements for Potential Applications within a Department of Transportation

Ebrahim P. KARAN,[1] Claus CHRISTMANN,[2] Masoud GHEISARI,[3] Javier IRIZARRY,[4] and Eric N. JOHNSON[5]

[1] Graduate Research Assistant, CONECTech Laboratory, School of Building Construction, Georgia Institute of Technology, Atlanta, GA 30332; PH (404) 385-6779; FAX (404) 894-6240; email: p.karan@gatech.edu

[2] Graduate Research Assistant, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA 30332; PH (404) 894-0657; FAX (404) 894-2760; email: hcc@gatech.edu

[3] Assistant Professor, School of Building Construction Science, Mississippi State University, MS 39762; PH (662) 325-8310; FAX (662) 325-1297; email: mgheisari@caad.msstate.edu

[4] Assistant Professor, School of Building Construction, Georgia Institute of Technology, Atlanta, GA 30332; PH (404) 385-6779; FAX (404) 894-6240; email: javier.irizarry@coa.gatech.edu

[5] Associate Professor, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA 30332; PH (404) 385-2529; FAX (404) 894-2760; email: eric.johnson@ae.gatech.edu

ABSTRACT

The continuous improvement in the function and performance of Unmanned Aerial Systems (UASs) promotes the need for specific research to integrate this leading edge technology into various applications across Departments of Transportation (DOTs). DOTs of several states have started looking into using UAS technology for different purposes from tracking highway construction projects and performing structure inventories to road maintenance, monitoring roadside environmental conditions, as well as many other traffic management or safety issues, albeit individually focusing on specific usage scenarios. This study investigates various divisions and offices within a Department of Transportation to determine the operational requirements for UAS usage in specific divisions which have the potential to implement this technology to aid and supplement their daily operations. Through a series of interviews with subject matter experts at the management and operational levels, a matrix of user requirements for tasks that have the potential to use UAS is developed. This matrix is mapped to a UAS technical matrix that embeds the technological and technical requirements for development of a potential UAS. These matrices can be used by other DOTs for defining the design specifications for UAS that can fulfill their construction related operational requirements.

INTRODUCTION

Unmanned Aerial Systems (UASs) are an emerging technology that can be widely used in various civil applications, ranging from monitoring tasks to simple item manipulation or cargo delivery scenarios. UASs are normally comprised of a portable control station for the human operator and one or more Unmanned Aerial

Vehicles (UAVs). The utilized UAVs can be equipped with various generic sensors, such as video or still cameras (including far and near infrared), radar or laser based range finders, or specialized communication devices, but they can also be equipped with sensors currently already used in DOT-related operations. Most UASs are capable of real-time data transfer between the UAV(s) and the control station; some have additional on-board data storage capabilities for enhanced data collection tasks. UASs can perform tasks similar to those that can be done by manned vehicles, but often faster, safer, and at a lower cost (Puri 2005). Although an initial wide spread application of UAS was within military operations, having reached a permanent position in the military arsenals of many forces (Nisser and Westin 2006), peaceful applications of these systems are currently investigated in border patrol, search and rescue, damage investigations during or after natural disasters (e.g. hurricanes, earthquakes, tsunamis), locating forest fires or farmland frost conditions, monitoring criminal activities, mining activities, advertising, scientific surveys, and securing pipelines and offshore oil platforms (Anand 2007).

UAS utilizing rotary wing aircraft (e.g. quad- and other multicopters, as well as traditional helicopters) are well suited as experimental platforms for various research efforts, ranging from system intrinsic topics such as autonomous surveillance/navigation (Krajník et al. 2011) or human-machine interaction (Ng and Sharlin 2011), to more extrinsic investigations into the use of unmanned systems as application tools, for example as a sport training assistant providing athletes with external imagery of their actions (Higuchi et al. 2011). One recent case of application based research in the context of construction is the work of Irizarry et al. (2012) to explore potential benefits to safety managers within a construction jobsite. Their study used a quadcopter-type UAV to provide safety managers with fast access to images as well as real time video from a range of locations around the jobsite.

As the continuous improvement in intrinsic function and performance of UASs promotes the need for specific research to integrate this leading edge technology into various applications, Departments of Transportation (DOTs) of several states have started using UAS technology for different applications from tracking highway construction projects and performing structure inventories to road maintenance, monitoring roadside environmental conditions as well as many other surveillance, traffic management or safety issues. Some examples of previous application of UASs by various DOTs across the country are listed in Table 1.

The Federal Aviation Administration (FAA) seeks to integrate UASs into the nation's space for civilian and public applications. Mandated by Congress, the FAA started the test site selection process on February 14th, 2013 and announced the selected sites on December 30th, 2013 (FAA 2013). Aligned with FAA goals of efficient integration of UASs into the nation's airspace, the presented work is performed to determine the potential applications of UASs within divisions and associated offices across the Georgia DOT (GDOT). The methodology for the identification of UASs requirements for potential applications within GDOT consists of three stages. The study started by analyzing the DOT divisions/offices through a series of semi-structured interviews. Then, the user requirements of each identified division/office. were investigated. Finally, a UAS specifications matrix based on design characteristics that fulfill the identified requirements was developed.

Table 1. Summary of previous UASs applications by DOTs

DOT	Application	Equipment
Virginia	real-time traffic surveillance, monitoring traffic incidents and signals, and environmental condition assessment of roadside areas (Carroll and Rathbone 2002)	video/digital camera
Florida	monitor remote and rural areas of the state of Florida (Werner 2003)	video/digital camera
Ohio	collect data about freeway conditions, intersection movement, network paths, and parking lot monitoring (Coifman et al. 2004)	Video/digital camera
Washington State	capturing aerial images for data collection and traffic surveillance purpose on mountain slopes above state highways (Coifman et al. 2004)	video/digital camera
Utah	take high-resolution pictures of highways to inventory their features and conditions at a very low cost and in short time (Barfuss et al. 2012)	video/digital camera

ANALYSIS OF GDOT DIVISIONS AND OFFICES

Of the twelve overall divisions of GDOT (administration, chief engineer, commissioner, construction, deputy commissioner, engineering, finance, intermodal, local grants and field services, program delivery, permits and operations, and planning), four divisions with the highest potential for benefitting from UAS technology were selected for further investigation (construction, engineering, intermodal, permits and operation). Through a series of interviews with employees at the division and office level, the user requirements of each identified division/office were investigated. Figure 1 shows some of the tasks and responsibilities associated with each of the selected GDOT divisions (GDOT 2013). Finally, a UAS specifications matrix based on design characteristics that fulfill the identified requirements was developed. Overall, 23 semi-structured interviews were conducted over four-month period.

The *Construction Division* is responsible for preparing proposals and letting to contract all GDOT highway and bridge projects. It conducts general construction oversight and also oversees project advertising, letting and awards, testing of materials. Furthermore, it inspects and monitors contractual field work, specifies material requirements, and provides geotechnical services. Interviews were conducted with eight engineers at management and operational levels.

The *Engineering Division* develops environmental studies, right-of-way plans, construction plans and bid documents through a cooperative effort that results in project design and implementation. Moreover, the division is responsible for supporting and maintaining all engineering software, engineering document management, and state wide mapping. Three interviews were conducted with persons in charge of activities conducted by the engineering division.

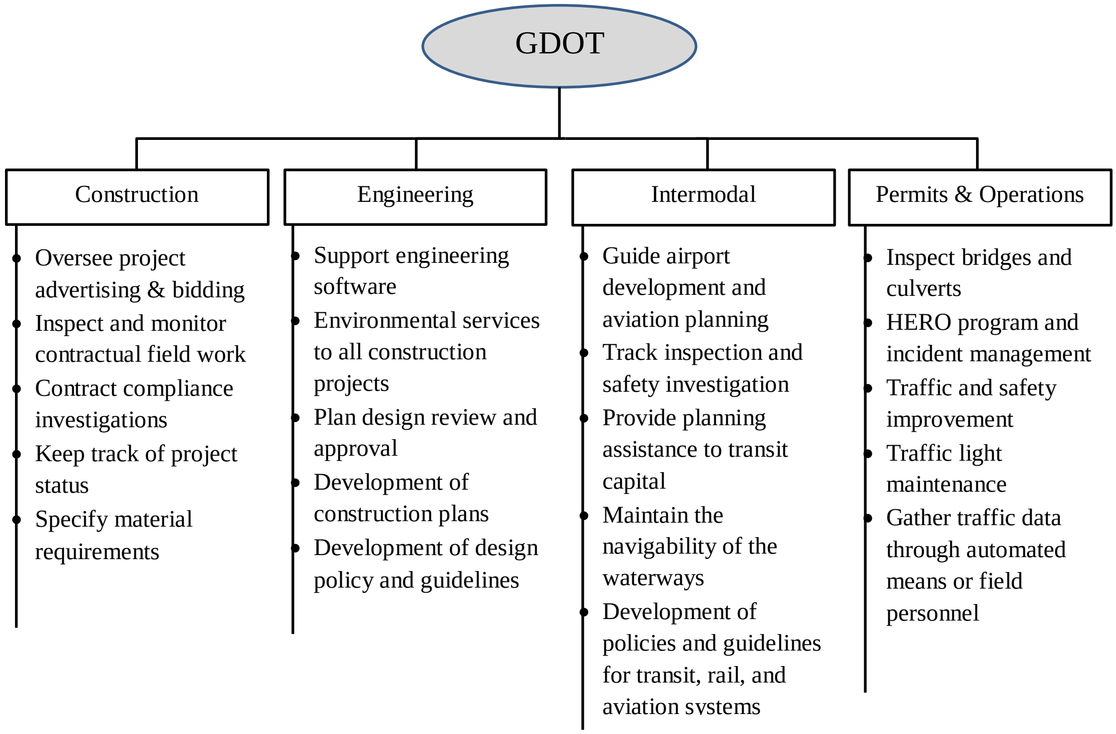

Figure 1. User requirements identification workflow

The main responsibility of the *Intermodal Division* is to support and facilitate the development and implementation of intermodal policies, planning, and projects in the highway program and organize all major statewide non-highway programs for the development of a comprehensive transportation system. The intermodal division consists of four main programs: (1) aviation programs is tasked to guide airport development and to assure a safe and well-maintained system of public-use airports; (2) transit programs provide transit capital and operating assistance to the urban and all metropolitan planning organizations in Georgia; (3) rail programs include track inspection and safety investigation for the Georgia rail system in cooperation with the Federal Railroad Administration; (4) waterways programs maintain the navigability of the Atlantic Intracoastal waterway and Georgia's deep water ports in Savannah and Brunswick. Consequently, five interviews were conducted with members from the intermodal division, including at least one interviewee from each of the above programs.

The *Permits and Operations Division* ensures a safe and efficient transportation system by collecting traffic data, addressing maintenance needs (e.g. related to traffic lights) and regulating the proper use of the state highway system. In order to improve traffic flow and coordinate traffic engineering, traffic safety, and incident management statewide, the division collects traffic data (e.g. flow, speed, counts) using a wide range of devices (e.g. video cameras, microwave sensors, and computer applications pertaining to traffic services). Additionally, the Bridge Design and Maintenance office is one of the service-oriented units of the division, responsible for all bridge maintenance activities, among them the biennial inspection of the 15,000 bridges and culverts in Georgia. Seven interviews were conducted with staff and officials involved in the division.

IDENTIFICATION OF OPERATIONAL REQUIREMENTS

The broad goals and objectives of each identified division were taken from interviews with the subject matter experts identified by their respective supervisors at the respective division. In order to determine the operational requirements for UAS usage for a specific division that could benefit from such technology, a user-centered top-down approach was chosen. In this user focused approach, the overall tasks and user requirements are categorized into various functions and components, enabling a comprehensive understanding of users' goals, their working environment, and decision-making processes. Detailed information about each task can then be translated into a set of requirements that should be considered when designing a UAS for use in a division that has the potential to implement the technology to aid and supplement their daily operations.

The selected approach consists of four different considerations, as shown in Figure 2: (1) defining the operational tasks in the division, (2) studying the environmental conditions of operational workplace, (3) analyzing the user characteristics, and (4) investigating the current technologies and tools used in the division's operations. Interview guides containing five sets of questions were prepared beforehand for collecting data for each consideration and for an evaluation of potential applications of UAS technology in the interviewee's area of expertise.

Defining the Operational tasks in the division: The first consideration is to define the tasks and operations performed in the identified division. A semi-structured interview format was chosen to develop exact definitions of those tasks and to expand their scope. The questions of this step are related to the basic goals of the operators, their major decisions for accomplishing those goals, and the information requirements for each decision. This step has resulted in identifying more than 40 tasks that could benefit from the implementation of UAS technology. The majority of the tasks are centered around collecting data, providing information, and decision making based on the data. Four representative tasks, one for each division, are given in Table 2. Currently most of the related data are collected through field personnel.

Studying the Environmental Conditions of the Workplace: Another important consideration that should be taken into account is the environmental conditions, in which the tasks are performed. These environmental conditions affect the design requirements for a UAS. Ambient noise levels, lighting levels, susceptibility to

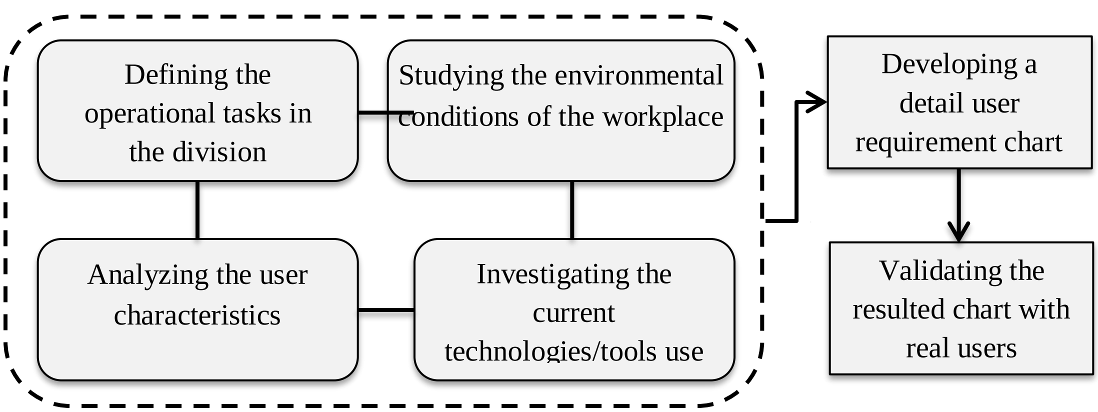

Figure 1. User requirements identification workflow

Table 2. Examples of the tasks performed by each GDOT division

Division	Task description	Location	Duration & Frequency
Construction	Performing several linear measurements, computing areas and volumes from linear measurements, and taking counts of items billed as “each”.	Local	> 2hrs & several times per week
Engineering	Managing archive of aerial photography procured by GDOT and other cooperating agencies.	Local	N/A & several times per month
Intermodal	Inspecting airports and their surrounding areas, identifying obstructions and determining the geometry of the runway(s).	Local	> 4hrs & several times per week
Permits and Operations	Field assessment and traffic data collection in order to review driveway permits or road changes (e.g. adding an access).	Distributed	> 2hrs & several times per week

weather and temperature variations, vibration, privacy, expected pace of operations, position of use (e.g. sitting, standing, while mobile), and frequency of use (e.g. occasional, intermittent, frequent, continuous) are some issues that should be considered (Endsley 2003). Each task is also characterized by some attributes that yield a better understanding of the environmental conditions including locations where the tasks are performed. A *local* task occurs at one location or a job site that can be best described as a patch of land where the *primary descriptor* would be the length and width of the area. A *distributed* task occurs on a strip of land (i.e. along a road, a river, or a railway), or any other place where the primary descriptor would be a length or distance. The time required to complete a given task is determined by the *duration* of the task and the *frequency* of the task occurrence (see Table 2).

Analyzing the User Characteristics: The third consideration is to identify user characteristics such as gender, skill level (e.g. familiarity with basic computer features), training, background knowledge (including technical capability), age ranges (with special note of young or aging populations), and languages to be accommodated. In addition, it is also desirable to take the type of special clothing of the user into consideration. Gloves, masks, backpacks, and any personal protective equipment are examples of clothing items that can be used while working.

Investigating the Current Tools/Technologies Used at the Division’s Operations: Then, as the last consideration, all different technologies or tools that are being used by the identified division’s personnel should be evaluated for possible integration with the UAS platform. There might be a need for integrating hardware (e.g. sensors, radars, or different type of cameras) with the UAS hardware or software. Additionally, the user interface might be required to incorporate or be compatible with other technologies that are currently used by GDOT in the identified division (e.g. asset management or traffic software). Figure 3 shows the resulting operational requirement matrix that includes each division’s operation, user characteristics, working environment, and technology use. A currently ongoing task is

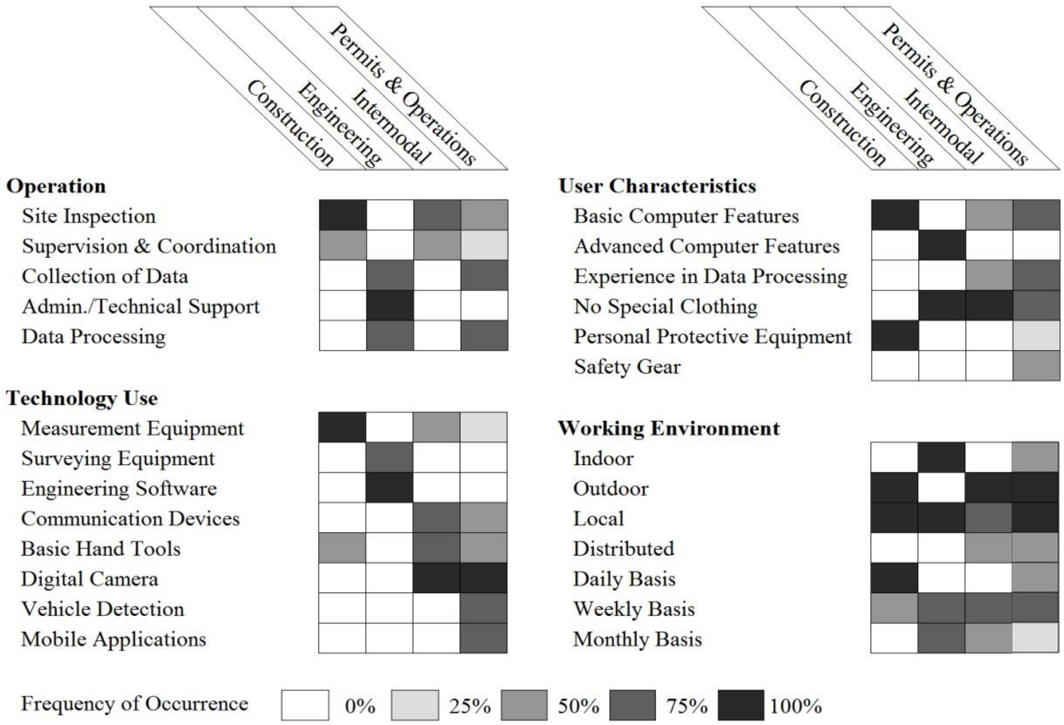

Figure 3. Operational requirements matrix

taking back this matrix to the subject matter experts who were interviewed to identify missing information and errors in the matrix and validate its outcomes.

IDENTIFICATION OF TECHNICAL REQUIREMENTS

Based upon the task classification of being either local or distributed, the related primary descriptor (a length or an area, respectively), and the task attributes duration and frequency, the identified tasks from the collected response data can be binned and several classes of potentially utilizable UAVs can be created and associated with these task bins. Once these classes have been established, combining them with a sensor and/or actuator suite provides for a particular UAS capable of aiding a particular set of tasks. The combination of the class and sensor suite descriptors then provide the technical requirements for a system used in all the tasks that fall into the class related bin and have data collection needs fulfillable by the particular sensor suite.

A major discriminator in classifying UAVs is whether the vehicle is a fixed wing system (e.g. an airplane), or a rotary wing system (e.g. a helicopter). The sizing of the vehicle is then driven by the required payload capacity in the context of the airframe choice. In general it can be assumed that payload can be divided among carried fuel and sensors (and/or other devices) required for the task. The fuel requirement of a specific task can be related to the primary descriptor, used as a notion for the required operational range, and to a certain degree, the task duration, as a notion for the required operational endurance. Using the airframe choice, the range requirement can then be transformed into an additional endurance requirement based upon different nominal cruise speeds of fixed wing and rotary wing systems. Based on the chosen binning, the UAV classes can then be picked in the related design space. At this point, it could also be decided whether a particular class should have the potential to trade fuel for sensors, for example through a modular sensor rack.

Sensor and other device requirements, the other main component making up the required payload, can also be extracted from operational requirements, although there is no direct one-to-one correspondence between the tools utilized (by a human) and the required set of sensors for the UAV as a UAV can or might need to use different measures to accomplish the same data collection task. However, having an understanding of the underlying data collection requirements of the tasks on the one hand and selecting from variable options to collect that data with a UAV on the other, opens up the potential for multi-use of installed sensors, which can lead to a reduced number of installed sensors and an overall expansion of the data collection capabilities of a particular UAV sensor suite. Of special interest in this context are sensors that could be considered “free” as they are already required for the operation of the UAS. Examples are global navigation satellite system sensors (e.g. GPS), inertial measurement units, or cameras, which, when combined with sufficient computational power and a suitable navigation solution, could harness the potential of geo-referenced pictures. A collection of several different sensors, multi-use and specialized, into sensor suits provides another set of discriminators for building the technology requirements matrix.

Depending on the characteristics of the chosen classes and the sensors, not all possible combinations of UAV classes with sensor suits are possible. One limiting factor is mass (installed sensors vs. carried fuel), another one is power consumption (sensor runtime vs. vehicle endurance). The inset in Figure 4 depicts three sensor suites in the context of the previously established classes, visualizing that not all classes are suited to carry all sensor suits as a class marker has to be at or above a suite line to indicate compatibility. A possible combination of a class with a sensor suite provides the largest part of the technical requirements for a UAV that should be suitable to aid all tasks that are in the corresponding class and sensor suit bins.

To complete the set of technical requirements, several other aspects have to be taken into account. Depending on the UAV class, for example, there might be the option for either an electric or gasoline powered system. The collected task frequency data could provide some guidance for specifying this. Additionally, the frequency could give a hint whether a system could be shared among users or whether several systems are required to fulfill the needs of all users.

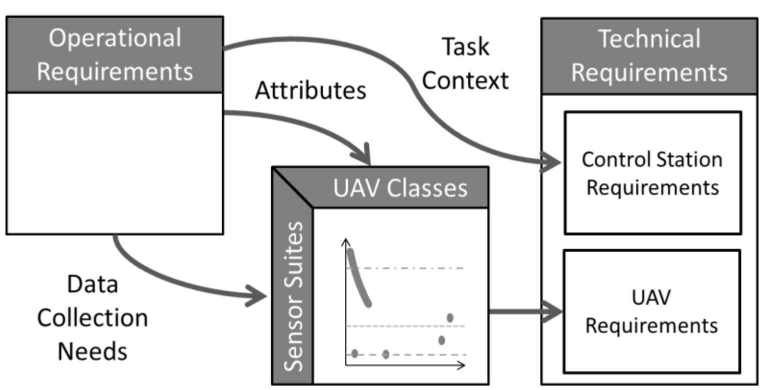

Figure 4. Technical Requirements Identification Workflow

Several other technical requirements can be associated with the control station. A major group of which can be related to the operation of the system and basic questions about the human machine interface. For smaller ad-hoc deployable systems, issues are related to things such as operability with gloves, outdoor readability, ingress protection ratings, or actual usability of the underlying software, for larger systems, another aspect relates to the utilized data links, for example availability, bandwidth, lag, and security. An additional aspect for all systems is the amount of required training a current performer of the task would need to utilize the UAS aid. Furthermore, requirements also arise from needed backend interfaces of the UAS to other potential software systems into which the operator has to transfer the collected data.

The level of autonomy of the system also is of importance; however, for the application purposes of GDOT, i.e. using UAS as an enabling tool, the underlying algorithms are of secondary nature and as such, for the purpose of this study, it was assumed that all systems could operate on an autonomy level comparable to that of the Georgia Tech UAV Simulation Tool (GUST; see Johnson 2013 for a recent overview). Figure 5 shows the created UAV requirement matrix for the identified divisions within GDOT; the left part is pertaining to the notion of UAV classes, while the right part shows the sensor suites.

CONCLUSION

The research is ongoing and aimed at improving the understanding of the current situation of UAS application across various DOTs in the US and determining the current status of different civilian applications of UAS technology. Through a series of interviews with subject matter experts at the management and operational levels, the operational requirements for each identified GDOT division/offices are identified and a UAS design characteristic for each identified GDOT division/office is mapped with operational requirements. The results of the proposed study have the potential for implementation at GDOT and other DOTs by providing the foundation for financial justification of UAS implementation as well as the foundation for technical requirements and application definition in applicable Divisions and Offices. The results will also provide GDOT with potential participation in efforts to provide

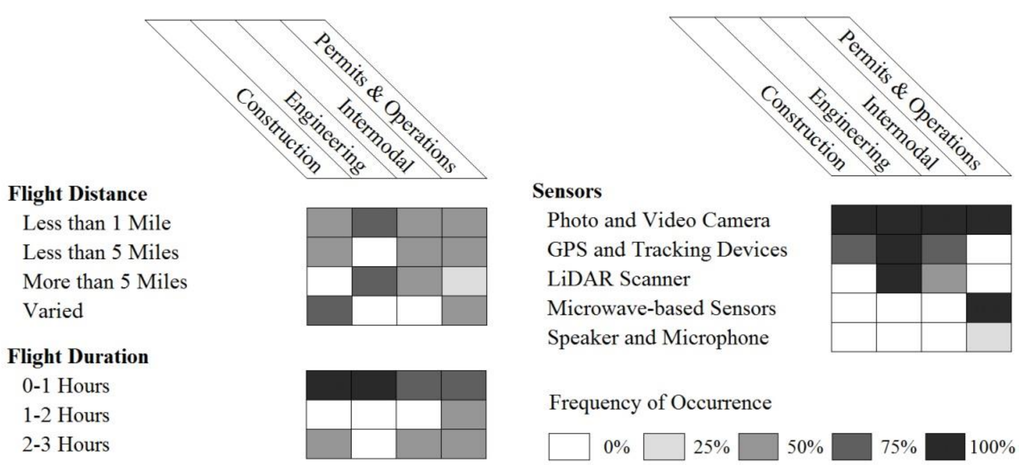

Figure 5. Technical requirements matrix

detailed data to the Federal Aviation Administration efforts on policy for safe, timely and efficient integration of UAVs into the nation's airspace.

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