ASSURE A21: Integrating Expanded and Non-Segregated UAS Operations into the NAS: Impact on Traffic Trends and Safety

Supplement B - Phase 2: Forecast of the Future Scope of UAS Operations

June 30, 2022

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The Alliance for System Safety of UAS through Research Excellence (ASSURE) team was tasked by the Federal Aviation Administration (FAA) with research related to Integrating Expanded and Non-Segregated UAS Operations Into the NAS: Impact on Traffic. Phase 2 of this project focused on developing a forecast for future sUAS activity, including those operations extending Beyond Visual Line of Sight (including expanded and non-segregated operations).

The research further provided insights into the factors limiting such expansion of sUAS operations and provided a forecast for when hindrances are likely to be resolved. This analysis included consideration of enabling advances in technologies, the need for clarity in guidance and regulations regarding such activities, and the impact of public opinion, considering 68 different factors. The results include a forecast that, by 2032, Additional investigations indicate that most of the 68 factors limiting the growth of sUAS operations will be resolved within this time period, the total size of the commercial/non-model fleet for sUAS will be larger by a factor of 2.7 relative to the FAA forecast for 2024. Thus, enabling this increased forecast.</td></tr>
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AAMS	Advanced Air Mobility Systems
AC	Advisory Circular
ACO	Aircraft Certification Office
ALIAS	Aircrew Labor In-Cockpit Automation System
AM	Additive Manufacturing
AR	Augmented Reality
ARC	Advisory Rulemaking Committee
ASIC	Application-Specific Integrated Circuits
ASSURE	Alliance for System Safety of UAS through Research Excellence
ASTM	American Society for Testing and Materials
ATM	Air Traffic Management
BLOS	Beyond Line of Sight
BVLOS	Beyond Visual Line of Sight
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAutoD	Computer Automated Design
CBA	Circuit Based Assembly
CFR	Code of Federal Regulations
CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelf
CSAIL	Computer Science and Artificial Intelligence Laboratory
DARPA	Defense Advanced Research Projects Agency
EEG	Electroencephalogram
EMI SE	Electromagnetic Interference Shielding Effectiveness
EO	Electro-Optical
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FCS	Flight Control Systems
FPGA	Field Programmable Gate Array
FTV	Fluid Thrust Vectoring
IOT	Internet of Things
IPP	Integration Pilot Program
IR	Infrared
IRB	Institutional Review Board
FEMA	Federal Emergency Management Agency
LAANC	Low Altitude Authorization and Notification Capability
LCASP	Low Cost Attritable Strike Demonstration
LiDAR	Light Detection and Ranging
LVC	Live, Virtual, & Constructive Simulation
MBSE	Model Based Systems Engineering
MEMS	Microelectromechanical Systems
MLS	Mission Logging System
NAS	National Airspace System

NASA	The National Aeronautics and Space Administration
NPRM	Notices of Proposed Rulemaking
OBSS	Off-Board Sensing Station
PASAUT	Predictive Analytical Simulation for Advanced UAS Technologies
PLD	Programmable Logic Devices
RTCA	Radio Technical Commission for Aeronautics
PSP	Partnership for Safety Plan
PWM	Pulse Width Modulation
RFID	Radio Frequency Identification
RP	Rapid Prototyping
RTK	Real-Time Kinematic
SME	Subject Matter Expert
TBO	Trajectory-Based Operations
TSO	Technical Standard Order
TVC	Thrust Vector Control
UAH	The University of Alabama in Huntsville
UAM	Urban Air Mobility
sUAS	Small Unmanned Aircraft System
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
USS	UTM Service Supplier
UTM	Unmanned Traffic Management

1. EXECUTIVE SUMMARY

The purpose of the research provided within this report is to forecast trends in the growth of small Unmanned Aircraft System (sUAS) traffic associated with the integration of expanded and non-segregated sUAS operations into the National Airspace System (NAS). In addition, the factors restraining such growth are identified and evaluated in terms of their urgency, difficulty of development or maturation, sensitivity to public opinion and impact on the growth of sUAS operations.

To accomplish these goals, two separate elicitations of expert opinion were conducted. For one elicitation, a set of knowledge elicitation questions was forwarded to 26 Subject Matter Experts (SMEs). Within this elicitation, these SMEs were prompted to provide their predictions regarding the growth of sUAS operations from 2024-2032. Four SMEs responded, and indicated that the average the number of sUAS flights per day will increase to 1,019,200 flights per day in 2024 and increase to 2,730,000 flights per day by 2032. Given the small sample size, it is recommended that additional data be collected in order to increase the precision associated with these estimates.

In the second knowledge elicitation study, an on-line interview was conducted involving 66 SMEs, asking them to evaluate 68 individual technologies/concepts that might affect the introduction of UAS into the NAS. Of the 22 influencing technologies and concepts that were scored as having a substantial effect on the UAS market, 10 or 45.45% were predicted to mature by the year 2027 and 20 or 90.9% were forecasted to have their critical factors addressed by 2030.

The UAH team[1] also conducted an analysis focused on a market forecast based on the equipment/technologies, regulations, and procedures required for BVLOS missions. It was determined that the necessary equipment, regulations, and procedures for BVLOS operations are detect and avoid and other forms of safety automation, remote ID and clarity of relevant standards and regulations. The UAH team then related specific influencing technologies/concepts from the online interview to these categories. This analysis was used to determine the predicted timeframe where most critical factors would be addressed and when the largest market growth would be expected. Based on the results of this analysis, the UAH team estimates that a major increase in BVLOS operations will occur between the time period of late 2025 to 2030.

2. INTRODUCTION/PURPOSE OF RESEARCH UNDER PHASE 2 OF A11.UAS.69: INTEGRATING EXPANDED AND NON-SEGREGATED UAS OPERATIONS INTO THE NAS: IMPACT ON TRAFFIC TRENDS AND SAFETY

The Alliance for System Safety of UAS through Research Excellence (ASSURE) team was tasked by the Federal Aviation Administration (FAA) with research related to Integrating Expanded and Non-Segregated UAS Operations Into the NAS: Impact on Traffic. Phase 2 of this project focused

[1] The UAH team consists of multiple engineering and aviation professionals who have extensive experience in the technology, development, and regulations related to UAS. This team conducts UAS focused research for a variety of government and industry customers. UAH was selected by ASSURE to complete this research based on this known expertise.

on developing a forecast for future sUAS activity, including those operations extending BVLOS or Beyond Visual Line of Sight (including expanded and non-segregated operations).

The research further provided insights into the factors limiting such expansion of sUAS operations and provided a forecast for when hindrances are likely to be resolved. This analysis included consideration of enabling advances in technologies, the need for clarity in guidance and regulations regarding such activities, and the impact of public opinion, considering 68 different factors.

To support these analyses, two knowledge elicitation studies with Subject Matter Experts (SMEs) were conducted. The first focused on forecasts of future sUAS activity, including consideration of the types of aircraft involved and the airspace utilized. In the second knowledge elicitation study, an on-line interview was conducted with SMEs, asking them to evaluate 68 individual technologies/concepts that might affect the introduction of UAS into the NAS. The UAH team also used these findings to support an analysis focused on a market forecast based on the equipment/technologies, regulations, and procedures required for BVLOS missions.

3. METHODS AND RESULTS

3.1 System Wide Forecast 1: Total Commercial/Non-Model Fleet – 2020-2025

At the beginning of each fiscal year, the FAA produces an FAA Aerospace Forecast report. These reports are developed to support budget and planning needs of the FAA. Forecasts presented within these reports are developed using statistical models that capture emerging aviation industry trends. In the FAA's 2021 Aerospace Forecast report titled, *FAA Aerospace Forecast Fiscal Years 2021-2041*, a forecast was presented on the total number of commercial/non-model sUAS units (Federal Aviation Administration, 2021b). Using trends in previous years of commercial/non-model sUAS aircraft registration, review of industry forecasts, and internal market/industry research, the FAA generated the 5-year forecast presented in Table 1. It is important to note that this forecast predicts the number of aircraft units, not the number of flights. This forecast predicts that over a five-year period (2021-2025) the commercial sUAS units will likely increase 1.7 times the original base in 2020.

Table 1. FAA sUAS Commercial Fleet Fiscal Year Forecast.

Total Commercial/Non-Model Fleet (Thousand sUAS Units)

Fiscal Year	Low	Base	High
Historical			
2020	488	488	488
Forecast			
2021	543	589	691
2022	569	665	871
2023	583	729	1,028
2024	601	784	1,094
2025	614	835	1,144

3.2 System Wide Forecast 2: UAH Extrapolation of Total Commercial/Non-Model Fleet

Referencing the FAA forecasted data, the UAH team calculated percentage differences between each of the five years for the low, base, and high forecasted total commercial sUAS fleet. These percentage differences were plotted over each of the time intervals. Based on the behavior of the graphs, a decaying exponential function was selected for data fitting. Using the curve fitting function in MS Excel, an exponential equation was derived for the low, base, and high forecasted sUAS commercial units. Using these equations, the forecast was extended over an additional 7 years to 2032 for the low, base, and high forecast. This forecast was created by curve fitting the FAA projected total commercial fleet data. This data was to be used as a helpful reference for the SMEs to answer the interview questions. UAH's extrapolated forecast is offered in Table 2. The UAH team extended the FAA forecast through the years 2026, 2028, 2030, and 2032. These forecasts are based on the following assumptions:

1. Data was calculated based on the trends observed in the FAA sUAS total commercial/non-model fleet.
2. As the present base (i.e., the cumulative total) increases, the FAA anticipates the growth rate of the sector will slow down over time (Federal Aviation Administration, 2021b)."
3. The UAH team did not make any adjustments to the total number of commercial/non-model fleet forecast based on future technology availability and future FAA-specified procedures/regulations.

Curve fitting the percentage difference generates a more conservative (i.e., lower) estimate than a logarithmic or linear fit of the FAA forecasted number of sUAS units for each year. For example, a linear extension of the FAA's forecast would estimate nearly 1330-thousand commercial sUAS units by 2032 instead of 975-thousand produced by the conservative extrapolation. A more conservative estimate was favored based on the following assumptions:

1) The FAA anticipates the growth rate of the sector to slow down over time (Federal Aviation Administration, 2021b).

2) Aircraft will be retired over time.

Based on this analysis, the UAH team projects that the total commercial/non-model sUAS fleet in the base scenario will have likely doubled within 12 years relative to 2020.

Table 2. Exponential Curve Fit Years 2026, 2028, 2030, and 2032 Projected sUAS Commercial Fleet.

Forecasted Total Commercial/Non-Model Fleet (Thousand sUAS Units)

Fiscal Year	Low	Base	High
2026	622	873	1160
2028	631	925	1174
2030	637	957	1178
2032	640	975	1180

3.3 Converging Evidence on System Wide Forecast

In the preceding two subsections, information has been provided regarding system wide forecasts UAS activity. In order to collect converging evidence, a study was designed to elicit SME judgments regarding a system wide forecast for sUAS activity as well as more specific forecasts focused on different mission types and different classes of airspace. The UAH team developed a set of 8 interview questions that were designed to provide specific insights into expanded and non-segregated sUAS operations in the NAS. Questions within this expert elicitation prompted participants to provide inputs related to sUAS traffic volume, aircraft configurations, airspace classes occupied, and specific expanded and non-segregated sUAS operations in the NAS. These operations included: sUAS operations from a moving vehicle, tethered sUAS operations, multiple sUAS controlled under one remote pilot, sUAS operations above 400 feet, and operations over moving vehicles. The list of 8 questions are provided below.

1. A scaling factor that converts the total baseline commercial sUAS units to total number of operations per day for each of the specified fiscal years.
2. Estimate the percentage of sUAS missions per fiscal year (specified in the table) that will require operations **from** a moving vehicle.
3. Estimate the percentage of sUAS missions per fiscal year (specified in the table) that will require operations above 400 feet above ground level (AGL).
4. Estimate the percentage of sUAS missions per fiscal year (specified in the table) that will require tethered operations.
5. Estimate the percentage of sUAS missions per fiscal year (specified in the table) that will require the operation of multiple aircraft controlled by a single RPIC.
6. Estimate the percentage of sUAS missions per fiscal year (specified in the table) that will require operations **over** moving vehicles.
7. What percentage of the total commercial sUAS usage will the following aircraft configurations be utilized in the fiscal year specified?
8. Estimate the percentage (of total flight hours) by category of airspace where you believe these sUAS operations will occur in the corresponding fiscal years.

3.3.1 Method

The UAH team identified and contacted 15 sUAS SMEs. Individuals invited included SMEs working in academia, industry, and for the FAA. These individuals were invited to participate and were sent the expert elicitation, which is contained in Appendix B1.

3.3.2 Converging Evidence: Results and Conclusions

Four participant responses are described below (two from academia – individuals whose academic research focus is on UAS and are part of the A21 ASSURE Team and two individuals from industry – an international aircraft services company which offers solutions to a wide variety of air transportation and related service needs and an individual with over 20 years of UAS related experience).

Each of the individual responses is provided in Appendix B2. One significant finding was the judgment by four of the invited SMEs who responded to the elicitation by indicating that they did not feel qualified to make the types of forecasts requested in the elicitation. Each of these four respondents shared a concern that there are too many uncertainties associated with the numerous factors that will determine future sUAS activity. These uncertainties included future FAA rulings, market demand, and emerging sUAS technology. An additional common concern expressed by these four respondents focused on their specific expertise. Respondents voiced that their expertise was only in a subset of the sUAS arena; therefore, they were unequipped to address nationwide sUAS trends.

Four individuals did, however, complete the interview questions, with an average of 8.75 years of experience working within the field of sUAS. The small number of responses to the expert elicitation does not allow for a thorough statistical analysis. However, qualitative extrapolations can be made from the responses received.

Within the elicitation, these SMEs were prompted to provide a specific sUAS operations scaling factor indicating their forecasts regarding the rate at which they judge sUAS operations will increase relative to the forecasts provided in Tables 1 and 2. Specifically, while looking at Tables 1 and 2, they were asked to provide:

1. A scaling factor that converts the total baseline commercial sUAS units to total number of operations per day for each of the specified fiscal years (e.g., 488,000 [sUAS in 2020] x **1.5 [Daily Ops / sUAS]** = 732,000 [Daily Operations for Fiscal Year 2020]). Please fill out the chart below.

Fiscal Year	Scaling Factor [Daily Ops / sUAS]	Reasoning*
2024		
2026		
2028		
2030		
2032		

*For Example, (1) Enabling Technology Emergence, (2) Emerging FAA Guidance | Procedures | Regulations, (3) Demand/Economic Factors

Example reasonings were presented purely as a guide, not response constraints. Based on the responses to the reasoning portion of Question 1, it appears as though most respondents selected from the examples provided. It is possible that these examples biased the responses. However, these reasonings align with the scope of the research provided herein. Thus, providing valuable insights to the study.

An average scaling factor between the four SMEs for the 8-year future prediction is provided below in Table 3. These data indicate that the SMEs predict the expected number of daily flight operations in 2024 will be 1,019,200 (784,000*1.3) and the expected number of daily flight operations in 2032 will be 2,730,000 (975,000*2.8).

Table 3. Average SME Responses for Question 1

Fiscal Year	**Scaling Factor [Daily Ops/ sUAS]**

2024	1.3
2026	1.5
2028	2.0
2030	2.4
2032	2.8

Together with the volume predictions presented in Table 3, SMEs were prompted to provide corresponding reasoning. The responses for each of the three respondents are provided in Table 4. Demand/economic factors as well as emerging FAA guidance, procedures, and regulations were the two most common reasonings behind selected scaling factors. Therefore, it can reasonably be assumed that these SMEs predict that the growing demand for commercial sUAS solutions, in addition to clarity in FAA regulations, will have the largest bearing on the volume of sUAS in the NAS. It could also be concluded that enabling technology emergence will play a less important role in volume of sUAS operations in the NAS than demand and emergent regulations in the shorter term (2022-2026) but will have an increasing impact starting after 2026.

Table 4. SME Reasoning for Associated Fiscal Year Forecast Responses to Question 1.

Fiscal Year	**Reasoning ***
2024	(3), (2), (2), still adoption period
2026	(2), (2), (3), (1)
2028	(1), (2), (1), (1)
2030	(3), (2), (3), (2)
2032	(3), (2), (1), (1)

* (1) Enabling Technology Emergence, (2) Emerging FAA Guidance | Procedures | Regulations, (3) Demand/Economic Factors

In regard to questions surrounding specific types of expanded and non-segregated operations (Questions 2-6 in Appendix-B1), it appears as though one of the respondents (Response 2) provided information as it applied specifically to their organization's commercial sUAS operations. Therefore, responses to these questions were flagged in the qualitative analysis of responses. Responses from the remaining two SMEs were utilized in the corresponding qualitative analysis.

It is intriguing that responses indicated sUAS operation above 400 feet would see significant growth in the future. It could be assumed that SMEs were considering inspection operations of large structures. Therefore, the 400 feet above ground level maximum altitude limit could be extended 400 feet above the height and within a 400-foot radius of the structure.

In contrast, tethered operations and operations from a moving vehicle were projected to saturate within the 8-year timeframe (2024-2032). This projection is also within reason as these types of operations have a somewhat niche usage (i.e., the majority of sUAS operations will not require a tethered aircraft or the manipulation of controls from a moving vehicle). Tethered operations could include security or surveillance as well as coverage of media events. Operations from a moving vehicle would be required for operations which need to cover large area of land or sea.

The results indicate that these SMEs hold the opinion that sUAS operations above 400 feet, over moving vehicles, and of multiple aircraft controlled by a single remote pilot will increase over the 8-year period (2024-2032). The prediction is certainly within reason for the latter two cases as sUAS operations continue to increase as viable solutions for sectors like delivery, emergency response, agriculture, and inspection.

Questions 7 and 8 were specifically developed to provide responses to the categories of aircraft and classes airspace involved in future expanded and non-segregated sUAS operations. Upon review of the answers provided by the three SMEs, unfortunately multiple responses had to be flagged. Flagged responses are listed below.

- Response 1 Question 7: Provided percentage inputs for types of aircraft configurations per fiscal year over 100%.
- Response 2 Question 7: Gives the impression to have provided answers specifically related to their organization's operations.
- Response 2 and 3 Question 8: Appears to have provided answers specifically related to their organizations' operations.

Though there were these issues with the responses provided, a qualitative analysis can still be conducted with the data provided.

A high-level assessment of responses provided to Question 7 reveals that there were differences of opinion, with some SMEs projecting that the hybrid VTOL aircraft configuration will emerge as the preferred configuration for commercial sUAS operations and some predicting that rotorcraft/multirotor aircraft will dominate. Hybrid VTOL aircraft have certainly gained popularity in the UAS industry in recent years. According to a Statista™ report published in 2022, the global commercial fixed wing hybrid vertical take-off and landing UAS market value from 2017 to 2028 will increase by over 1.5 billion U.S. dollars (Statista, 2022).

An average numerical value of the responses provided by Response 1, Response 3 and Response 4 are offered in Table 5. It is important to keep in mind the aforementioned flags to these data.

Table 5. Average SME Responses for Question 7 (Based on Responses 1, 3 and 4).

Fiscal Year	Rotorcraft/Multirotor [%]	Fixed Wing [%]	Hybrid VTOL [%]
2024	53	30	13
2026	49	27.9	23.1
2028	44.1	25.9	30
2030	40.5	26.1	33.4
2032	38	23.3	38.7

Upon assessment of the responses provided by SMEs for Question 8, Class G airspace is expected to experience the majority of expanded and non-segregated sUAS operations. This result is as anticipated. However, SMEs project that over time all classes of airspace will be involved in such operations. This projection is certainly within reason as sUAS have the potential to emerge as solutions in day-to-day airport operations (i.e., fence and runway inspection). Additionally, UTM Service Supplier (USS) have made the process of receiving Low Altitude Authorization and Notification Capability (LAANC) and Air Traffic Control (ATC) authorization to operate in controlled airspace more accessible. Class E airspace is expected to have the second largest occupation of commercial sUAS operations. This could be within reason if it is assumed that sUAS inspection of large structures which extend sUAS operational altitude into Class E airspace as well as surface level Class E airspace missions are expected to experience large market growth. An average numerical value of the responses provided by Response 1 and Response 4 for Question 8 are provided in Table 6.

Table 6. Average Projected Expanded and Non-Segregated sUAS Operations Airspace Occupation (Responses 1 and 4).

Fiscal Year	B [%]	C [%]	D [%]	E [%]	G [%]
2024	0	0	1.0	11.5	87.5
2026	1.0	2.5	3.5	12.0	81.0
2028	1.5	3.5	5.0	14.0	76.0
2030	2.0	4.0	7.0	21.0	66.0
2032	2.5	5.0	9.0	22.5	61.0

3.4 Extrapolations from Phase 1 Data Set

Sections 3.1-3.3 focused on system wide forecasts regarding sUAS activity. An extrapolation from Phase 1 Task 1-3 using a time-series analysis provides a system-wide forecast regarding approved waiver requests. Figure 1 illustrates a forecast through 2025 regarding Part 107 waivers issued. Note that, unlike the FAA and UAH forecasts discussed in Sections 3.1 and 3.2 as well as the SME forecasts discussed in Section 3.3, this extrapolation is not influenced by any factors discussed in Section 3.5 that could have a major impact on the number of approved waiver requests. For example, if the FAA were to complete rulemaking in 2024 for BVLOS operations that reduced the need to submit waiver requests, this would not be reflected in this forecast.

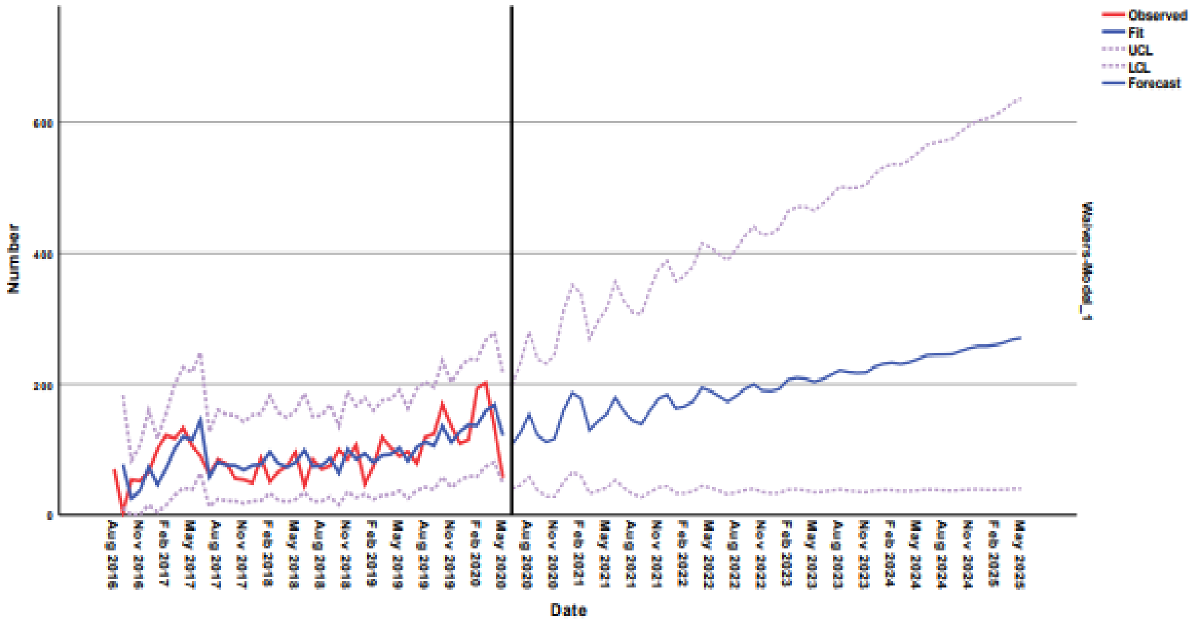

Figure 1. Phase 1 Extrapolation of Number of Part 107 Waivers Issued.

As contrasted with the system-wide predictions discussed in Sections 3.1-3.3, Phase 1 also provided the data to make an extrapolation on the number of BVLOS operations. Figure 2 presents a forecast of the number of BVLOS operations for 2021-2025 based on the Phase 1 data reflecting the historical growth trend. Like the forecast for approved waiver requests based on historical trends, this extrapolation for BVLOS operations is not influenced by any of the 68 technologies and influencing concepts described in more detail in Section 3.5 that could have a major impact.

The results provided in Section 3.5, however, indicate that there is likely to be a major inflection point in this graph starting in 2026, reflecting a significant increase in the rate at which the number of BVLOS operations are forecast to increase relative to the growth trend up to 2025 shown in Figure 2. Thus, the forecast shown in Figure 2 could be used as the 2025 baseline (expected value of approximately 1050 operations and a 95% upper limit of approximately 2800 operations), with a significantly faster growth rate (increasing the slope of the fitted line) starting in 2026 as indicated in the results in Section 3.5.

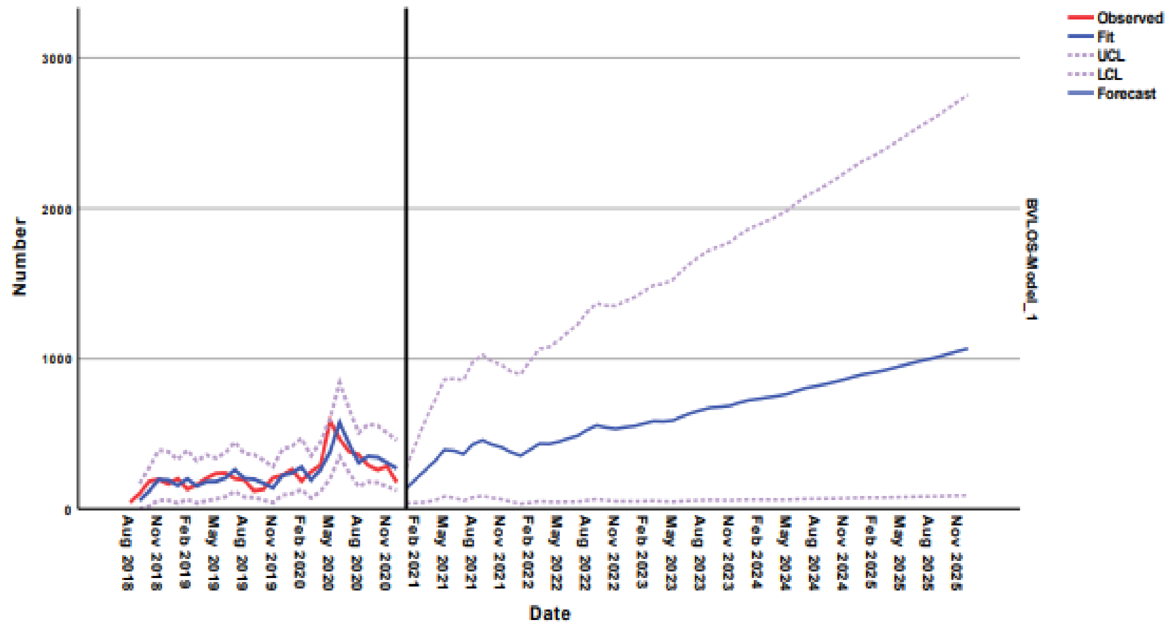

Figure 2. Phase 1 Extrapolation: Number of BVLOS Operations.

3.5 SME Forecast for the Maturation of Enabling Technologies and Standards

Given the hesitancy of a number of the SMEs who were solicited to provide system-wide forecasts in the interview study described in Section 3.3, another interview study was conducted with more narrowly focused questions. The expectation was that a greater number of SMEs would feel comfortable providing responses to these more narrowly focused questions that dealt with the impacts on sUAS activity based on the future maturation of specific technologies and the maturation of standards and regulations to provide greater clarity in terms of approval for sUAS operations.

3.5.1 Method

The UAH team interviewed a collection of industry, academia and government experts focused on aviation with the large majority being in the Unmanned Aircraft Systems area. Their expertise crossed the boundaries of pilots, developers, researchers, and regulators. To make the process efficient and consistent from one participant to another, an on-line software application called PASAUT was developed to conduct the interviews. PASAUT was developed specifically for this research by a third-party firm who specializes in creating online database applications.

A list of 68 technologies and influencing concepts (such as regulatory items, standards, and FAA initiatives) that could affect the integration of UAS into the NAS was defined. This list was formulated over time through multiple discussions with the FAA representatives and ASSURE team members in A21 technical interchange meetings. 499 invitations were sent requesting individual SMEs to participate in the research. Each responding participant was assigned several[2] of the technology/concept areas based on their known areas of expertise.

This technology assignment required a priori knowledge of the SME's expertise. This knowledge was collected through university and company websites as well as professional referrals. A series of standardized questions was used to elicit the opinions of the experts as applied to each of their assigned subjects. Upon completion of the on-line interviews, the results were tabulated and evaluated using a business intelligence application called Microsoft Power BI™.

3.5.1.1 Detailed Procedure – Development of the Technology/Concept List

Starting in March 2020, Mr. Jerry Hendrix, the Principal Investigator, presented an image as part of the monthly Technical Interchange Meetings (TIMs) that depicted an extensive listing of "influencers" that might determine the growth of UAS activity in the future, including enabling technologies and the regulatory environment at various intervals of time – 2025, 2030, 2035, and beyond 2040. These influencers were categorized into four subsets – Materials, Technology, Manufacturing, and Enablers. Lines divide each of the four influencer subsets. Specific technologies and concepts populate the figure at different time periods – designated by the overlapped shapes. The figure depicts the intersection of the four influencer subsets and its effect on future UAS innovation. Figure 3 became the foundation of the technology/concept list that ultimately defined this research.

[2] In most cases, the number of topics assigned to any single SME was limited to eight in consideration of the time required and the fact that no compensation was being provided. The UAH research team felt that this would take no longer than one hour of the SME's time.

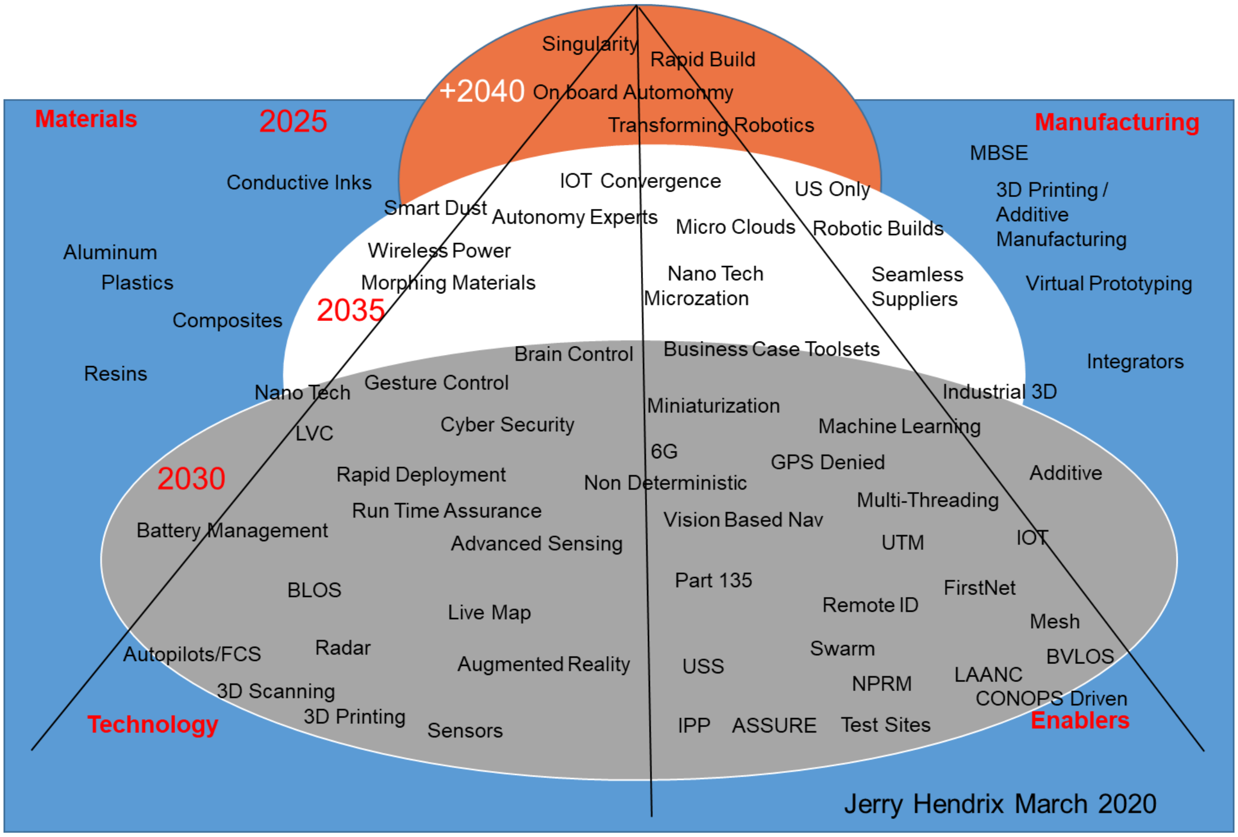

Figure 3. Initial Concept Illustration – March 2020.

At each subsequent TIM, the UAH team invited the other ASSURE team participants and FAA representatives to suggest changes or additions to this chart, and changes were incorporated accordingly. When the list began to be incorporated into the PASAUT application and serious discussions were addressing the analysis of data, the research team refined the list and its defining categories, resulting in 68 influencers organized into 9 categories as shown in Table 7. Feedback and recommendations from FAA representatives and the A21 ASSURE team shaped the technologies selected for the PASUAT interview.

Table 7. Influencing Technologies/Factors in their Final Categories.

Aerodynamics/ Performance	Data/ Comm/ Security	Materials	Operations/ Flight	Power	Regulation	Research/ Design/ Systems	Sensors/ Imagery	Supply Chain/ Manufacturing
Adaptive Aerostructures	6G	Aluminum/Aluminum Alloys	Autopilots/Flight Control Systems (FCS)	Alternative Power	BLOS	ASSURE	3D Scanning	3D Printing/Additive Manufacturing
Autonomy Expert Systems	Cyber Security	Composites	Brain Control	Battery Management	BVLOS	Business Case Tool Sets	Advanced Sensing	Rapid Build
Beyond Aerodynamic Maneuvers (Supermaneuverability)	First Net	Conductive Inks	Gesture Control	Wireless Power	Certification	CONOPS Driven	Augmented Reality	Robotic Builds
Machine Learning	IOT Convergence	Metamaterials	GPS Denied		Integration Pilot Program (IPP)	Integrators	Off-board Sensors	Seamless Suppliers
Morphing Materials	Live Map	Plastics	LAANC		Notice of Proposed	Miniaturization	Radar	U.S. Only
Non Deterministic Approach	LVC	Resins	On-Board Autonomy		Part 135	Model Based Systems Engineering	Sensors	
Vectored Propulsion - Thrust Vector	Mesh Networks		Rapid Deployment		Remote ID	NanoTech	Smart Dust	
	Micro Clouds		Run Time Assurance		RTCA Standards: DO-178B - Software Considerations in Airborne	Singularity		
	Multi-Threading		Swarm		RTCA Standards: DO-254 - Design Assurance Guidance for Airborne	Virtual Prototyping		
			Transforming Robotics					
			UAS Service Suppliers (USS)					
			UAS Traffic Management					
			Vision-Based Navigation					

3.5.1.2 Detailed Procedure – Development of the Standardized Questions

One challenge in a standardized interview process is developing questions that are universal enough to be applied to the broad spectrum of characteristics of the topics that have been defined. The team decided to use a scalar system, eliciting ratings on a range of possible factors for categories in which such a scaled approach could be applied to all the technologies/concepts in all 9 categories. After substantial brainstorming, the final evaluation factors and their categories were delineated as seen in Table 8.

Table 8. Standardized Evaluation Factors and Their Categories.

Technical Factors	Enabling/Hindering Factors	Timeframe Factors
Difficulty of Development	Regulatory Hurdles	Estimate of Initial Technology Availability
Urgency of Need	Ease of Commercialization	Estimate of First Use in UAS
Scale of Market Impact	Public Opinion	Estimated Level of Uncertainty
Availability of Consituent Technologies	Environmental Considerations	
Ease of Integration/Testing	Infrastructure Considerations	
	Political Resistance/Acceptance	
	Impact of NPRMs	

Each of the standardized evaluation factors were translated into a question that could be answered with a numerical ranking. The questions were carefully worded to ensure that a lower number represented an easier (earlier) path to incorporation, whereas a higher score represented a more challenging (and likely therefore later) introduction into a standard operating environment. For any question that required a timeframe, we allowed the SMEs to provide specific dates and ranges in their responses. These questions are presented in Table 9.

Table 9. The Questions which Evolved Out of Their Related Evaluation Factors.

Factors	Question: In all cases, higher score = more difficult, longer range, delaying; Lower score = easier, nearer-term, accelerating
Difficulty of Development	Rate the difficulty of bringing this technology to maturity on a scale of 1-10, with 10 being the most difficult.
Urgency of Need	Rate the urgency of using this technology to serve society's needs on a scale of 1-10, with 10 being the least urgent.
Scale of Market Impact	Rate the expected impact of this technology when mature on the UAS industry with 1=Small market impact, 5=Moderate market impact, 10=significant or substantial market impact
Availability of Consituent Technologies	Rate the availability of the technology components needed to bring this technology to maturity with 1 being currently available and 10 being the least available.
Ease of Integration/Testing	Assuming this technology has reached maturity, rate the ease of integrating and testing it in a UAS on a scale of 1-10. 1 is the easiest; 10 is the most difficult.
Regulatory Hurdles	For the selected technology, rate anticipated regulatory challenges required before it can be regularly available on a 1-10 scale. 1 is the easiest; 10 is the most difficult.
Ease of Commercialization	For the selected technology, rate anticipated commercialization challenges required before it can be regularly available on a 1-10 scale. 1 is the easiest; 10 is the most difficult.
Public Opinion	For the selected technology, rate anticipated public opinion (acceptance or resistance) affecting its regular availability on a 1-10 scale. 1 is acceptance; 10 is resistance.
Environmental Considerations	For the selected technology, rate anticipated environmental challenges required before it can be regularly available on a 1-10 scale. 1 is the easiest; 10 is the most difficult.
Infrastructure Considerations	For the selected technology, rate anticipated infrastructure development challenges required before it can be regularly available on a 1-10 scale. 1 is the easiest; 10 is the most difficult.
Political Resistance/Acceptance	For the selected technology, rate anticipated political challenges required before it can be regularly available on a 1-10 scale. 1 is the easiest; 10 is the most difficult.
Impact of NPRMs	For the selected technology, rate anticipated impact of Notices of Public Rulemaking (NPRMs) required before it can be regularly available on a 1-10 scale. 1 is the least impact; 10 is the most impact.
Estimate of Initial Technology Availability	What year do you estimate that this technology will first reach maturity?
Estimate of First Use in UAS	What year do you estimate that this technology will first be used operationally in a UAS?
Estimated Level of Uncertainty	For you previous estimate, please estimate your level of uncertainty: +/- (X) Months.

3.5.1.3 Detailed Procedure – Complying with the University's Institutional Review Board (IRB)

Every institution of higher learning has an Institutional Review Board (IRB) that governs all research involving human subjects. The purpose of IRB review is to ensure, both in advance and by periodic review, that appropriate steps are taken to protect the rights and welfare of humans participating as subjects in the research. To accomplish this purpose, IRBs use a group process to review research protocols and related materials (e.g., informed consent documents and investigator brochures) to ensure protection of the rights and welfare of human subjects of research.

Prior to initiating any contact with potential SME candidates, the UAH IRB required that the research team submit a detailed description of the research to be conducted, exact documentation of the interviews being conducted, and exact wording of all expected correspondence with the subjects including the initial contact email, the email accompanying the Informed Consent Form, the Informed Consent Form itself, the process by which the form would be signed and returned, and the follow up email providing the subjects with their initial username and password.

The team also described in detail to the IRB the procedures to ensure the anonymity of the subjects and the means by which the team would preclude any attribution of specific responses to individual respondents.

3.5.1.4 Detailed Procedure – Development of the On-Line PASAUT Application

The team chose to engage a firm that specializes in developing on-line interactive database applications, OLH, Inc.

The following design criteria governed the development of the tool.

1. There would be two categories of users, Subject Matter Experts and Administrators.
2. Immediately upon entering the application, a user would be required to change their password as one means of protecting anonymity.
3. The Administrator could add, delete, or modify data relating to any of the following: users, technologies assigned to users, technology titles and definitions (in a dictionary-like function), user organizational categories (e.g., government, private sector – manufacturing, private sector – service provider, academia, media, etc.), weighting factors that might be applied to either evaluation categories or classifications of technologies.
4. The tool would use an integer value to represent individual users to protect their anonymity,
5. The application would be hosted by OLH, Inc. to improve security,
6. All data would be collected in a relational database to lend itself to multidimensional analysis.

OLH suggested that the team also employ a Business Intelligence application called Microsoft Power BI™ to discern certain patterns or insights that might escape detection otherwise.

The final product was first used by subjects in late September 2021. Samples from the PASAUT application are included in Appendix B4.

3.5.1.5 Detailed Procedure – Developing the Target List of Subject Matter Experts

The team hoped to identify and solicit participation of 500 candidates, with an acceptance/participation rate of around 20 percent. This would yield roughly 100 participants. If each subject was assigned an average of eight technology/concept areas, the team hoped to observe the completion of around 800 individual technology assessments, an average of about 11.5 opinions/technology to produce useful, meaningful numerical data. The actual acceptance/participation rate was 13.2 percent. 499 individuals were contacted and 66 participants completed all of their assigned evaluations.

The team used several sources to develop the list of potential subjects:
1. Public listings of government officials dealing with UAS technology and regulation. (Example: FAA, FEMA websites, NASA),

2. Public listings of academic faculty members associated with UAS technology and regulation. (University and research organization websites),

3. Authors of recently published academic papers centered around some of the defined technology areas,

4. Authors of academic journal articles relating to some of the defined technologies,

5. Attendance sheets from recent industry days, professional organization conferences, and consortiums,

6. Sign-up sheets at registration tables of professional meetings focused on UAS development and technologies,

7. Business cards collected at UAS expositions, consortiums, and other professional gatherings.

The team also asked ASSURE partners to suggest individuals who might be valued contributors. In addition, the FAA provided a list of potential SMEs in specified technology/concept categories, all of whom were contacted. Using these methods, the team succeeded in the goal of identifying 499 potential subjects.

Once a subject was identified, researchers used sites such as LinkedIn to determine contact information. To verify expertise, each SME was prompted to provide the number of years they have been involved with UAS within the PASAUT online interview. The average number of years of experience from all SMEs who participated in the online interview was calculated. This figure was 11 years of UAS related experience. To get more potential SMEs for the PASAUT interview, the email with the Informed Consent Form for the subject's signature included the following statement: "If you have any colleagues or acquaintances who might be good candidates to contribute to this research, please don't hesitate to send us their names and contact information. We thank you in advance if you can provide us with other subject matter experts with knowledge and experience in drone technology and/or regulation." This resulted in several additional candidates being identified and solicited. The distribution of individuals who completed evaluations within their respective professional groups can be seen in Table 10. It is important to note that multiple evaluations were completed by each SME. Some participants elected to skip certain assigned categories if they felt they were not sufficiently expert in that area. A total of 506 evaluations were completed.

Table 10. Occupational Distribution of Participants.

Category	Completed Evaluations	% of Evaluations
Academia	117	23%
ASSURE	107	21%
FAA	79	15%
NASA	73	14%
Other Government	15	3%
Industry	122	24%
Other	3	1%
Total	516	100%

3.5.1.6 Detailed Procedure – Assigning Technologies/Concepts to Individual SMEs

Having identified an expert through one of the processes previously listed, the team attempted to assign technologies that aligned with their area of expertise. For example, if a specific SME was recognized as a propulsion expert, they might be likely to be assigned Alternative Power, as well as Vectored Propulsion - Thrust Vector Control (TVC). The remaining technologies assigned would be generally aligned or peripheral to their primary expertise.

For individuals who were generalists or for whom the research team might not be able to identify the primary area(s) of expertise, researchers assigned topics that needed evaluations to keep the overall numbers of evaluations in balance. For clarification, this does not imply generalists were assigned only obscure technologies or concepts. In an effort to mitigate evaluation difficulties, advanced technologies and concepts were assigned to individuals who possessed related or peripheral expertise. Additionally, respondents were permitted to skip evaluations if they felt unequipped to provide evaluation responses.

3.5.1.7 Detailed Procedure – Conducting the Email Solicitation and On-Line Interview

Having completed the prerequisite IRB qualification and developed an initial list of potential SMEs, researchers began the formal process of contacting individuals. The sequence of correspondence is as follows.

1. An initial inquiry is made by email.

“Dear Colleague:

The University of Alabama in Huntsville, as part of the FAA Center of Excellence for UAS Research, the Alliance for System Safety of UAS through Research Excellence (ASSURE), is conducting important research to forecast future directions in UAS evolution. We have been tasked with predicting projected trends (i.e., waiver petitions and traffic volume) regarding future demand for expanded and non-segregated Unmanned Aircraft Systems (UAS) operations integration into the National Airspace System (NAS). This analysis will include development of an expected timeline for the projected demand, including the rate at which the demand will progress.

Our research includes conducting on-line interviews with recognized experts in various UAS-related fields. That’s why we are contacting you. We are inquiring as to your willingness to participate in this important research. It would involve an on-line “interview” of sorts, in which you would be asked to respond to a series of 15 questions as they relate to a specific enabling technology (for example, additive manufacturing, or sensors, or composite materials). We estimate that the response to these questions will take no longer than 10 minutes for a specific technology, and we would envision eliciting your input on approximately 6-8 technology areas that we think relate to your expertise.

This research is important. It may well influence decisions and policies affecting the direction and processes of integrating UAS fully into the NAS. We would very much appreciate your participation as we respect your role in the advancement of UAS.

If you are willing to become a participant in this research, please respond by email and we will forward the necessary form to be completed prior to your involvement. We look forward to hearing from you and to your participation in this important research.

Most Respectfully,

Jerry Hendrix, Director of UAS Research Programs, Principal Investigator"

2. If the individual showed an interest and expressed a willingness to participate, an Informed Consent Form was generated in pdf format and sent to the SME with this correspondence:

"Dear {Name of SME},

Thanks for agreeing to participate in our research. Attached you will find an informed consent form in pdf format. Please sign it electronically and return it. As soon as we receive your signed form, we'll forward to you the url address of our Predictive Analytical Simulation for Advanced UAS Technologies (PASAUT), your username, and temporary password. We really appreciate your willingness to share your expertise to support this important research.

If you have any colleagues or acquaintances who might be good candidates to contribute to this research, please don't hesitate to send us their names and contact information. We thank you in advance if you can provide us with other subject matter experts with knowledge and experience in drone technology and/or regulation.

Regards,"

3. Upon receipt of the signed Informed Consent Form, the following email was sent:

"Dear {Name of SME},

Thanks for agreeing to participate in this important research and for returning your signed informed consent document. You may now access the interview software at http://olhapps.olhinc.com/UASTech/login.aspx

Your Username is XXXXXXXX

Your initial Password is XXXXXXXX

Again, thanks for your participation."

4. Throughout this process, UAH sent hundreds of reminders to individuals who had not responded or had paused unexpectedly during the process after committing to participation in the interview process.

3.5.1.8 Detailed Procedure – Maintaining Non-Attributability

The system was designed to ensure that no individual response to any evaluation assessment is attributable to an individual respondent in any product that results from this research effort. As data is added to the PASAUT database, individual SMEs are represented as integer values rather than names. With the exception of the internal table that contains each user's name, username, and password (all of which are confidential), no tables contain personal identification data. As will be seen in Appendix B3, reports and analysis are based on aggregate data such as numbers of responses, standard deviations, and sums. Nowhere will the reader find any suggestion of a specific input by a named SME.

3.5.1.9 Detailed Procedure – Assimilating Data and Transferring to Power BI®

OLH, Inc. was tasked with three primary jobs. They were responsible to:

1. Develop the PASAUT application based on requirements defined by UAH personnel, and maintain the PASAUT website on a secure web server,
2. Create the interface between PASAUT and the Microsoft Power BI product, manipulate the Power BI application in coordination with the UAH team to produce insightful data outputs and graphics, and assist UAH personnel in producing a quality final Report,
3. Upon completion of the project, delete all files that might contain sensitive data, including names and titles of participating SMEs.

3.5.1.10 Detailed Procedure – Use of Power BI to Evaluate Raw Data

PASAUT produces outputs in any of Excel's 29 standard output file formats. Power BI is capable of importing a vast array of file formats including all of the ones generated by Excel. OLH transferred the completed tabular data (based on interview responses) from the PASAUT application to the Power BI application. Power BI then formats the data into a Microsoft Power BI Desktop Document (*.pbix file) format. Once this transfer had taken place, OLH delivered the Power BI file to the UAH team for evaluation/analysis.

The UAH team used the Power BI desktop application to open and view the OLH provided files. Additionally, the team met with the OLH staff on several occasions to examine different ways of viewing, filtering, sorting, categorizing, and formatting the raw data to produce the most straightforward, intuitively evident tables and graphs. Once the data was transformed into useful information, UAH analysts examined the resulting tables and graphs to discern indicators of significance from which conclusions were drawn.

3.5.1.11 Responses to Solicitation and Resulting Participation by SMEs

The initial expectations for invitees to engage in this research were unrealistic. The team had hoped that approximately one in five of the solicited SMEs would become engaged in the project and complete their assigned evaluation topics. That turned out to be optimistic. A summary of step-by-step responses is shown in Table 11.

Table 11. Response Rate by Process Increment.

Step	Number Responding

Distribute 499 invitations to participate	146
Distribute 146 Informed Consent forms	107
Distribute 107 PASAUT usernames & passwords	66

3.5.2 Results – Maturation Forecast

This knowledge elicitation exercise was very successful in providing some important insights regarding:

- What are the most urgent needs in terms of technology advances and the development of standards and regulations by the FAA and standards organizations in order to allow the sUAS industry to progress?
- In addition to technology and regulatory factors, what are other important enabling or hindering factors such as political resistance or acceptance that need to be addressed in order to allow the sUAS industry to progress?
- When are the limiting factors for the development or use of a particular technology or operation expected to be sufficiently addressed for the relevant mission/market to progress?
- What is the expected market impact associated with the development or use of a particular technology or operation once the limiting factors have been addressed?

Below the detailed responses for one technology (3D printing/additive manufacturing) and one class of UAS operations (BVLOS). These sample comprehensive assessments are described as illustrations of how to interpret the results received. The responses for all of the other technology and influencer categories are contained in Appendix B3.

In preparing the following section, the team found that examining the numerical values resulting from the SME inputs could be confusing. To assist in interpreting the information, the team developed a table of text descriptions for ranges of numerical scores as shown in Tables 12 and 13. These numerical values are strictly for standardized analysis purposes. Therefore, there are no timeframe units (i.e., months) associated with the values in Table 12 and 13. This evaluation table was not provided to the respondents. Tables 12 and 13 were used to evaluate the average responses for each technology and concept. The team acknowledges that this could introduce differences in respondent vs. the team's scoring interpretation.

Table 12. Standardized Evaluation Terms Technical Factors.

From	To	Urgency of Need	Scale of Market Impact	Integration/ Testing	Difficulty of Develop-ment	Availability	Regulatory Hurdles
0	2	Extremely Urgent	Small Impact	Easy to Integrate	Easy to Develop	Currently Available	No Regulatory Hurdles
2.1	4	Quite Urgent	Below Moderate Impact	Moderately to Easy Integration	Slight Difficulty	Mostly Available	Minor Regulatory Hurdles
4.1	6	Moderately Urgent	Moderate Impact	Moderately Difficult to Integrate	Moderate Difficulty	Somewhat Available	Moderate Regulatory Hurdles
6.1	8	Slightly Urgent	Above Moderate Impact	Somewhat Difficult to Integrate	Substantially Difficult	Slightly Available	Substantial Regulatory Hurdles
8.1	10	Little Urgency	Substantial Impact	Difficult to Integrate	Extremely Difficult	Unavailable	Serious Regulatory Hurdles

Table 13. Standardized Evaluation Terms Enabling and Hindering Factors.

From	To	Urgency of Need	Scale of Market Impact	Integration/ Testing	Difficulty of Develop-ment	Availability	Regulatory Hurdles
0	2	Extremely Urgent	Small Impact	Easy to Integrate	Easy to Develop	Currently Available	No Regulatory Hurdles
2.1	4	Quite Urgent	Below Moderate Impact	Moderately to Easy Integration	Slight Difficulty	Mostly Available	Minor Regulatory Hurdles
4.1	6	Moderately Urgent	Moderate Impact	Moderately Difficult to Integrate	Moderate Difficulty	Somewhat Available	Moderate Regulatory Hurdles
6.1	8	Slightly Urgent	Above Moderate Impact	Somewhat Difficult to Integrate	Substantially Difficult	Slightly Available	Substantial Regulatory Hurdles
8.1	10	Little Urgency	Substantial Impact	Difficult to Integrate	Extremely Difficult	Unavailable	Serious Regulatory Hurdles

The results of SME inputs for 3D Printing/Additive Manufacturing are summarized in Figure 4. Additive manufacturing (AM), also known as 3D printing, is a transformative approach to industrial production that enables the creation of lighter, stronger parts and systems. It is a technological advancement made possible by the transition from analog to digital processes. In recent decades, communications, imaging, architecture, and engineering have all undergone their own digital revolutions. Now, AM can bring digital flexibility and efficiency to manufacturing operations. Additive manufacturing uses data, computer-aided-design (CAD) software, or 3D object scanners to direct hardware to deposit material layer upon layer in precise geometric shapes. As its name implies, additive manufacturing adds material to create an object. By contrast, an object is created by traditional methods, it is often necessary to remove material through milling, machining, carving, shaping or other means. Although the terms "3D printing" and "rapid prototyping" are casually used to discuss additive manufacturing, each process is a subset of additive manufacturing (General Electric [GE], 2021).

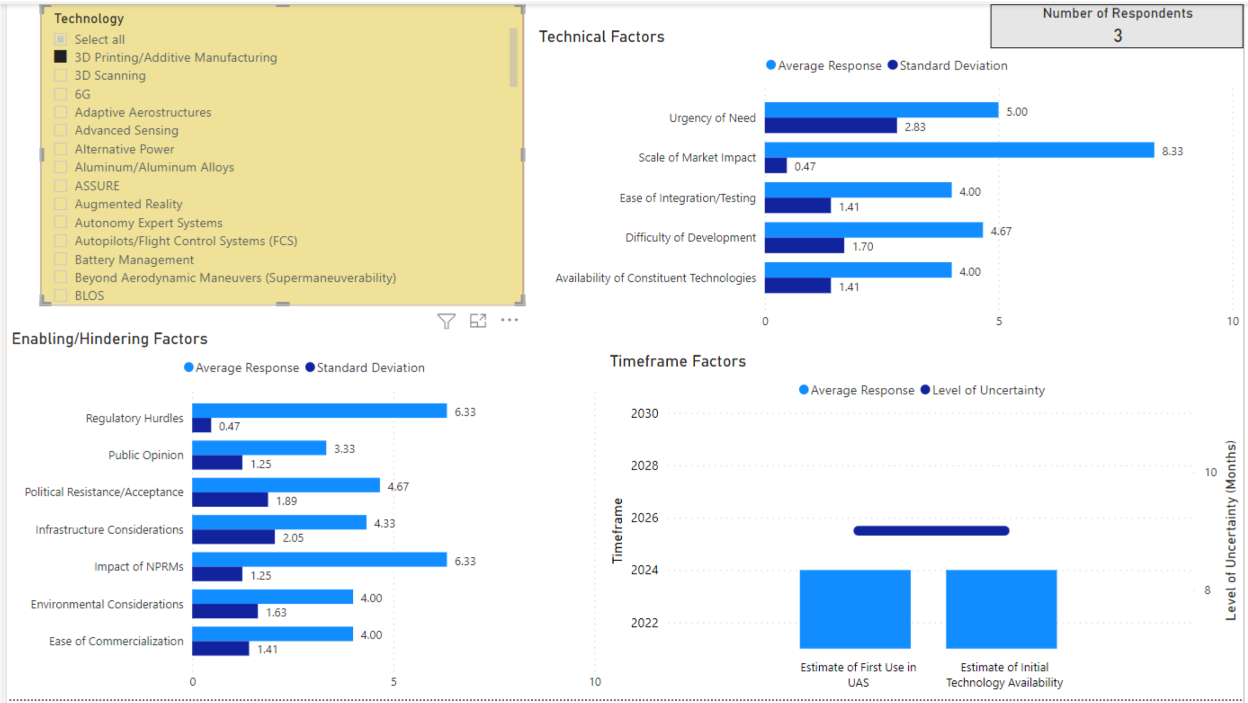

Figure 4. 3D Printing Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Challenges
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2024.00 ± 9/12 (9 months)
  - **Estimate of Initial Technology Availability:** 2024.00 ± 9/12 (9 months)

Note that this result for 3D Printing has a number of important implications:

- The need for this technology to mature for its routine application in the manufacturing of sUAS is moderately urgent. On average, the 3 SMEs considering this category indicated that the expected level of attention and effort needed to mature this technology as well as provide clarity in the relevant standards and regulations, should result in an initial availability of this technology in sUAS by 2024 ± 9 months. To put this another way, the SMEs predicted that the hurdles necessary to begin large scale use of additive manufacturing in the production of sUAS should be overcome by 2024 ± 9 months.

- Once mature, it is expected to have a substantial impact on the market, increasing the affordability of sUAS and thus increasing the number of sUAS sold and used. It is likely that widespread use will take some time once the critical factors have been addressed, so the actual market impact may be seen closer to 2026 (i.e., 2 years after the expected availability). For simplicity, this "2-year buffer" assumption will be consistently used throughout the report.
- The most significant barrier to its maturity focuses on associated standards and/or regulations to provide clarity regarding its use as a routine manufacturing process. Thus, the FAA and standards organizations should make this a priority in developing appropriate guidance and standards. A failure to do so will retard the rate of growth of the sUAS market.

The results of SME inputs regarding BVLOS operations are summarized in Figure 5. Unmanned aircraft flying beyond an operator's visual line-of-sight present unique challenges to the FAA's existing regulatory framework. Most aviation regulations that would apply to UAS operations besides Part 107 assuming the aircraft has an onboard pilot who is responsible for avoiding other aircraft. Not only do UAS lack an onboard pilot, but even a remote pilot pushes the boundaries of the traditional regulatory role of a pilot. However, the UAS capability to fly without the pilot onboard and beyond the pilot's visual line-of-sight is what offers the most economic and societal benefits. Today, companies, communities, and industrial sectors are eager to realize these benefits and have invested substantial resources developing UAS technologies. The FAA's existing regulatory framework must change to better support the long-term viability and sustainability of this evolving aviation sector. However, these are challenges the entire UAS community must confront together, because they have implications not only to safety, but also security and society at large. The FAA recognizes the significant safety, economic, and environmental considerations associated with BVLOS unmanned aircraft operations. Over the past five years, the FAA has engaged in multiple pilot programs and partnership arrangements – including the UAS Integration Pilot Program (IPP), Partnership for Safety Plans (PSPs), and currently BEYOND – to further both the Agency's and stakeholder community's collective understanding of the minimum performance criteria for safe BVLOS operations. The UAS BVLOS ARC will consider the various lessons and insights gained from these and other activities to inform the FAA on performance-based criteria to enable safe, scalable, economically viable, and environmentally advantageous BVLOS operations in the NAS (U.S. Department of Transportation Federal Aviation Administration, 2021).

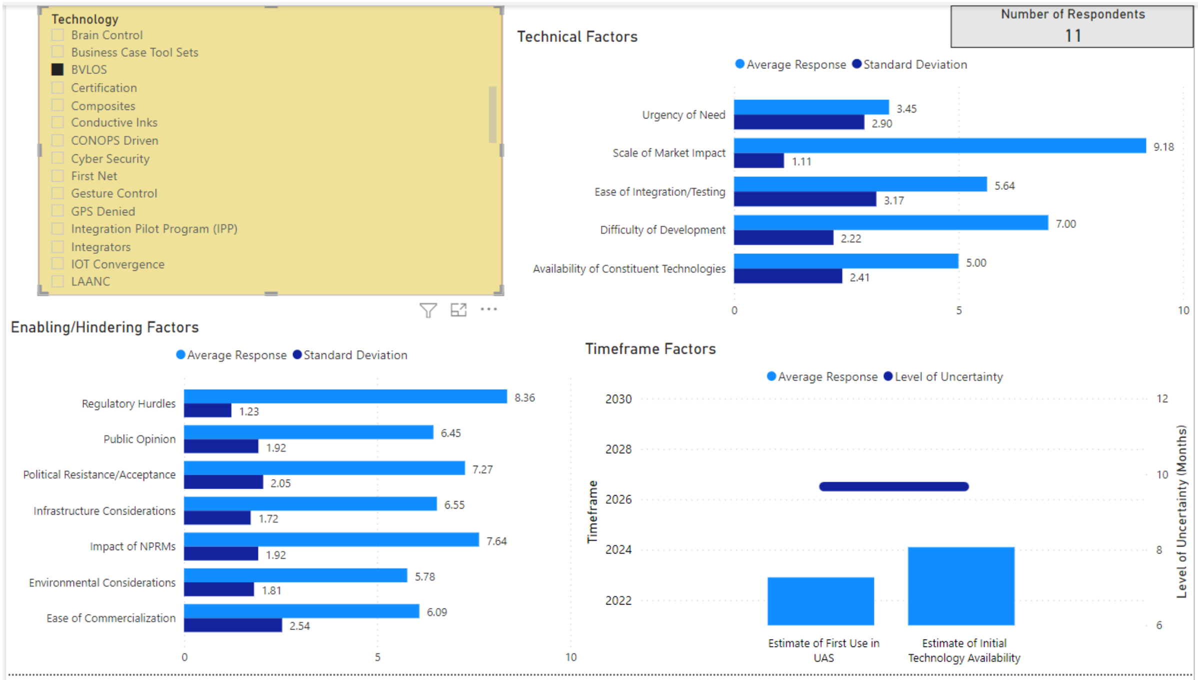

Figure 5. BVLOS Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Somewhat Unacceptable
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2022.90 ± 9.67/12
  - **Estimate of Initial Technology Availability:** 2024.10 ± 9.67/12

These responses indicate that the need for the development of clear guidance and standards to permit BVLOS operations, as well as the maturation of supporting technologies (such as DAA) are of critical importance to the increased growth of the UAS in the NAS. When these factors have been adequately addressed, a substantial increase in the rate of growth of sUAS activity can be expected.

- On average, the 11 SMEs considering this category predicted that the expected level of attention needed to mature the enabling technologies, along with the expected level of effort expended to provide clarity in the relevant standards and regulations, should result in an initial availability of BVLOS operations for large scale use by sUAS by 2024.10 ± 9.67 months. To put this another way, the SMEs predicted that the hurdles necessary to enable large scale integration of BVLOS operations for sUAS in the NAS should be overcome by 2024.10 ± 9.67 months.
- Once mature, this is expected to have a substantial impact on the market, resulting in a significant increase in the growth of sUAS operations. It is likely that the substantial increase in BVLOS operations will take some time once the critical hurdles have been addressed, so the actual market impact may be seen closer to 2026 (i.e., 2 years after the expected availability). For simplicity, this "2-year buffer" assumption will be consistently used throughout the report.

Note that this finding can be combined with the forecast described in Section 3.3 regarding BVLOS operations. That forecast, based solely on historical trends as characterized by the data collected in Phase 1 of this project, was not influenced by any factors that are expected to have a major impact on the number of BVLOS operations that were presumably considered by the SMEs in this interview study. The results in this study with the SMEs indicates, however, that there will be an inflection point in the rate at which BVLOS operations increase starting at 2026, reflecting a significant increase in the rate at which the number of BVLOS operations are forecast to increase. Thus, the forecast shown in Figure 2 could be used as the 2025 baseline (expected value of approximately 1050 operations and a 95% upper limit of approximately 2800 operations), with a significantly faster growth rate (increasing the slope of the fitted line) starting in 2025-2026.

The two previous examples (3D Printing and BVLOS Operations) illustrate how the questions used in the interviews were consistently designed in a way that low scores would indicate less hindered development and higher scores where development is difficult, challenging, and disadvantaged by non-technical factors. The timescale questions were similarly structured, allowing the participant to select specific dates to generate timeframe predictions on early and future introductions into the NAS. Therefore, when looking at average responses, whether combined or isolated into subsets, the team would interpret lower numeric scores to equate to earlier, less hampered availability and higher scores to equate to more challenging technologies with realization further in the future. In Appendix B3, summary statistics are presented for the complete set of 68 categories.

3.5.3 Findings Relative to Technologies and Concepts Evaluation Factors as a Function of Time

The following sections present scatter charts of the aggregate response data relating to each of the evaluation factors, upon which each evaluation question was based. The horizontal axis represents the average date of first use in UAS, while the vertical axis is the aggregate score for the selected evaluation factor. One might expect the general pattern of these indicators to run from lower left (lower difficulty, urgently needed, fewer hindrances, earlier availability) to upper right (greater difficulty, more hindrances, later availability). That general pattern appears in all of the resulting scatter graphs.

There appear to be some individual cases that run counter to that assumption. For example, swarm technology generally has a high aggregate score (higher difficulty of achievement) but is anticipated to be in use almost immediately. The team attributes this apparent anomaly to a failure to specify use cases as part of the technology definition. Although the team attempted to clarify the precise meanings of the technologies by providing definitions within PASAUT, the team suspected that some participants didn't avail themselves of these. In the case of swarm technology, the team was aware that certain swarm applications, such as light shows, have already been granted waivers and have received wide publicity.

In much the same way as the charts in Section 3.5.2, the team notes that items on the far left of the display tend to be currently available, widely used materials. Their low technology composite scores highlighted in Section 3.5.2 reflect consistently low scores in the factors that comprise the technical evaluations and which are the focus of the following charts. These include urgency of need, scale of market impact, ease of integration/testing, difficulty of development, and availability of constituent technologies.

Considering these factors in scatter graphs that cross-relate technologies and concepts with their anticipated first use in UAS, a general pattern emerges. The subsequent scatter charts indicate that many advances in technologies, procedures, and clarity of standards and regulations will occur from 2022-2027, thus forecasting very substantial increases in the number of sUAS operations over the next several years.

3.5.3.1 Urgency of Need

Figure 6 represents the urgency of need with first use in UAS timeframe. Urgency of Need is an abstraction that is most definitely a factor in the introduction of new technologies into the marketplace. One need only look at the Manhattan Project or the Apollo lunar landing programs to recognize that urgency can be a substantial driver in reducing the time to completion of a project or in lessening budgetary constraints in order to accelerate the project. In this case, because the numerical scale of time (the horizontal axis) moves from earlier (left, lower numerical value) to later (right, higher numerical value), the numerical scoring for "Urgency of Need" in the PASAUT application gave a lower value to higher urgency and a higher numerical value to lower urgency. Lower urgency tends to slow down or delay the introduction of a technology or driving factor. Therefore, with regard to the timescale, one would expect the lowest urgency to be given the highest numerical value.

Certain technologies represented on the leftmost side of the chart seem to make sense, especially those that already are in place, such as LAANC, Live Map, and Model-Based Systems Engineering.

One somewhat baffling data point is that of “Gesture Control” indicating the lowest urgency of any factor, yet a relatively near-term date of first use (2026). Eight SMEs provided input on this topic, so it truly is a consensus finding, albeit difficult to understand. One possible explanation is that some early versions of gesture control are already available. That may have influenced the respondents to lower their estimated urgency of need ratings.

Examination of the lower left portion of the scatter chart will reveal those topics that combine both a high urgency of need and a forecast of first use that is near-term. These include several material-related issues – plastics, composites, aluminum/aluminum alloys, and resins – indicating the importance of these items in developing lighter, stronger, more capable sUAS.

Another group of items appearing in this area of the chart are time related – Model-Based Systems Engineering (MBSE) (efficient engineering processes), NPRM (have the potential to delay the introduction of a technology), Rapid Build, and Rapid Prototyping. Their appearance in the leftmost position recognizes that they are already wholly in use or largely in use. Their appearance in the lowest positions of the vertical scale indicate that the respondents placed high urgency on these time-affecting factors.

Two of the highest priority issues that the responding SMEs envision being realized in the near term are BVLOS and improved Battery Management, both of which also appear in this lower left region. That agrees with what we witness in the marketplace with a high level of BVLOS interest in related waiver requests and with an extensive ongoing research effort in battery technology/management.

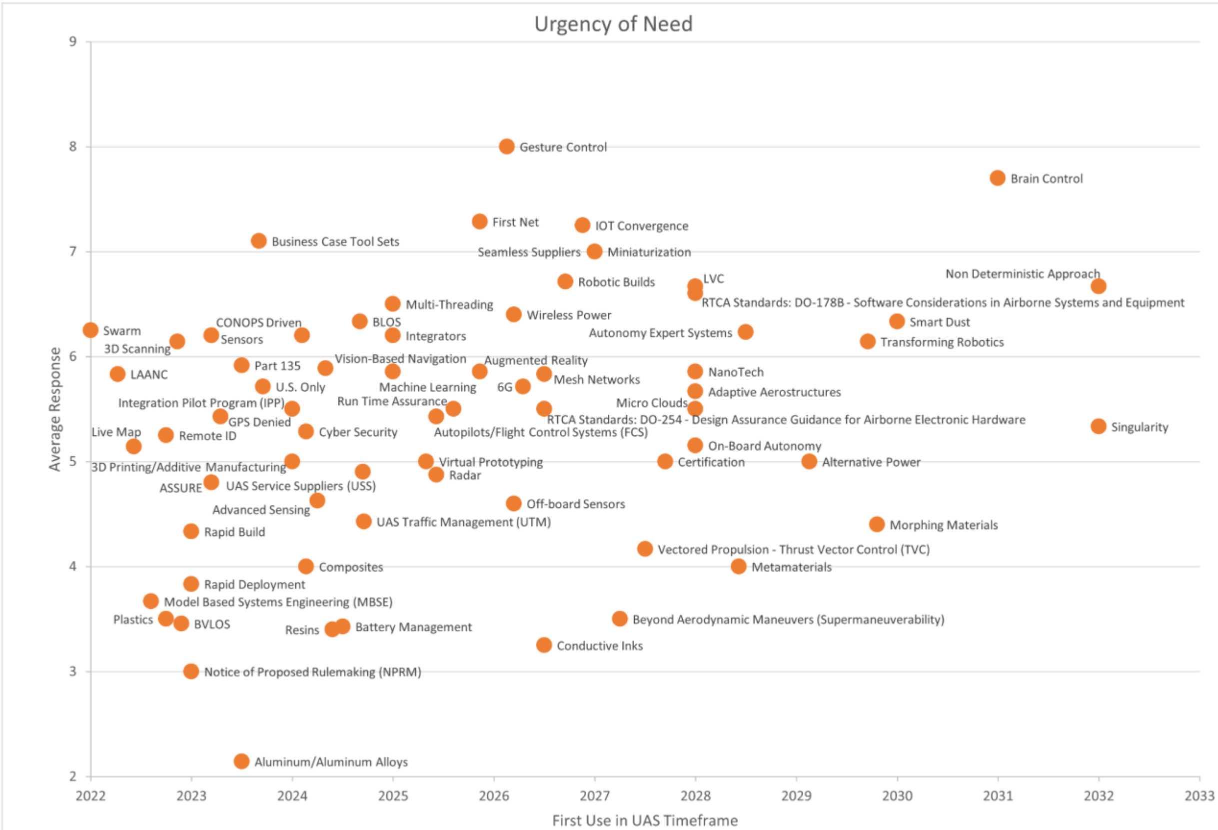

Figure 6. Urgency of Need vs. Estimated First Use Scatter Chart.

3.5.3.2 Difficulty of Development

It makes sense to assume that those technologies/factors with the highest difficulty of development are likely to take longer to reach first use or introduction into non-segregated air space. Looking at Figure 7 from a distance reveals a distinct line of data points that aligns from lower left to upper right, just as we would expect based on the definition of the axes. Several of the leftmost data points are known to be in use, such as LAANC, MBSE, ASSURE, Part 135, Remote ID, and NPRM. The fact that they are not all identified with the year 2022 indicates that some of the involved SMEs either didn't totally understand the definition of the subject as it was presented or are not as expert on a certain topic as the research team had presumed based on the SME's backgrounds.

The results indicate that the respondents ranked Brain Control, Transforming Robotics, Smart Dust, Singularity, Nano Tech, Alternative Power, Certification, Machine Learning, On-Board Autonomy, Autonomy Expert Systems, and Cyber Security as the eleven most difficult items to develop. With the exception of Certification, these all involve complex software development and equally challenging hardware/software interfaces that will need to be fail safe. It makes sense that the SME's combined opinion is that these items will be realized between 2025 and 2032.

Some of the influencing technologies and concepts provided interesting results as they possess the unlikely combination of a high difficulty of development combined with a relatively short-term forecast of first use. These outliers include technologies and concepts like swarming, vision-based navigation, and BVLOS. This likely reflects a perception by high level by the respondents that these areas are getting a great deal of focus and effort.

It is beneficial to seek out those items that have a high difficulty of development along with a short-term forecast first use but not already in use. These include Cyber Security (an on-going evolutionary introduction), Vision-Based Navigation, Machine Learning, BLOS, Integrators, UTM, Multi-Threading, and Run Time Assurance. These are items that may require specialized attention on the part of the FAA with regard to guidance and regulation.

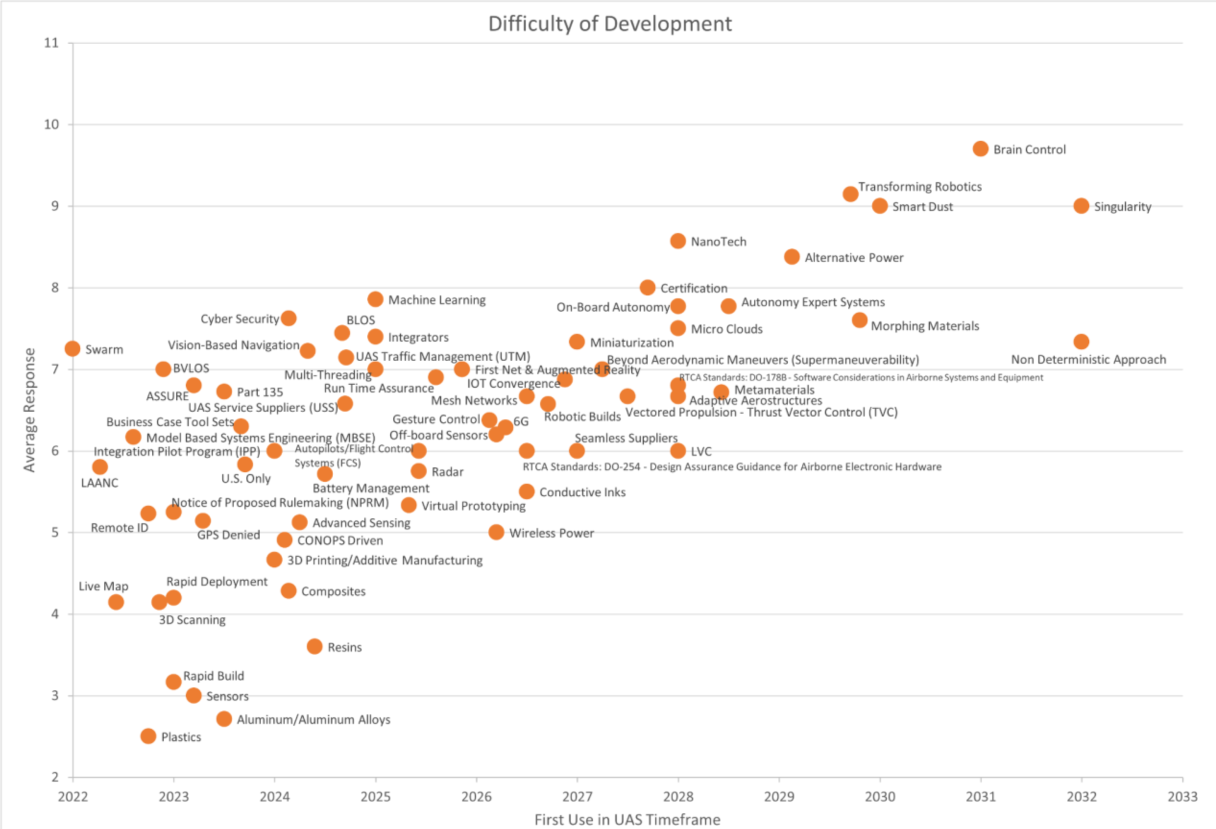

Figure 7. Difficulty of Development vs. Estimated First Use Scatter Chart.

3.5.3.3 Scale of Market Impact

Figure 8 indicates that there are many factors or hindrances that, once dealt with, will have a significant impact on the market. This suggests that the increase in sUAS activity will not be a simple linear increase over time but will be a series of step functions.

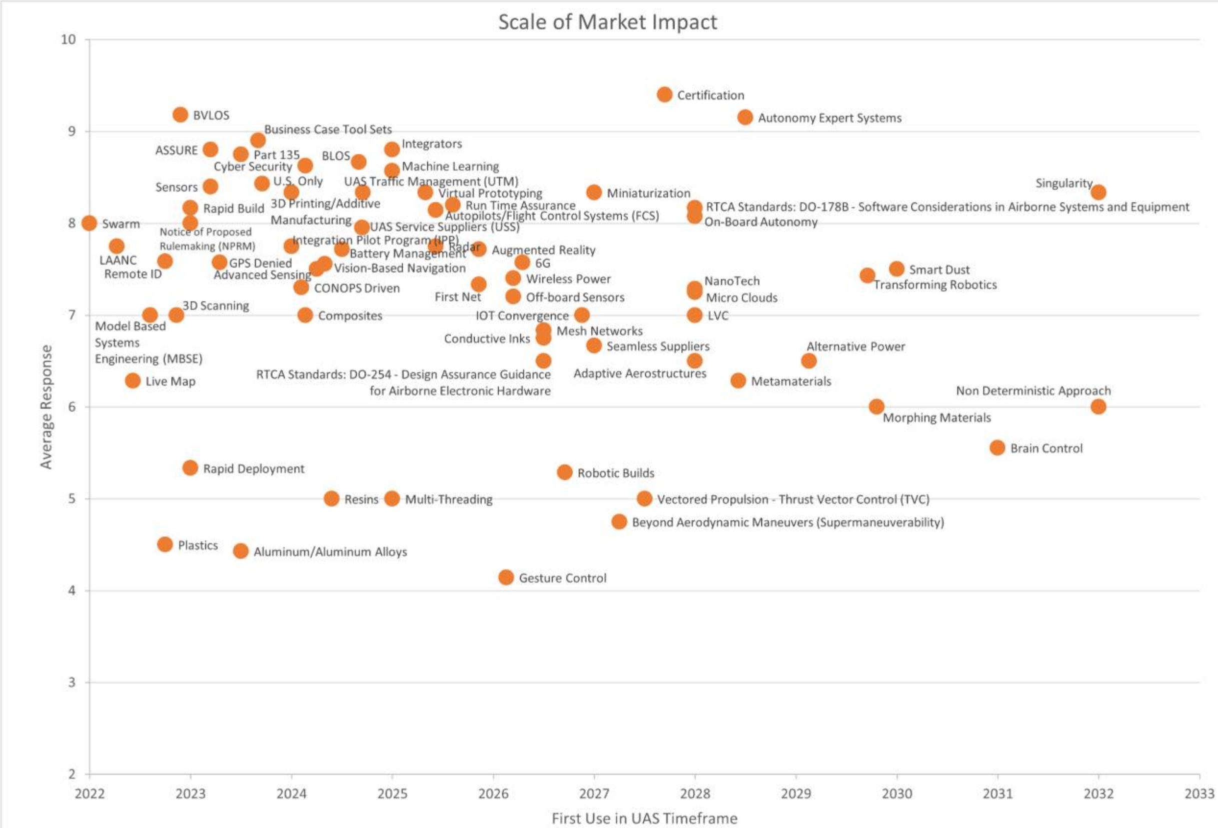

Figure 8. Market Impact vs. Estimated First Use Scatter Chart.

3.5.3.4 Availability of Constituent Technologies

Figure 9 correlates the availability of technologies needed for a named technology/ concept versus the time of first use exhibits the lower left to upper right pattern quite distinctly. This indicates that in general, those named technologies/factors used in the PASAUT interviews align in first use with the availability of their enabling underlying technologies. In this case, it’s informative to look at the outliers that don’t fall within the main cluster of intersects.

Keeping in mind that a low numerical score on the vertical axis indicates highly available technologies, outliers below the mainstream cluster of data should not be of concern. These items lie in a region where the underlying technologies will be available in plenty of time to support the forecast first use.

The outliers that are above the main cluster are worth further consideration. They are in a region of low availability of constituent technologies (in the opinion of the participating SMEs) but are forecasted to reach first use earlier than other technologies similarly challenged by the underlying technologies. The most evident is Vision-Based Navigation with relatively low availability of constituent technologies, yet a forecast first use in 2024. Others in this situation include Nanotech, Metamaterials, and Transforming Robotics. If we include all the technologies along the upper zone of the main data cluster as being challenged by the availability of their underlying constituent technologies, this list would include UAS Traffic Management (UTM), Run Time Assurance, Off-Board Sensors, Miniaturization, On-Board Autonomy, Micro Clouds, Autonomy Expert Systems, Morphing Materials, Smart Dust, and Brain Control. A reasonable conclusion from this data is that if one of these technologies is crucial to the future well-being of the National Airspace System, it might be prudent to invest in the underlying enabling technologies related to the crucial ones.

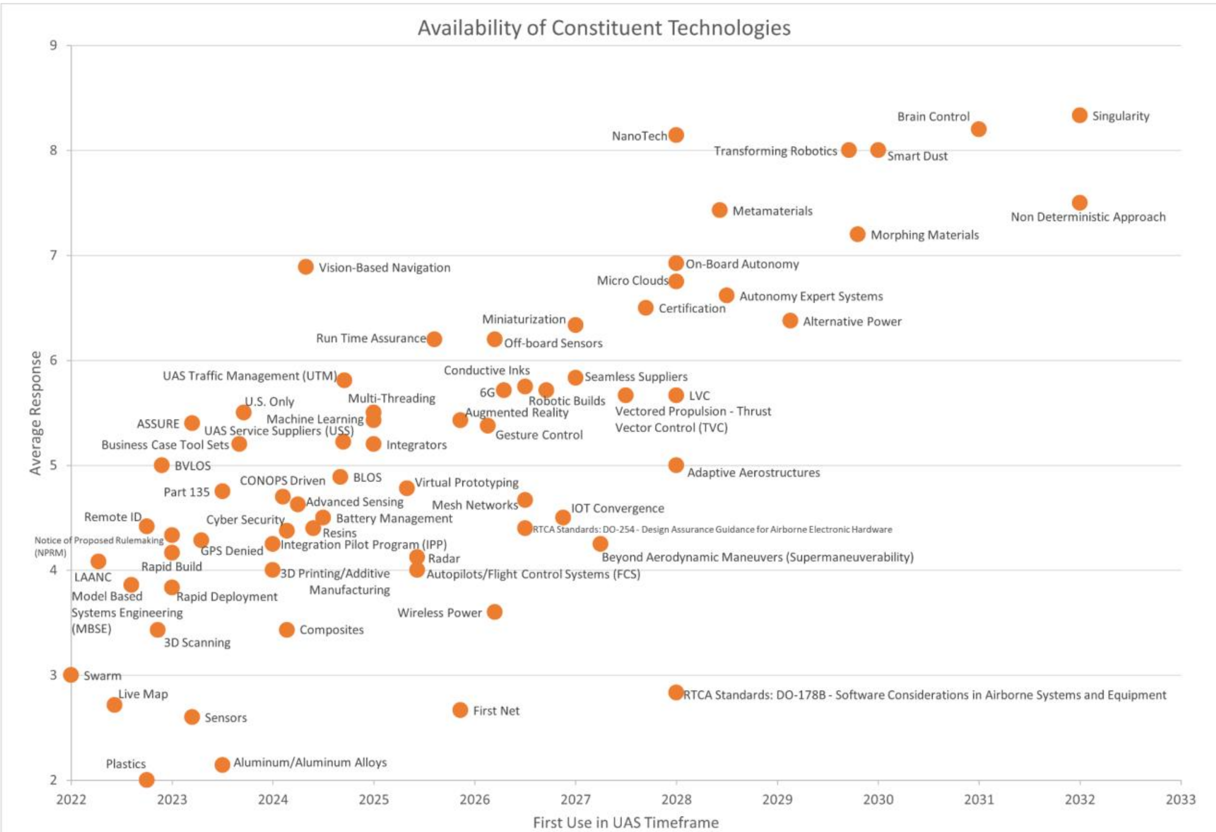

Figure 9. Availability of Constituent Technologies vs. Estimated First Use Scatter Chart.

3.5.3.5 Ease of Integration/Testing

Figure 10 once more exhibits a distinct pattern correlating the more difficult integration and testing with a longer-term estimate of first use. It is valuable to look at outliers on the upper side of the data points, as those indicate technologies/factors for which the participating SMEs combined an estimated higher-than-average difficulty of integration/testing (outlier on vertical scale) with a somewhat optimistic view of first availability (outlier on horizontal scale).

In the near term, items falling into this category include Cyber Security, UAS Traffic Management, Integrators, Vision-Based Navigation, and Machine Learning. In the longer term, they include LVC, Autonomy Expert Systems, Micro Clouds, On Board Autonomy, Morphing Materials, Brain Control, and Alternative Power. The implication here is that the governing agencies may need to focus on the availability of standards and practices to make testing of these complex systems as straightforward as possible.

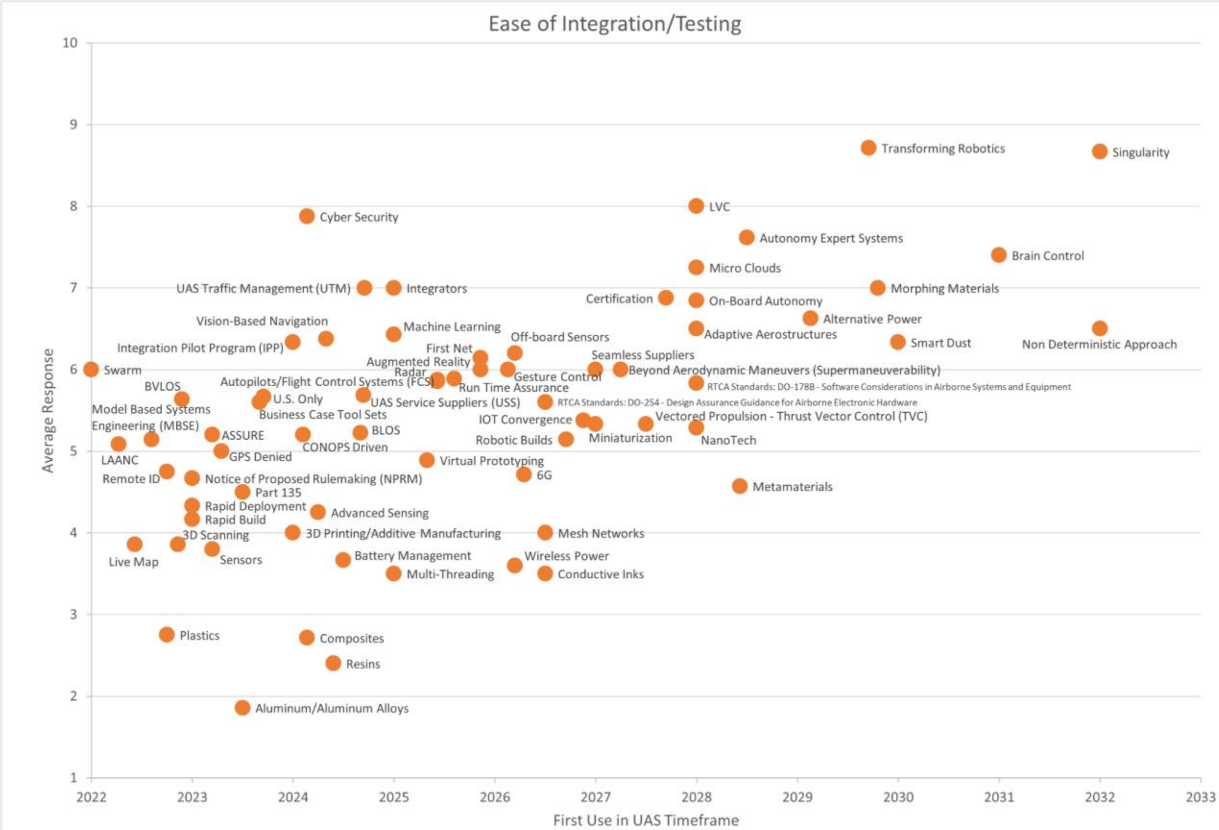

Figure 10. Ease of Integration/Testing vs. Estimated First Use Scatter Chart.

3.5.3.6 Regulatory Hurdles

Although Figure 11 continues to exhibit the lower left to upper right pattern, there is extreme variation in the data that may render it less useful than some of the other factor charts. For instance, examining the slice of time of first use that includes the calendar year 2023 where a low score of regulatory constraint might be anticipated. However, the Regulatory Hurdles scores range from 2 to 9. The UAH team believes that this chart informs that there is little correlation between the regulatory hurdles involved with a specific technology's introduction and its anticipated first use.

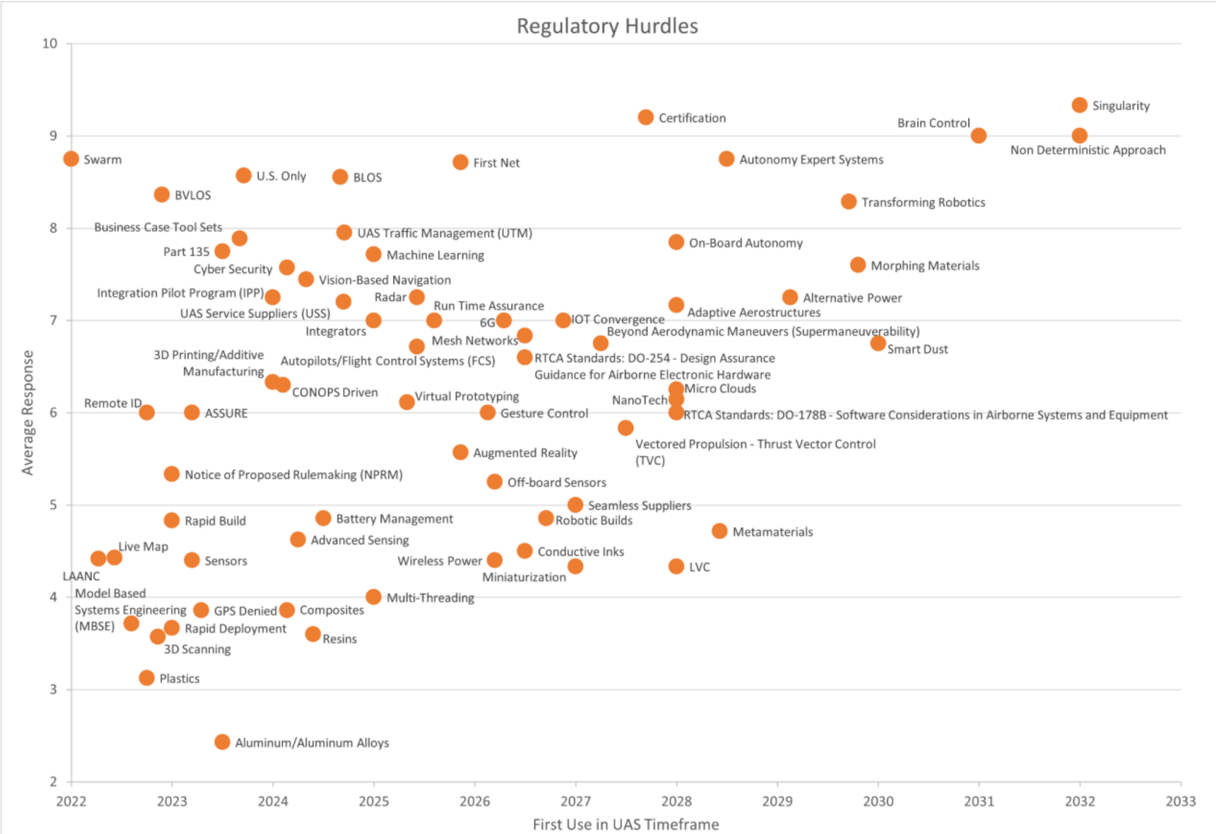

Figure 11. Regulatory Hurdles vs. Estimated First Use Scatter Chart.

3.5.3.7 Ease of Commercialization

Figure 12 shows very broad ranges of Ease of Commercialization for any given time of first use. As an example, for 2023, the range of values runs from below 3 to nearly 7. Upon further examination, it becomes evident that a substantial number of early-realization technologies and enablers are either 1) already in use, but with remaining barriers to their widespread use, or 2) technologies that are going to be "game changers" with enormous profit implications for the organizations that are first to market. Examples of the first category include Swarm, LAANC, ASSURE, Remote ID, Plastics, and Part 135. The second category includes BVLOS, Vision-Based Navigation, Cyber Security, Advanced Sensing, Rapid Build, Rapid Deployment, Battery Management, Virtual Prototyping, and UAS Service Suppliers. One possible conclusion from this data is that the speed of introduction of the technology/factor is not only driven by its ease of commercialization, but also by its profit potential (return on investment). The implication for the FAA is that a clear regulatory framework will be needed for the subject technologies sooner rather than later.

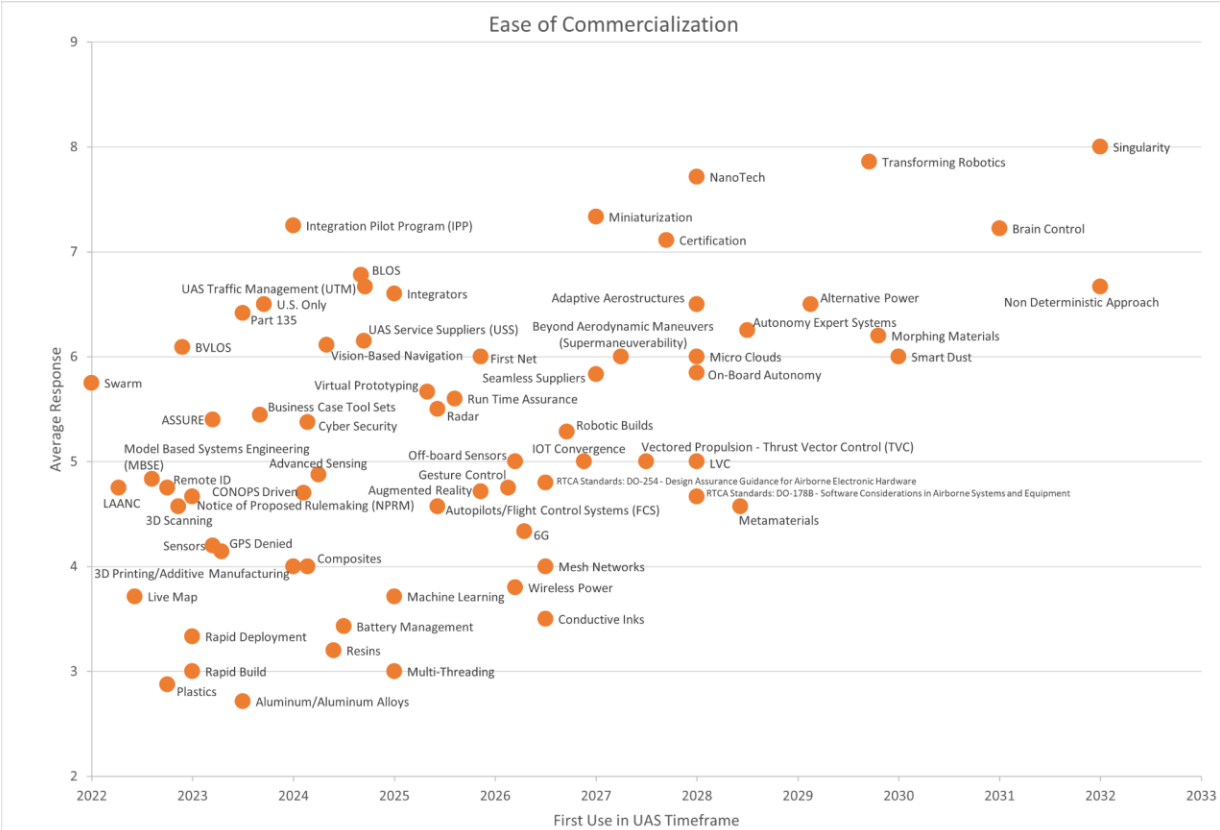

Figure 12. Ease of Commercialization vs. Estimated First Use Scatter Chart.

3.5.3.8 Public Opinion

Public opinion is somewhat akin to urgency of need. Although it is an abstraction and therefore difficult to quantify, it certainly has a powerful influence on social and political issues related to technological advances and the increase in sUAS operations.

One of the first observations about Figure 13 is the indication that all but 9 of the technologies/concepts will be realized by 2028. Only Metamaterials, Autonomy Expert Systems, Morphing Materials, Transforming Robotics, Smart Dust, Brain Control, Non-Deterministic Approach, and Singularity are forecast to achieve first use beyond that time. The most obvious outlier is Swarm technology. It is clearly already in use, but the participating SMEs perceived that public opinion was highly resistant to its introduction.

The upper band of the data points in the leftmost region of the chart include more of this seemingly conflicting data – cases in which the first use is forecast sooner rather than later in spite of a higher-than-average resistance in public opinion. These include BVLOS, Remote ID, BLOS, U.S. Only, UAS Traffic Management (UTM), Autopilots/Flight Control Systems (FCS), and Machine Learning. One possibility is that public opinion tends to oppose those technologies and procedures that grant more autonomous control to the UAS and supporting infrastructure and thereby reduce direct human involvement. Yet it is understood that these are some high-priority technologies and enablers that are nearly at a point where the barriers to larger scale use will soon be addressed.

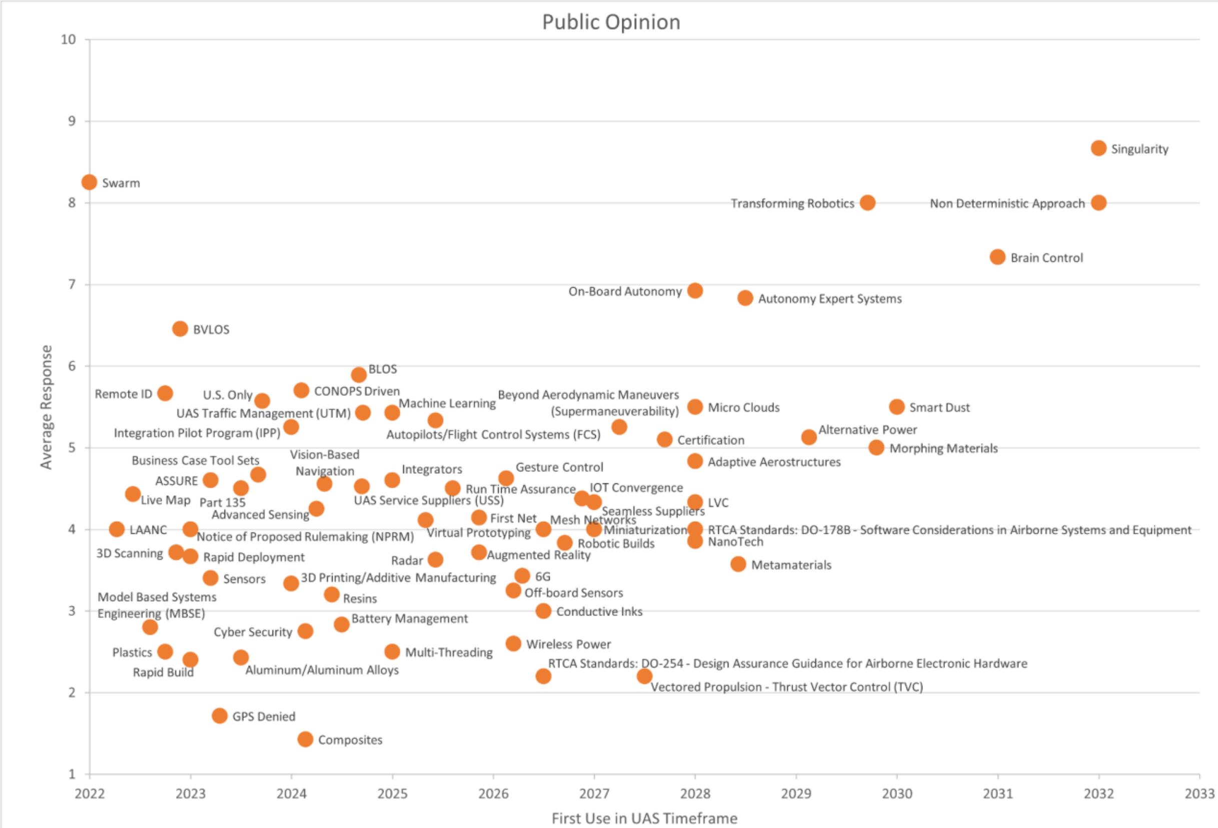

Figure 13. Public Opinion vs. Estimated First Use Scatter Chart.

3.5.3.9 Environmental Considerations

Figure 14 exhibits a considerable amount of randomness compared with many of the accompanying scatter charts. Interestingly, the same set of 9 technologies as were indicated in the Public Opinion scatter chart are forecast to experience first use after 2028. To the left of that date, we observe broad variance in the score (average response) for Environmental Considerations within any narrow time band for first use. For example, for 2025, The UAH team does not believe that this chart provides any useful insight that would influence "both the technology and procedure requirements necessary to facilitate expanded and non-segregated operations."

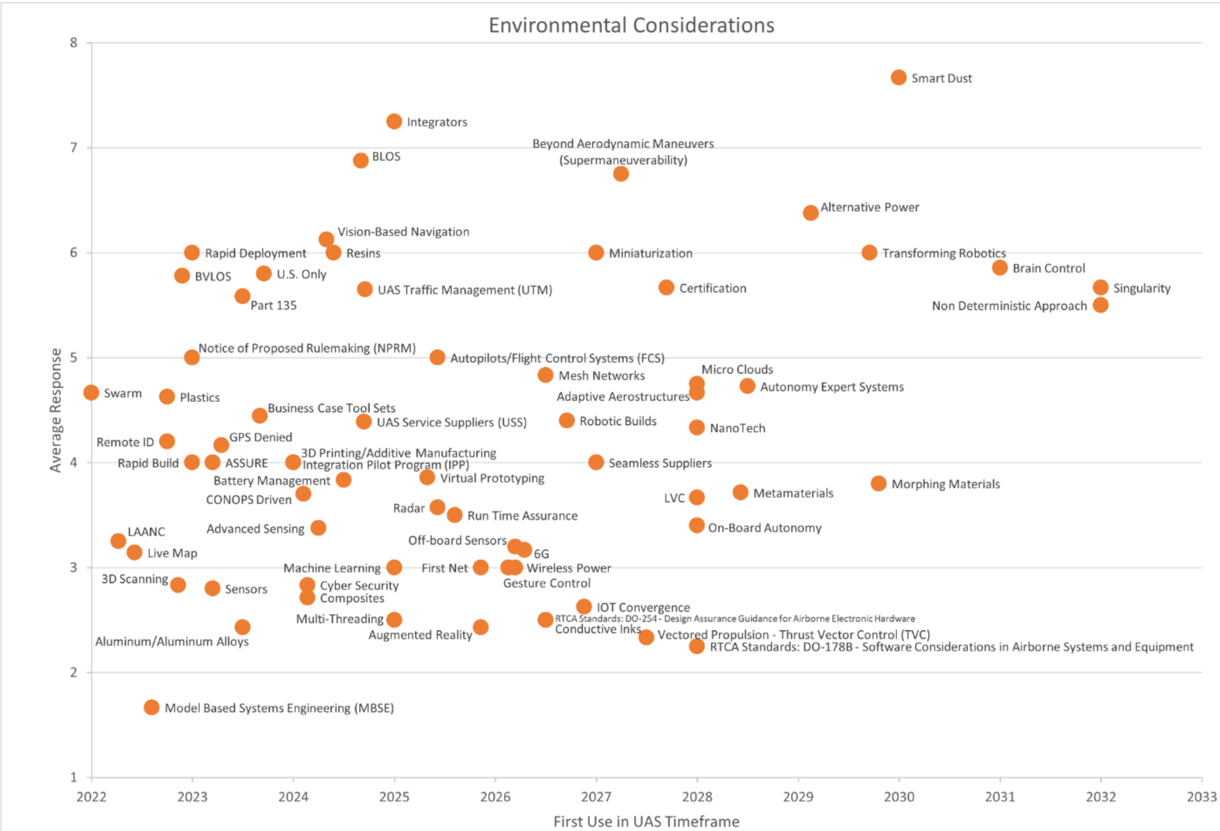

Figure 14. Environmental Considerations vs. Estimated First Use Scatter Chart.

3.5.3.10 Infrastructure Considerations

A high value in the vertical scale of Figure 15 implies "Challenging Infrastructure Considerations." These would be the items that one would anticipate to be costly relative to their required supporting infrastructure. This is probably the evaluation category most closely related to the technology side of "both the technology and procedure requirements necessary to facilitate expanded and non-segregated operations." The technologies forecast with the earliest first use (left end of the horizontal scale) and the greatest infrastructure needs (high value on vertical scale), according the participating SMEs, include the following: BLOS, UAS Traffic Management (UTM), U.S. Only, Wireless Power, First Net, Integrators, Part 135, UAS Service Suppliers (USS), BVLOS, 6G, and Cybersecurity.

Many of the inputs highlight areas for which a high infrastructure challenge is reasonable – UTM, Wireless Power, First Net, USS, 6G and Cybersecurity, for instance. The UAH team recommends that the FAA consider these left most technologies as prime candidates for both technology and procedure requirements necessary for them to be addressed in order to enable increased sUAS operations in the NAS.

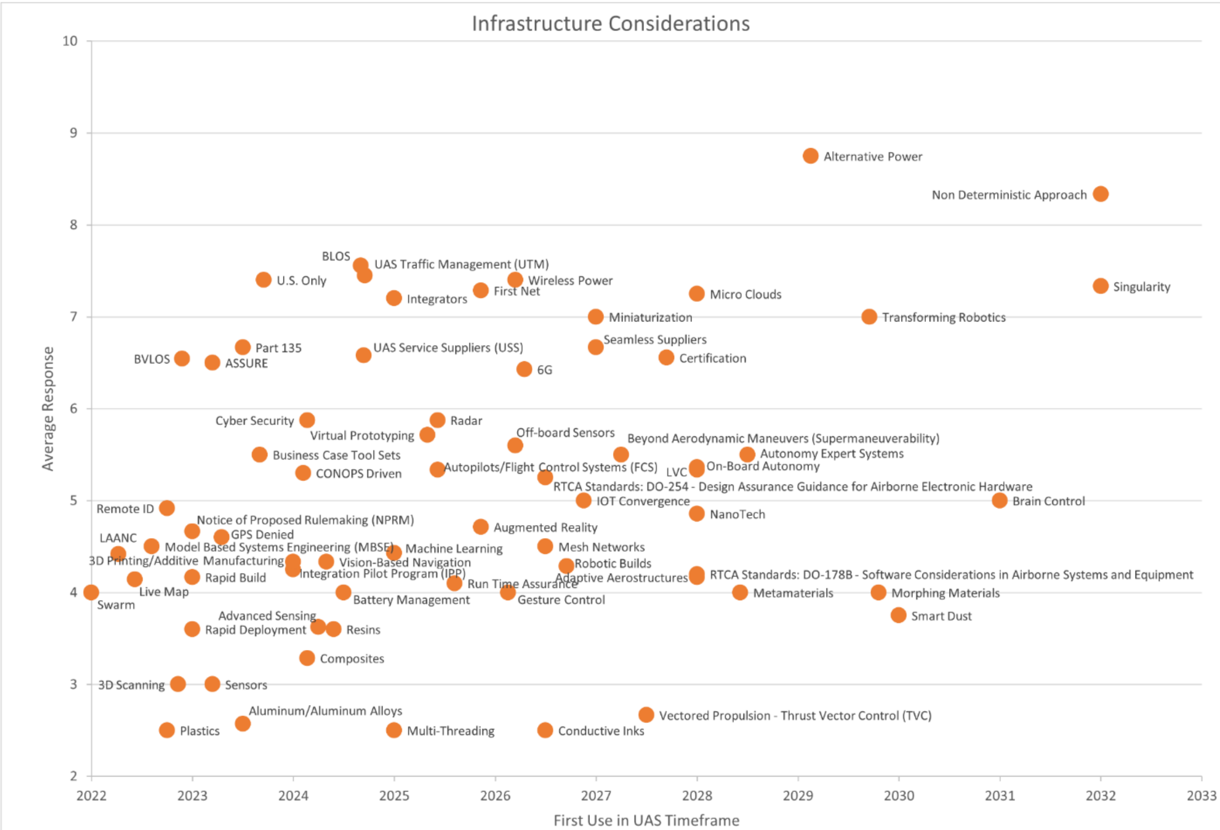

Figure 15. Infrastructure Considerations vs. Estimated First Use Scatter Chart.

3.5.3.11 Political Resistance/Acceptance

Federal funding is often affected by or driven by political considerations, and therefore politics may indirectly affect the FAA's investment in technology or the timing of regulatory actions. Congress is not shy about imposing very specific direction in funding bills, so the UAH team felt it prudent to include this factor in our evaluation process. In Figure 16, the vertical scale represents political *resistance*, from low (bottom of scale) to "Extreme Anticipated Political Resistance" at the top of the scale. Once more, the scale was set up to anticipate a lower-left to upper-right pattern, which is somewhat evident. A few outliers may be informative.

Swarm technology is already in use, but our SMEs were of the opinion that it still is politically unpopular, with an average score of 7.5. BVLOS and BLOS both scored high in political resistance for reasons we don't know. Certain FAA initiatives that are already in place were judged to be politically unpopular, even some that were mandated by politicians (NPRM, Remote ID, Part 135, IPP (now BEYOND), UAS Service Suppliers (USS), and ASSURE). LAANC on the other hand had a rather benign score of less than 4.

Many manufacturing-related technologies were assessed to be politically innocuous – Aluminum/Aluminum Alloys, Rapid Build, Plastics, Composites, and Virtual Prototyping.

In terms of anticipating areas in which the FAA will need to address both technology and procedure requirements necessary for them to be introduced into the NAS, the following appear to be in the "sweet spot" of both early first use and low political resistance: Rapid Deployment, Battery Management, Multi-Threading, GPS Denied, Cyber Security and Advanced Sensing.

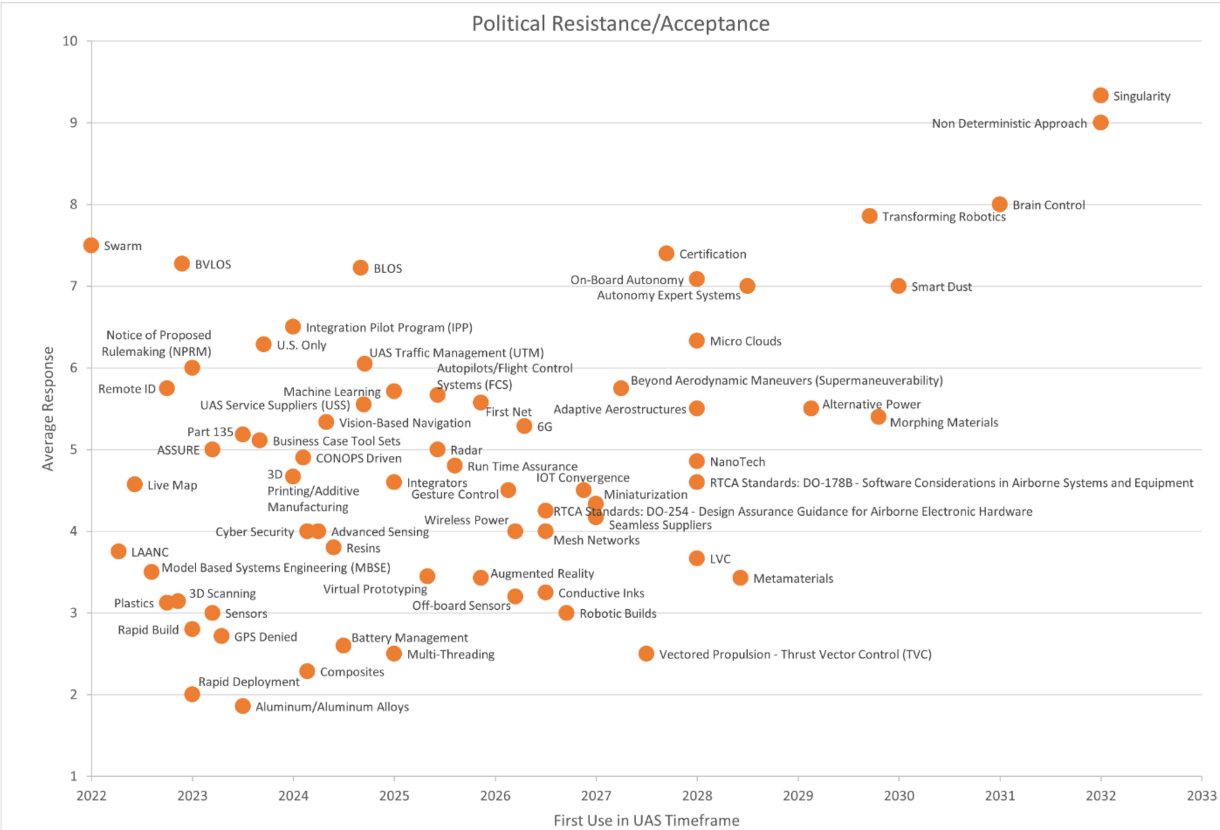

Figure 16. Political Resistance/Acceptance vs. Estimated First Use Scatter Chart.

3.5.4 Summary

The use of the scatter charts to cross relate individual factors with anticipated times of first use for specific factors appears to have merit. Depending on the evaluation factor in play (Urgency of Need, Difficulty of Development, etc.), the resulting charts showed correlation to a greater or lesser extent. (The band of scatter is narrower along the lower-left to upper-right axis in cases of higher correlation.). The result is that some of these results are more useful than others in forecasting "both the technology and procedure requirements necessary to facilitate expanded and non-segregated operations."

There seem to be a few major issues with the results shown relative to the provided estimates of initial first use:

1. Some of the technologies should have probably been described in the context of a specific use case. Some of the scatter chart results only make sense if it is assumed that different SMEs applied different use cases for a given technology.
2. The interview may have had too broad an array of technologies/factors that, when combined in a single elicitation, tended to overwhelm the respondents. For example, the UAH team presented the SME with a common set of questions, but asked them to apply these evaluations to technologies, regulatory items, operational techniques, production considerations, and the like. In some cases, it may have been a "bridge too far."

3.6 Forecast of Market Impact

The results of this knowledge elicitation exercise also provide a qualitative estimate of break points when a critical factor has been adequately addressed, resulting in an increase in the rate of growth in sUAS activity. The knowledge elicitation data provide the following forecasts for the different critical factors in terms of expected time frame for an impact on sUAS activity and the size of the market impact. Here the UAH team addresses each of the 68 UAS influencing technologies and concepts involved in the Maturation Forecast of Enabling Technologies and Standards. The qualitative assessment of market impact is based on the standardized evaluation presented in Table 12 of Section 3.5.2. The expected year presented in Table 14 is either the estimated first use in UAS or estimate of initial technology availability (provided by SMEs in knowledge elicitation) depending on which date was the furthest in the future. A "two-year buffer" period was added to the final date selected. It is likely that widespread increase in sUAS activity as a result of the maturation of some hindrance will take some time once a critical factor has been addressed; therefore, the actual market impact may be seen closer to a couple years after maturation. This assumption is congruent throughout the results presented in the subsequent sections. If an influencing technology or concept has already matured (i.e., ASSURE, LAANC, Part 135, USS, and IPP/BEYOND) the timeframe factor was dropped from the analysis.

3.6.1 Market Forecast for 68 Influencing Technologies and Concepts

Table 14 provides a market forecast for the 68 influencing technologies and concepts based on market impact and expected year of maturity. Out of the 22 influencing technologies and concepts that were scored as having a substantial effect on the UAS market, 10 or 45.45% were predicted to mature by the year 2027 and 20 or 90.9% were forecasted to have their critical factors addressed by 2030. Therefore, it can be reasonably presumed that an increased volume of UAS activity will occur in this timeframe.

Referencing the results discussed in Section 3.3.2, SMEs forecast significant increases in the volume of commercial sUAS operations across the years 2026-2028, 2028-2030, and 2030-2032 relative to the FAA forecast and extrapolation presented in Tables 1 and 2. These timeframes are consistent with the estimates of the dates at which the studied enabling factors were predicted by a separate set of SMEs to mature, no longer acting as hindrances to the growth of sUAS activity.

Table 14. Market Forecast for 68 Influencing Technologies and Concepts.

Category	# Participants	Market Impact	Expected Year	Uncertainty
3D Printing/Additive Manufacturing	3	Substantial	2026	± 9 Months
3D Scanning	7	Above Moderate	2025	± 7 Months
6G	7	Above Moderate	2028.29	± 9.86 Months
Adaptive Aerostructures	6	Above Moderate	2030	± 11 Months
Advanced Sensing	8	Above Moderate	2026.25	± 9.75 Months
Alternative Power	8	Above Moderate	2031.13	± 13.71 Months
Aluminum	7	Moderate	2025.5	± 8 Months
ASSURE	5	Substantial		
Augmented Reality	7	Above Moderate	2028.71	± 10.5 Months
Autonomy Expert Systems	13	Substantial	2031.5	± 12 Months

Autopilots/Flight Control Systems	7	Substantial	2029.14	± 10.2 Months
Battery Management	7	Above Moderate	2026.5	± 6 Months
Beyond Aerodynamic Maneuvers	4	Moderate	2029.25	± 12 Months
BLOS	9	Substantial	2027	± 12 Months
Brain Control	10	Moderate	2033	± 13 Months
Business Case Tool Sets	10	Substantial	2026.33	± 12.75 Months
BVLOS	11	Substantial	2026.1	± 9.67 Months
Certification	10	Substantial	2029.7	± 13.33 Months
Composites	7	Above Moderate	2026.14	± 7.2 Months
Conductive Inks	4	Above Moderate	2028.5	± 10.5 Months
CONOPS Driven	11	Above Moderate	2027.3	± 11.4 Months
Cyber Security	8	Substantial	2026.14	± 14 Months
First Net	7	Above Moderate	2027.86	± 11.5 Months
Gesture Control	8	Moderate	2029.25	± 10.5 Months
GPS Denied	7	Above Moderate	2026.14	± 9 Months
IPP/BEYOND	4	Above Moderate		
Integrators	5	Substantial	2027.75	± 14 Months
IOT Convergence	8	Above Moderate	2028.88	± 12.75 Months
LAANC	12	Above Moderate		
Live Map	7	Above Moderate	2026.57	± 8.14 Months
LVC	3	Above Moderate	2030	± 11 Months
Machine Learning	7	Substantial	2027.43	± 9.86 Months
Mesh Networks	6	Above Moderate	2028.5	± 9.5 Months
Metamaterials	7	Above Moderate	2030.43	± 13.71 Months
Micro Clouds	4	Above Moderate	2030	± 12 Months
Miniaturization	3	Substantial	2030	± 16 Months
MBSE	7	Above Moderate	2026.5	± 8.5 Months
Morphing Materials	5	Moderate	2031.8	± 14.4 Months
Multi-Threading	2	Moderate	2027	± 12 Months
Nano Tech	7	Above Moderate	2030	± 12.86 Months
Non-Deterministic Approach	3	Moderate	2034	± 15 Months
NPRM	5	Above Moderate		
Off-Board Sensors	5	Above Moderate	2030	± 10.2 Months
On-Board Autonomy	13	Substantial	2030	± 12 Months
Part 135	12	Substantial		
Plastics	8	Moderate	2024.86	± 5.4 Months
Radar	8	Above Moderate	2027.43	± 7 Months
Rapid Build	6	Substantial	2025	± 7.5 Months
Rapid Deployment	6	Moderate	2025	± 7.5 Months
Remote ID	12	Above Moderate		
Resins	5	Moderate	2026.4	± 8.25 Months
Robotic Builds	7	Moderate	2029.14	± 12 Months
DO178	6	Substantial	2030	± 12 Months

DO254	5	Above Moderate	2028.5	± 11.25 Months
Run Time Assurance	10	Substantial	2027.6	± 10.8 Months
Seamless Suppliers	6	Above Moderate	2029	± 14.4 Months
Sensors	5	Substantial	2025.2	± 4.8 Months
Singularity	3	Substantial	2034	± 5 Months
Smart Dust	4	Above Moderate	2031	± 16 Months
Swarm	4	Above Moderate	2029.25	± 10.5 Months
Transforming Robotics	7	Above Moderate	2032.14	± 17 Months
U.S. Only	7	Substantial	2027.86	± 11.57 Months
USS	20	Above Moderate		
UTM	21	Substantial	2026.86	± 11 Months
Vectored Propulsion	6	Moderate	2029.5	± 10.8 Months
Virtual Prototyping	9	Substantial	2027.33	± 9 Months
Vision-Based Navigation	9	Above Moderate	2027.33	± 9 Months
Wireless Power	5	Above Moderate	2028.2	± 16.8 Months

3.6.2 Market Forecast for BVLOS Missions by Equipment/Technologies, Regulations, Procedures

The UAH team conducted a supplementary analysis that included a market forecast by the equipment/technologies, regulations, and procedures required for BVLOS missions. Using the team’s expert opinion, an operations breakdown by equipment, regulation, and procedures was conducted for BVLOS missions. This operations breakdown is presented in Figure 17. Here the UAH team related the equipment, regulations, and procedures needed for the safe integration of BVLOS missions in the NAS with related influencing technologies and concepts from the PASAUT interview.

It was concluded that the necessary equipment, regulations, and procedures for BVLOS operations are detect and avoid, remote ID, and UAS corridors, respectively. For example, essential equipment for a BVLOS sUAS mission would be a detect and avoid system and other safety automation. Essential technologies studied using PASAUT would be advanced sensing, run time assurance, machine learning, vision-based navigation, and GPS denied. An additional example is structural procedures that would need to be in place to conduct BVLOS missions such as specification of sUAS corridors. Here, UTM and USS are two PASAUT categories that would belong under this description.

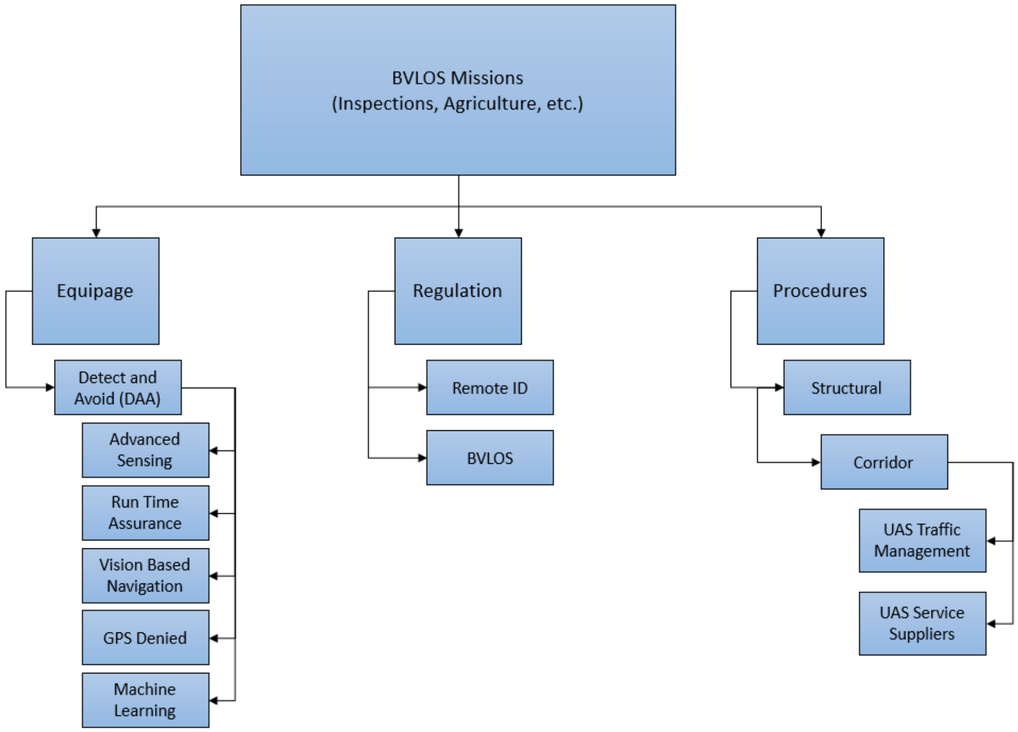

Figure 17. BVLOS Mission Breakdown.

Table 16 provides a forecast for BVLOS missions by equipment/related technologies, regulations, and procedures. In the subsequent sections, the UAH team conducted a related market analysis for BVLOS missions. In this investigation the UAH team identified several expanded and non-segregated sUAS operations that would benefit from BVLOS. These missions selected included: Aerial Data, Photography, and Mapping, Agriculture, Inspection, and Delivery. The team then identified specific PASAUT influential factors for each mission. Using these factors as well as the PASAUT equipment related technologies, regulations, and procedures identified in Figure 17, the UAH team developed forecasts on the predicted timeframe period where most critical factors would be addressed and when the largest market growth would be expected.

Table 15. Market Forecast for BVLOS Missions by Equipment/Technologies, Regulations, and Procedures.

Category	**# Participants**	**Market Impact**	**Expected Year**	**Uncertainty**
Advanced Sensing	8	Above Moderate	2026.25	± 9.75 Months
BVLOS	11	Substantial	2026.1	± 9.67 Months
GPS Denied	7	Above Moderate	2026.14	± 9 Months
Machine Learning	7	Substantial	2027.43	± 9.86 Months

Remote ID	12	Above Moderate		
Run Time Assurance	10	Substantial	2027.6	± 10.8 Months
USS	20	Above Moderate		
UTM	21	Substantial	2026.86	± 11 Months
Vision-Based Navigation	9	Above Moderate	2027.33	± 9 Months

3.6.3 Market Forecast by BVLOS Missions

3.6.3.1 Introduction

Using a literature review, expert interviews, and an internal analysis, the UAH team conducted an investigation to support the development of forecasts of expanded and non-segregated UAS operations. The provided non-segregated UAS operations forecast includes: the scope and types of UAS, the types of airspace involved, and a projected timeframe of UAS traffic volume. Additionally, recommendations regarding influential technologies and procedures that will facilitate these expanded and non-segregated operations are provided. The first step in the analysis included identifying 4 expanded and non-segregated BVLOS sUAS mission types. These mission types are:

- Aerial Data, Photography, and Mapping
- Agriculture
- Inspection
- Delivery

There are several unique categories of sUAS used for many applications in the NAS. However, the UAH analysts narrowed the scope of the investigation to the following four sUAS configurations.

1. Single-Rotor sUAS – Single-rotor, vertical take-off and land (VTOL) aircraft that uses swash-plates and a tail rotor to adjust its attitude and position.
2. Multirotor sUAS – Multiple-rotor, VTOL aircraft that uses differential thrust to adjust its attitude and position.
3. Fixed-Wing sUAS – Conventional take-off or launched (i.e., catapult or hand launched) aircraft that uses propellers for horizontal flight and traditional control surfaces to adjust its attitude and position.
4. Hybrid Fixed-Wing sUAS – VTOL aircraft that transitions to fixed-wing forward flight.

3.6.3.2 Forecasting Approach

To develop a forecast for each mission type, the UAH team conducted an internal analysis to determine expanded and non-segregated UAS mission-critical technologies and concepts from the PASAUT interviews. Using these factors as well as the PASAUT equipment related technologies, regulations, and procedures identified in Figure 17, the UAH team developed forecasts on the predicted timeframe period where most critical factors would be addressed and when the largest market growth would be expected. Influencing technologies and concepts selected for each operation type are listed within each mission's analysis section.

A probability distribution that incorporated the expected technology/concept maturity date and related uncertainty (provided by SME responses) was used to determine when most (~68%, one standard deviation from the mean) of the selected technologies were expected to have matured. For clarity, a normal distribution was selected to help determine where the majority of PASUAT influencing factors were expected to have matured for each mission. A normal distribution is a probability distribution that is symmetric about a data set's mean (or central peak). These distributions are effective at showing where the majority of the data rests in relation to the mean. The expected year used in this analysis was either the estimated first use in UAS or estimate of initial technology availability (provided by SMEs in knowledge elicitation) depending on which date was the furthest in the future. Then, a "two-year buffer" period was added to the final date selected. This was the same method used to develop the market forecasts presented in Section 3.6 of this document

For each mission, the UAH team developed two forecasts. The first forecast predicts the period when most critical factors are expected to have been addressed. This forecast incorporated all influencing factors within each mission type and their relative uncertainties. A normal distribution bell curve was generated using this data. Then, one standard deviation above and below the mean was marked (i.e., when 68% of the influencing factors are expected to have matured). This range was labeled as "Predicted Period of Most Critical Factors Addressed." The second forecast estimates the period of largest market impact. This forecast incorporated only the factors identified by the SMEs as having a "Substantial Market Impact." An identical process was utilized as the first forecast to generate the second predicted timeframe. This timeframe range is labeled as "Predicted Period of Largest Market Growth."

3.6.3.3 Aerial Data, Photography, and Mapping

3.6.3.3.1 Types of sUAS Involved

Depending on the size of the area being surveyed, the most common types of aircraft used in aerial data collection are fixed-wing and multirotor. Multirotor drones are easily maneuverable and are capable of maintaining a fixed position in the air. This is especially useful for surveying urban areas or capturing 3D maps of buildings and small features. Fixed-wing drones are capable of much longer flight times; consequently, beneficial in surveying large areas. Regardless of the aerostructure configuration, the selected aircraft will need to be capable of automated, pre-planned flight in order to ensure accurate tracking, data consistency, and reliable area-of-interest coverage. Drones used for aerial data collection will also need the proper sensors associated with the data they wish to gather, often a 4K or multispectral camera. Furthermore, the inclusion of an RTK GPS module can provide greatly increased geospatial accuracy (Pilot Institute, 2020).

3.6.3.3.2 Scope of Operations and Types of Airspace Involved

Drones are used for aerial data collection by both commercial entities and individuals for personal use. Common applications of sUAS aerial mapping are assessing crop and wildlife health for farming or conservation efforts, creating real-time maps of disaster-stricken areas for first responders, and urban planning. Aerial data collection can be performed in any airspace, as long as the operation acquires controlled airspace authorization and approval.

3.6.3.3.3 Forecast

Figure 18 illustrates the probability distributions of the influencing factors for BVLOS aerial data, photography, and mapping UAS missions. Based on these data, the UAH team predicts that between late 2025 and early 2029 UAS aerial data, photography, and mapping operations will have most critical factors addressed as well as experience its largest market growth.

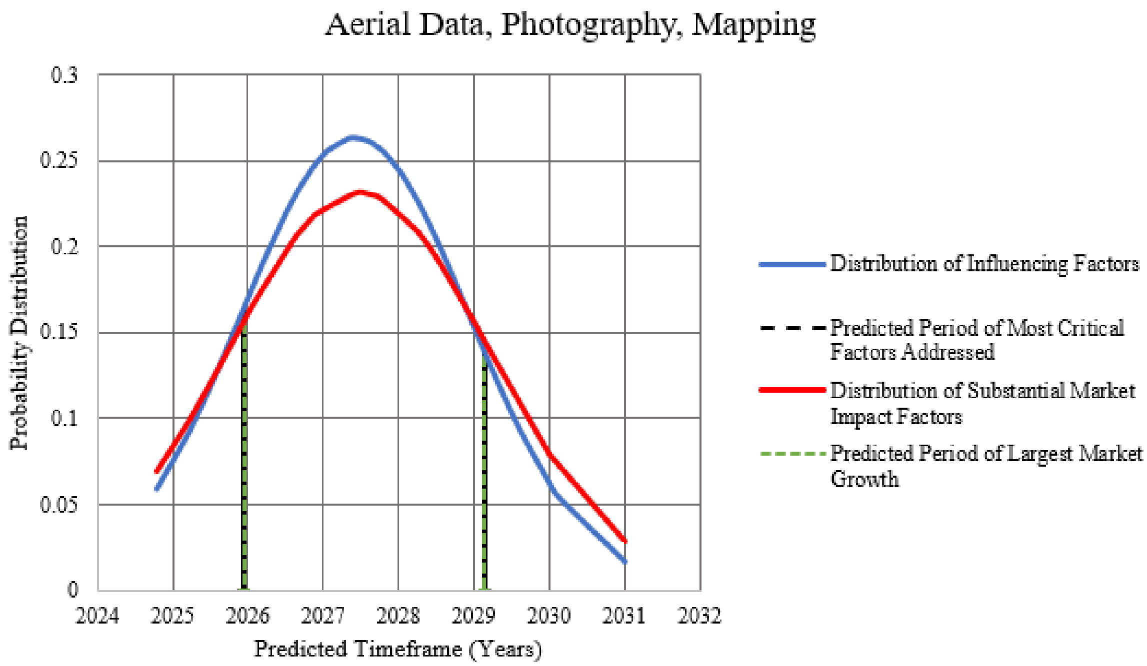

Figure 18. BVLOS Aerial Data, Photography, and Mapping sUAS Operations Forecast.

3.6.3.3.4 Selected Technologies and Concepts

The following technologies and influencing concepts were selected in the evaluation of the aerial data, photography, and mapping mission type:

- Advanced Sensing
- Augmented Reality
- Autopilots/Flight Control Systems
- Battery Management
- BVLOS
- GPS Denied
- Machine Learning
- Off-Board Sensors
- On-Board Autonomy
- Radar
- Remote ID
- Run Time Assurance
- Sensors

- Swarm
- USS
- UTM
- Vision-Based Navigation

3.6.3.4 Agriculture

3.6.3.4.1 Types of sUAS Involved

There are several types of drones used in agriculture. However, primarily multirotor drones and fixed-wing aircraft are used in agricultural sUAS operations. The additional thrust provided by supplementary propulsion sources allows multirotor aircraft to support larger payload weights needed for the dispersion of liquid insecticides. The fault tolerant nature of multirotor UAS, specifically hexacopters and octocopters, adds additional protection to expensive payloads like multispectral cameras and LiDAR sensors. Fixed-wing drones are better suited for high-altitude aerial mapping of crops and other monitoring activities because they can sustain longer flights and cover a larger geographical area - perfect for large scale monitoring of crops. Fixed-wing UAS can carry several cameras that allow the operator to capture a number of different images and a variety of data from crops (Stapleton, 2022).

3.6.3.4.2 Scope of Operations and Types of Airspace Involved

Gathering useful, timely insights on the wellbeing of crops and livestock scattered across large areas poses a significant challenge in the agriculture industry. UAS can be equipped with sophisticated cameras and sensors that can provide comprehensive data quickly. Additionally, drones outfitted with precise agricultural spraying equipment allow for efficient and convenient crop maintenance. According to a 2016 PricewaterhouseCoopers report on the global market for commercial applications of drone technology, agriculture was predicted second only to infrastructure in the global market for drone-powered solutions (PWC, 2016). Agricultural UAS operations will most likely occur in Class G airspace. UAS agriculture operations could occur in Class B, C, or D airspace if proper airspace authorizations and notifications are acquired.

3.6.3.4.3 Forecast

Figure 19 illustrates the normal distribution of the influencing technologies and concepts for an agriculture mission type. Based on data analysis, the UAH team projects that between early 2026 and 2030 BVLOS UAS agricultural operations will have most critical factors addressed and between late 2025 and 2030 will experience its largest market growth.

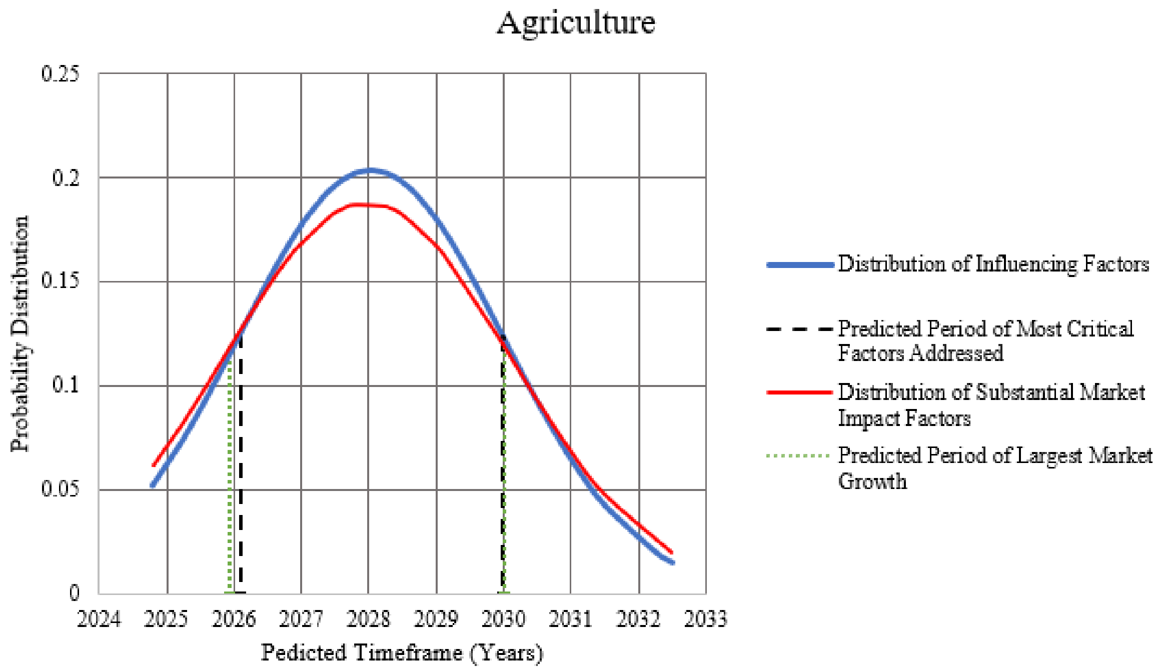

Figure 19. BVLOS Agriculture sUAS Operations Forecast.

3.6.3.4.4 Selected Technologies and Concepts

The following technologies and influencing concepts were selected in the evaluation of the agriculture mission type:

- Advanced Sensing
- Alternative Power
- Augmented Reality
- Autonomy Expert Systems
- Autopilots/Flight Control Systems
- Battery Management
- BVLOS
- GPS Denied
- Machine Learning
- Off-Board Sensors
- On-Board Autonomy
- Radar
- Remote ID
- Run Time Assurance
- Sensors
- Swarm
- USS
- UTM
- Vision-Based Navigation

3.6.3.5 Inspection

3.6.3.5.1 Types of sUAS Involved

Typically, a stable aircraft platform is ideal for inspections. Provided the aircraft is not overloaded, the quantity of rotors increases the fault tolerance of the drone – important for ensuring expensive payloads are protected in the event of a motor failure. Therefore, multirotor aircraft configurations are ideal for conducting inspections. Fixed-wing sUAS can also be an excellent tool for rapid inspection when the object(s) of inspection do not require especially high-resolution imagery. Inspections that do not include video but rather mapping and terrain inspection could be accomplished with fixed-wing, multirotor, or single-rotor aircraft configurations.

3.6.3.5.2 Scope of Operations and Types of Airspace Involved

UAS inspection operations may include examinations of public and private property, or their surrounding terrain. Each of these UAS inspection mission types demands a different inspection approach. Therefore, the selection of UAS will be based on that need. Inspections can be accomplished in any airspace assuming compliance with controlled airspace authorization and, or approvals.

3.6.3.5.3 Forecast

Figure 20 illustrates the normal distribution of the influencing technologies and concepts for inspection UAS operations. Based the SME interview data analysis, the UAH team believes that between late 2025 and mid-year 2028 BVLOS UAS agricultural operations will have most critical factors addressed and between late 2025 and early 2029 will experience its largest market growth.

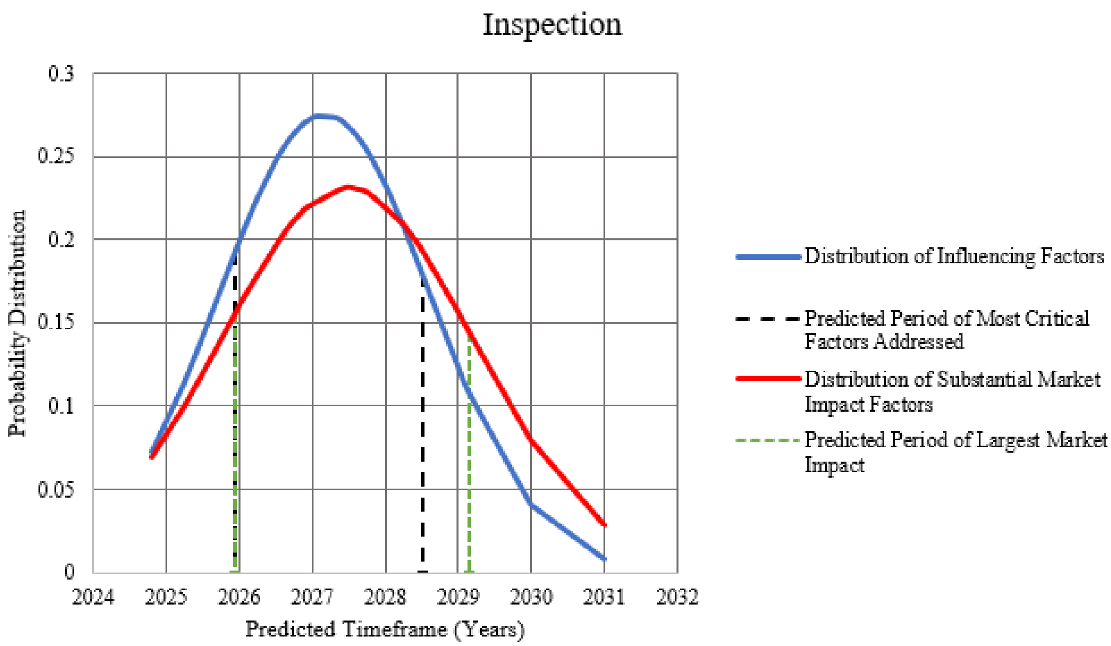

Figure 20. BVLOS Inspection sUAS Operations Forecast.

3.6.3.5.4 Selected Technologies and Concepts

The following technologies and influencing concepts were selected in the evaluation of the inspection mission type:

- Advanced Sensing
- Autopilots/Flight Control Systems
- Battery Management
- BVLOS
- GPS Denied
- Machine Learning
- On-Board Autonomy
- Radar
- Remote ID
- Run Time Assurance
- Sensors
- USS
- UTM
- Vision-Based Navigation

3.6.3.6 Delivery

3.6.3.6.1 Types of sUAS Involved

The two primary configurations of UAS used for delivery operations are multirotor and hybrid fixed-wing. UAH team members' experience from over 1000 deliveries sUAS for a major UUS corporation revealed that the two aforementioned aircraft configurations are the most practical for delivery operations – primarily due to their ability to take-off and land at desired locations accurately. Other UAS configurations may not have the capacity, are impractical for safe deliveries, or logistically untenable

3.6.3.6.2 Scope of Operations and Types of Airspace Involved

Approximately one billion people lack access to all seasons roads and drones can delivery medicine and critical goods in a timely manner. Congested roads in large cities exacerbate the problem of getting goods and medicines to people quickly (Greco, 2022). BVLOS operations have massive potential benefits for package delivery. However, Part 135 certification is the only legal option for UAS delivery operations beyond visual line of sight (Federal Aviation Administration, 2021d). Operations in Class G, E or even B, C, D and E airspace may be applicable to UAS delivery operations. Again, any operations in controlled airspace would need the appropriate authorization and, or approvals.

3.6.3.6.3 Forecast

Figure 21 shows the normal distribution of the influencing technologies and concepts for UAS delivery operations. Based this data analysis, the UAH team projects that between late 2025 and early 2029 BVLOS UAS agricultural operations will have most critical factors addressed and experience its largest market growth.

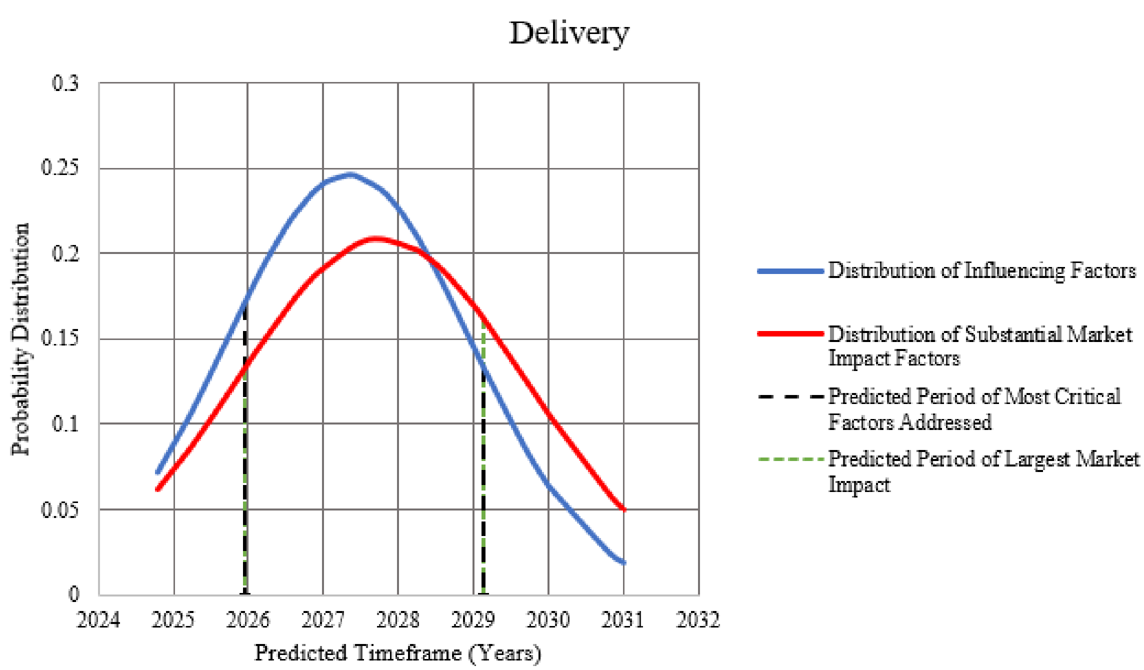

Figure 21. BVLOS Delivery sUAS Operations Forecast.

3.6.3.6.4 Selected Technologies and Concepts

The following technologies and influencing concepts were selected in the evaluation of the delivery mission type:

- Advanced Sensing
- Autopilots/Flight Control Systems
- Battery Management

- BVLOS
- GPS Denied
- Machine Learning
- On-Board Autonomy
- Part 135
- Radar
- Remote ID
- Run Time Assurance
- Sensors
- USS
- UTM
- Vision-Based Navigation

3.6.3.7 Summary: Technology and Procedural Recommendations

An investigation was focused to determine the most significant procedures and technologies to be considered in the facilitation of the previously identified four expanded and non-segregated UAS operations into the NAS. Forecasts were generated to determine the predicted timeframe period where most critical factors would be addressed and when the largest market growth would be expected. It was determined that the time period of late 2025 to 2030 is when most critical factors will be addressed, and the largest market impact will occur. Therefore, the UAH expects increases in volume of BVLOS sUAS operations to reflect this prediction.

The UAH team has concluded that BVLOS regulation will have the most substantial bearing on future UAS traffic in the NAS. BVLOS received an overall score in the top 10% in terms of its scale of market impact and urgency of need. Additionally, BVLOS scored in the top 15% in its associated regulatory hurdles, political resistance, and impact on NPRMs. Therefore, expert opinion considers BVLOS highly needed and desired while being difficult to enable with many factors that hinder its introduction into the NAS. Historical data on CFR Part 107.31, visual line of sight aircraft operation, waivers issued confirms that the number of BVLOS waivers have increased year-to-year (Federal Aviation Administration, n.d.-c). Data from years 2018 to 2021 indicates that only 72 such waivers were administered. Over half of these waivers were issued in the year 2021 alone. According to statistics from the FAA's Part 107 Waivers Issued website, the number of 107.31 distributed waivers increased over 215% from year 2020 (13 waivers issued) to 2021 (41 waivers issued). Assuming this trend continues, it will be necessary for the FAA to revise the current BVLOS regulation. Significant strides have been made through the FAA's BEYOND Program and the recent (March 10, 2022) delivery of the Advisory Rulemaking Committee (ARC) recommendations on BVLOS operations. The ARC represents a collaboration between industry and regulators designed to define new, needed regulations. The ARC developed a series of recommendations to the FAA with the expectation of enabling the economic and societal benefits associated with UAS BVLOS operations while maintaining safety. For more information on the ARCs and their BVLOS recommendations to the FAA, see (Federal Aviation Administration, n.d. -a).

Revisions to BVLOS regulation similar to those recommended by the ARC will undoubtedly have a positive effect on the number of UAS operations in the NAS. BVLOS regulation revisions will present unique challenges for the FAA including the consideration of new certifications for UAS operators and aircraft as well as defining and setting acceptable levels of risk for such operations. Therefore, it will be imperative for the FAA to develop specific expertise in technology that will enable BVLOS and other expanded and non-segregated UAS operations in the NAS. Advanced technologies like autonomy expert systems, alternative power systems, swarming, transforming robotics, and vision-based navigation were considered in the investigation of these mission types. Results from the PASAUT interview revealed expert opinion placed each of these technologies in the top 10% of least one of the associated enabling/hindering factors categories; many of the technologies were placed in the top 10% in multiple enabling/hindering factors categories. Therefore, expert opinion perceives these technologies as publicly and politically resisted, difficult to commercialize, and associated with considerable environmental and infrastructural ramifications. The UAH team recommends that the FAA become thoroughly conversant in these technologies in preparation for future expanded and non-segregated UAS operations enablement.

4. CONCLUSION

The primary purpose of the research provided within this report was to forecast the growth of the sUAS market and gain insights into the hindering factors that need to be addressed in order to enable this growth. To support this forecast and associated insights, a set of knowledge elicitation questions were forwarded to a small group of 26 SMEs that the UAH team identified. Individuals invited included SMEs working in academia, industry, and for the FAA. The UAH team received 4 completed evaluations.

Within the elicitation, these SMEs were prompted to provide their predictions regarding the growth of sUAS operations from 2024-2032. These data indicate that on average the SMEs predict that the number of commercial sUAS flights per day will increase to 1,019,200 flights per day in 2024 and increase to 2,730,000 flights per day by 2032.

Together with these volume predictions, SMEs were prompted to provide their corresponding reasoning. Demand/economic factors as well as clarity in emerging FAA guidance, procedures, and regulations were the two most common reasonings behind selected scaling factors. Advances in technologies were also indicated as a significant factor later in this time period. The analysis further suggests that growth in the number of commercial non-model sUAS fleet is expected to decelerate over the forecasted period. However, SMEs predicted the average number of commercial sUAS flights per day would increase. This implies that the forecasted number of commercial units is not the only determining factor in the volume of sUAS operations in the NAS.

As a caveat, however, another significant finding was the judgment by four of the 26 invited SMEs who responded to the elicitation by indicating that they did not feel qualified to make the types of forecasts requested in the elicitation. Each of these four respondents shared a concern that there are too many uncertainties associated with the numerous factors that will determine future sUAS activity. An additional common concern expressed by these four respondents focused on their specific expertise. Respondents voiced that their expertise was only in a subset of the sUAS arena; therefore, they were unequipped to address nationwide sUAS trends.

In addition to an overall forecast of the growth of the UAS market, from the results of this elicitation, it these SMEs predicted that operations below 400 feet in general, sUAS operations above 400 feet, over moving vehicles, and involving multiple aircraft controlled by a single remote pilot will all increase over the 8-year period. In contrast, tethered operations and operations from a moving vehicle were projected to saturate within the 8-year timeframe.

A high-level assessment revealed that SMEs project that the hybrid VTOL aircraft configuration will emerge as the preferred configuration for commercial sUAS operations. Upon assessment of the responses provided by SMEs, Class G airspace is expected to experience the majority of expanded and non-segregated sUAS operations.

Though forecasting the number of commercial non-model sUAS units is a valuable insight regarding the volume of sUAS operations in the NAS, it is useful to also consider the impacts of factors that are likely to contribute to such growth. Emerging FAA guidance, procedures, and regulation as well as economic demand will serve as equal, if not, greater factors in this determination.

As a second knowledge elicitation study, an on-line interview was conducted involving a group of 66 specialized SMEs, asking them to evaluate 68 individual technologies/concepts as those items might affect the introduction of UAS into the NAS. 22 of the influencing technologies and concepts that were scored as having a substantial effect on the UAS market, 10 or 45.45% were predicted to mature by the year 2027 and 20 or 90.9% were forecasted to have their critical factors addressed by 2030.

Using these data, the UAH team also conducted an analysis that included a market forecast by the equipment/technologies, regulations, and procedures required for BVLOS missions. It was determined that the necessary equipment, regulations, and procedures for BVLOS operations are detect and avoid and other safety automation, remote ID and BVLOS guidelines, and UAS corridors, respectively. The UAH team then related specific influencing technologies/concepts from the online interview to these categories. This analysis was used to determine the predicted timeframe period where most critical factors would be addressed and when the largest market growth would be expected. Based on the results of this analysis, the UAH team estimates substantial increases in BVLOS operations in particular and sUAS operations in general will occur between the time period of late 2025 to 2030.

5. APPENDIX – B1: EXPERT ELICITATION

BEFORE COMPLETING, PLEASE PROVIDE YOUR NUMBER OF YEARS OF UAS RELATED EXPERIENCE IN THE SPACE PROVIDED BELOW

For reference, data from the FAA's report title *FAA Aerospace Forecast Fiscal Years 2021-2041* on the forecasted number of commercial sUAS units in the United States is provided in Table 16 below (Federal Aviation Administration, 2021b). This data was based on trends in previous years of commercial/non-model sUAS aircraft registration, review of available industry forecasts, and internal market/industry research to generate a total commercial/non-model fleet sUAS forecast.

Table 16. FAA sUAS Commercial Fleet Fiscal Year Forecast.

Total Commercial/Non-Model Fleet (Thousand sUAS Units)

Fiscal Year	Low	Base	High
Historical			
2020	488	488	488
Forecast			
2021	543	589	691
2022	569	665	871
2023	583	729	1,028
2024	601	784	1,094
2025	614	835	1,144

We have extended the FAA forecast through the years 2026, 2028, 2030, and 2032 by curve fitting the FAA projected total commercial fleet data. This data is provided as a helpful reference in answering the interview questions. The forecasted data is based on the following assumptions:

- Data shown in Table 17 is calculated based on the trends observed in the FAA sUAS total commercial/non-model fleet.
- "As the present base (i.e., the cumulative total) increases, the FAA anticipates the growth rate of the sector will slow down over time (Federal Aviation Administration, 2021b)."
- The UAH team did not make any adjustments to the total number of commercial/non-model fleet forecast based on future technology availability and future FAA-specified procedures/regulations.

Table 17. Exponential Curve Fit Years 2026, 2028, 2030, and 2032 Projected sUAS Commercial Fleet.

Forecasted Total Commercial/Non-Model Fleet (Thousand sUAS Units)

Fiscal Year	**Low**	**Base**	**High**
2026	622	873	1160
2028	631	925	1174
2030	637	957	1178
2032	640	975	1180

<u>Please provide Responses to the Following Questions</u>

1. A scaling factor that converts the total baseline commercial sUAS units to total number of operations per day for each of the specified fiscal years (e.g., 488,000 [sUAS in 2020] x **1.5 [Daily Ops / sUAS]** = 732,000 [Daily Operations for Fiscal Year 2020]). Please fill out the chart below.

Fiscal Year	Scaling Factor [Daily Ops / sUAS]	Reasoning*
2024		
2026		
2028		
2030		
2032		

*For Example, (1) Enabling Technology Emergence, (2) Emerging FAA Guidance | Procedures | Regulations, (3) Demand/Economic Factors

2. Estimate the percentage of sUAS missions per fiscal year (specified in the table) that will require operations **<u>from</u>** a moving vehicle. Please fill out the chart below.

Fiscal Year	Total Percentage [%]
2024	
2026	
2028	
2030	
2032	

3. Estimate the percentage of sUAS missions per fiscal year (specified in the table) that will require operations above 400 feet above ground level (AGL). Please fill out the chart below.

Fiscal Year	Total Percentage [%]
2024	
2026	
2028	
2030	
2032	

4. Estimate the percentage of sUAS missions per fiscal year (specified in the table) that will require tethered operations. Please fill out the chart below.

Fiscal Year	Total Percentage [%]
2024	
2026	
2028	
2030	
2032	

5. Estimate the percentage of sUAS missions per fiscal year (specified in the table) that will require the operation of multiple aircraft controlled by a single RPIC. Please fill out the chart below.

Fiscal Year	Total Percentage [%]
2024	
2026	
2028	
2030	

Fiscal Year	Total Percentage [%]
2032	

6. Estimate the percentage of sUAS missions per fiscal year (specified in the table) that will require operations **<u>over</u>** moving vehicles. Please fill out the chart below

Fiscal Year	Total Percentage [%]
2024	
2026	
2028	
2030	
2032	

7. What percentage of the total commercial sUAS usage will the following aircraft configurations be utilized in the fiscal year specified? Please fill out the chart below.

Fiscal Year	Rotorcraft/Multirotor [%]	Fixed Wing [%]	Hybrid VTOL [%]
2024			
2026			
2028			
2030			
2032			

8. Estimate the percentage (of total flight hours) by category of airspace where you believe these sUAS operations will occur in the corresponding fiscal years. For reference, a diagram of airspace guidance for sUAS operators is provided below in Figure 22.

Fiscal Year	B [%]	C [%]	D [%]	E [%]	G [%]
2024					
2026					
2028					
2030					

2032

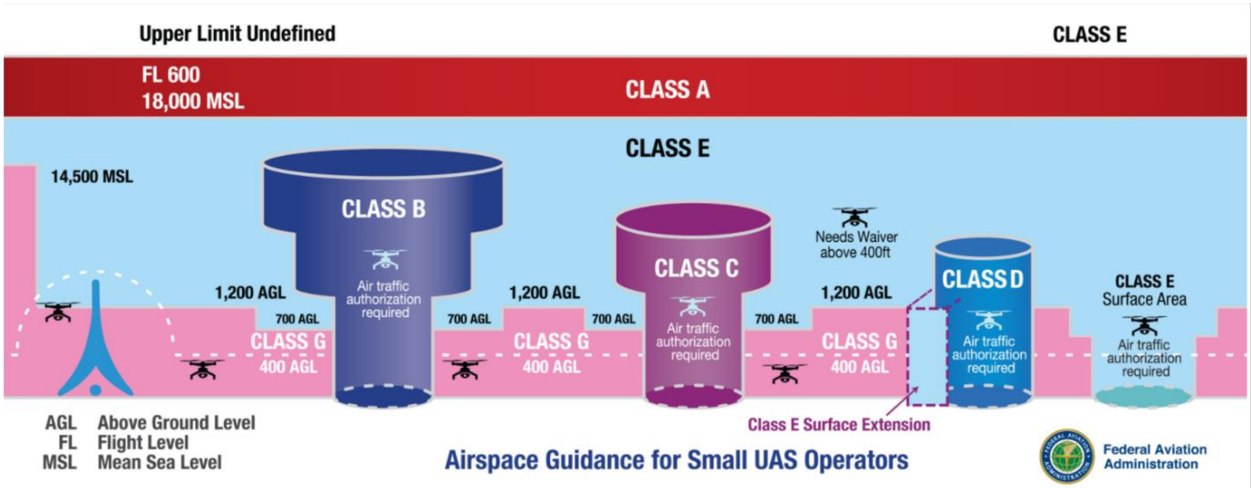

Figure 22: FAA Airspace Guidance for sUAS Operators.

6. APPENDIX – B2: EXPERT ELICITATION RESPONSES

6.1 Response 1: SME with 6 Years of UAS Related Experience

6.1.1 Question 1

Fiscal Year	Scaling Factor [Daily Ops / sUAS]	Reasoning*
2024	0.5	Economic Recovery
2026	0.7	FAA Guidance
2028	2.0	New Battery Tech
2030	2.1	New Manufacturing
2032	3.0	Resurgence in Interest

6.1.2 Question 2

Fiscal Year	Total Percentage [%]
2024	10
2026	10
2028	8
2030	8
2032	6

6.1.3 Question 3

Fiscal Year	Total Percentage [%]
2024	10
2026	15
2028	20
2030	20
2032	25

6.1.4 Question 4

Fiscal Year	Total Percentage [%]
2024	10
2026	8

2028	6
2030	5
2032	4

6.1.5 Question 5

Fiscal Year	Total Percentage [%]
2024	10
2026	12
2028	15
2030	20
2032	21

6.1.6 Question 6

Fiscal Year	Total Percentage [%]
2024	5
2026	10
2028	15
2030	20
2032	20

6.1.7 Question 7

Fiscal Year	Rotorcraft/Multirotor [%]	Fixed Wing [%]	Hybrid VTOL [%]
2024	50	20	30
2026	45	22	35
2028	40	25	45
2030	35	27	53
2032	30	30	60

6.1.8 Question 8

Fiscal Year	B [%]	C [%]	D [%]	E [%]	G [%]

2024			1	19	80
2026	2	5	4	19	70
2028	3	7	7	23	60
2030	4	8	11	37	40
2032	5	10	15	40	30

6.2 Response 2: SME with 8 Years of UAS Related Experience

6.2.1 Question 1

Fiscal Year	Scaling Factor [Daily Ops / sUAS]	Reasoning*
2024	1.1	Emerging FAA Procedures
2026	1.1	Emerging FAA Procedures
2028	1.1	Emerging FAA Procedures
2030	1.5	Emerging FAA Regulations
2032	1.5	Emerging FAA Regulations

6.2.2 Question 2

Fiscal Year	Total Percentage [%]
2024	50
2026	50
2028	80
2030	90
2032	90

6.2.3 Question 3

Fiscal Year	Total Percentage [%]
2024	0
2026	0
2028	5
2030	10

2032	15

6.2.4 Question 4

Fiscal Year	Total Percentage [%]
2024	0
2026	0
2028	0
2030	0
2032	0

6.2.5 Question 5

Fiscal Year	Total Percentage [%]
2024	0
2026	0
2028	0
2030	0
2032	0

6.2.6 Question 6

Fiscal Year	Total Percentage [%]
2024	50
2026	50
2028	50
2030	50
2032	50

6.2.7 Question 7

Fiscal Year	Rotorcraft/Multirotor [%]	Fixed Wing [%]	Hybrid VTOL [%]
2024	100	0	0
2026	100	0	0

2028	90	0	10
2030	90	0	10
2032	90	0	10

6.2.8 Question 8

Fiscal Year	B [%]	C [%]	D [%]	E [%]	G [%]
2024	0	0	5	5	90
2026	5	5	5	5	80
2028	5	5	5	5	80
2030	5	5	5	5	80
2032	5	5	5	5	80

6.3 Response 3: SME with 1 Year of UAS Related Experience

6.3.1 Question 1

Fiscal Year	Scaling Factor [Daily Ops / sUAS]	Reasoning*
2024	1.6	Emerging FAA Guidance | Procedures | Regulations
2026	1.8	Demand/Economic Factors
2028	1.8	Enabling Technology Emergence
2030	2	Demand/Economic Factors
2032	2	Emerging FAA Guidance | Procedures | Regulations

6.3.2 Question 2

Fiscal Year	Total Percentage [%]
2024	11
2026	12
2028	13
2030	12
2032	11

6.3.3 Question 3

Fiscal Year	Total Percentage [%]
2024	10
2026	12
2028	14
2030	16
2032	18

6.3.4 Question 4

Fiscal Year	Total Percentage [%]
2024	2
2026	3
2028	2
2030	2
2032	1

6.3.5 Question 5

Fiscal Year	Total Percentage [%]
2024	2
2026	3
2028	4
2030	5
2032	5

6.3.6 Question 6

Fiscal Year	Total Percentage [%]
2024	20
2026	24
2028	26
2030	28

2032	30

6.3.7 Question 7

Fiscal Year	Rotorcraft/Multirotor [%]	Fixed Wing [%]	Hybrid VTOL [%]
2024	20	60	20
2026	18	50	32
2028	16	40	44
2030	16	40	44
2032	14	30	56

6.3.8 Question 8

Fiscal Year	B [%]	C [%]	D [%]	E [%]	G [%]
2024	10	20	50	10	10
2026	10	22	52	8	8
2028	12	22	54	6	6
2030	15	23	54	4	4
2032	16	24	52	4	4

6.4 Response 4: SME with 20+ Years of UAS Related Experience

6.3.1 Question 1

Fiscal Year	Scaling Factor [Daily Ops / sUAS]	Reasoning*
2024	2	Adoption Period
2026	2.5	Technology Emergence (Endurance)
2028	3	Technology Emergence (Endurance)
2030	4	FAA Guidance
2032	4.5	Technology Emergence (High Autonomy)

6.3.2 Question 2

Fiscal Year	Total Percentage [%]

2024	3
2026	4
2028	5
2030	5
2032	5

6.3.3 Question 3

Fiscal Year	Total Percentage [%]
2024	10
2026	10
2028	10
2030	12
2032	15

6.3.4 Question 4

Fiscal Year	Total Percentage [%]
2024	< 5
2026	< 5
2028	< 5
2030	< 5
2032	< 5

6.3.5 Question 5

Fiscal Year	Total Percentage [%]
2024	< 5
2026	< 5
2028	< 10
2030	< 10
2032	< 10

6.3.6 Question 6

Fiscal Year	Total Percentage [%]
2024	< 10
2026	< 15
2028	< 25
2030	< 30
2032	< 35

6.3.7 Question 7

Fiscal Year	Rotorcraft/Multirotor [%]	Fixed Wing [%]	Hybrid VTOL [%]
2024	< 90	< 10	< 1
2026	< 85	< 12	< 3
2028	< 80	< 15	< 5
2030	< 75	< 15	< 10
2032	< 75	< 15	< 10

6.3.8 Question 8

Fiscal Year	B [%]	C [%]	D [%]	E [%]	G [%]
2024			< 1	< 4	95
2026			< 3	< 5	92
2028			< 3	< 5	92
2030			< 3	< 5	92
2032			< 3	< 5	92

7. APPENDIX – B3: RESPONSES FOR ALL 68 TECHNOLOGIES AND INFLUENING CONCEPTS

7.1 3D Scanning

3D scanning is the process of analyzing a real-world object or environment to collect data on its shape and possibly its appearance (e.g. color). The collected data can be used to construct digital 3D models. A 3D scanner can be based on many different technologies, each with its own limitations, advantages, and costs. Many limitations in the kind of objects that can be digitized are still present. For example, optical technology may encounter many difficulties with shiny, reflective, or transparent objects. As another example, industrial computed tomography scanning and structured-light 3D scanners can be used to construct digital 3D models, without destructive testing. Collected 3D data is useful for a wide variety of applications. These devices are used extensively by the entertainment industry in the production of movies, video games, and generating virtual reality simulations. Other common applications of this technology include: augmented reality, motion capture, gesture recognition, robotic mapping, industrial design, orthotics and prosthetics, reverse engineering and prototyping, quality control/inspection, and the digitization of cultural artifacts. Aerial photogrammetry uses aerial images acquired by satellite, commercial aircraft, or UAVs to collect images of buildings, structures, and terrain for 3D reconstruction into a point cloud or mesh (Izadi et al., 2011).

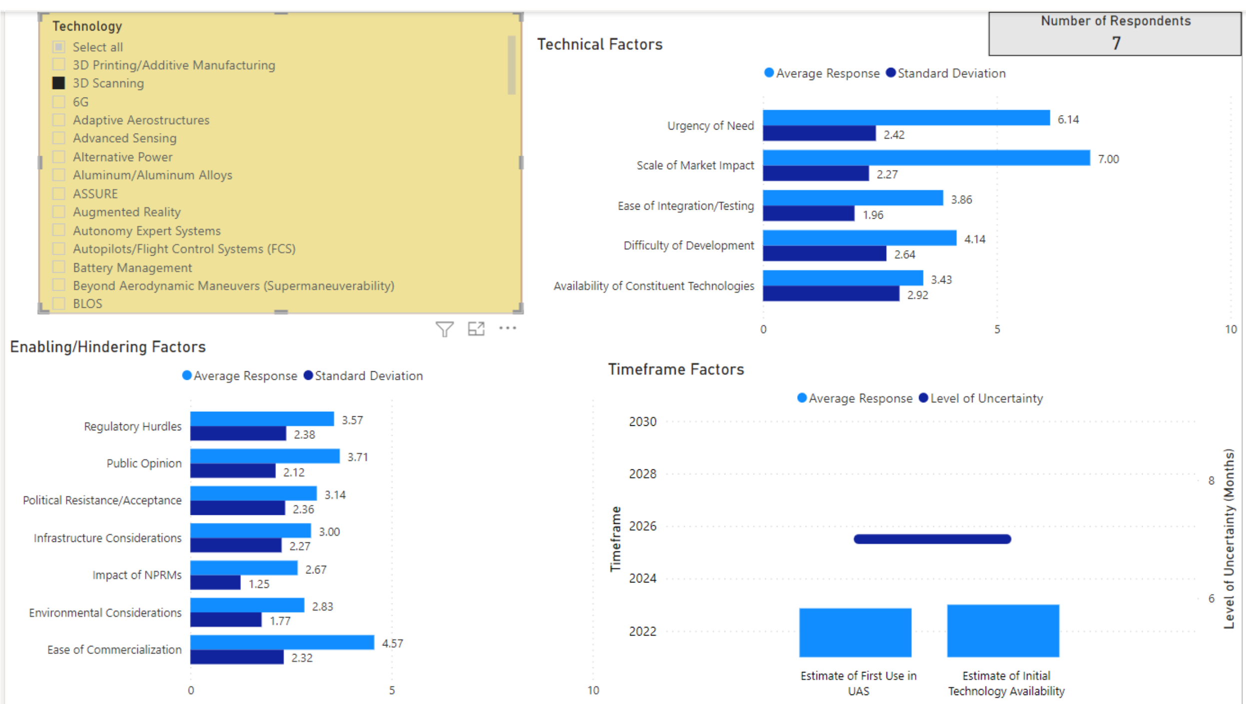

Figure 23. 3D Scanning Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent

- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderate to Easy Integration
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Minor Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2022.86 ± 7/12
    - **Estimate of Initial Technology Availability:** 2023.00 ± 7/12

7.2 6G

In telecommunications, 6G is the sixth-generation standard currently under development for wireless communications technologies supporting cellular data networks. It is the planned successor to 5G and will likely be significantly faster. The large-scale and ever-growing use of unmanned aerial vehicles (UAVs) in a wide range of applications is foreseen to be a major part of beyond 5G and 6G wireless networks in the next decade. The effective support of such massive deployment of UAVs requires offering reliable, secure, and cost-effective wireless connectivity. In this regard, cellular networks play essential roles in serving UAVs acting as flying user equipment (Mozaffari et al., 2021).

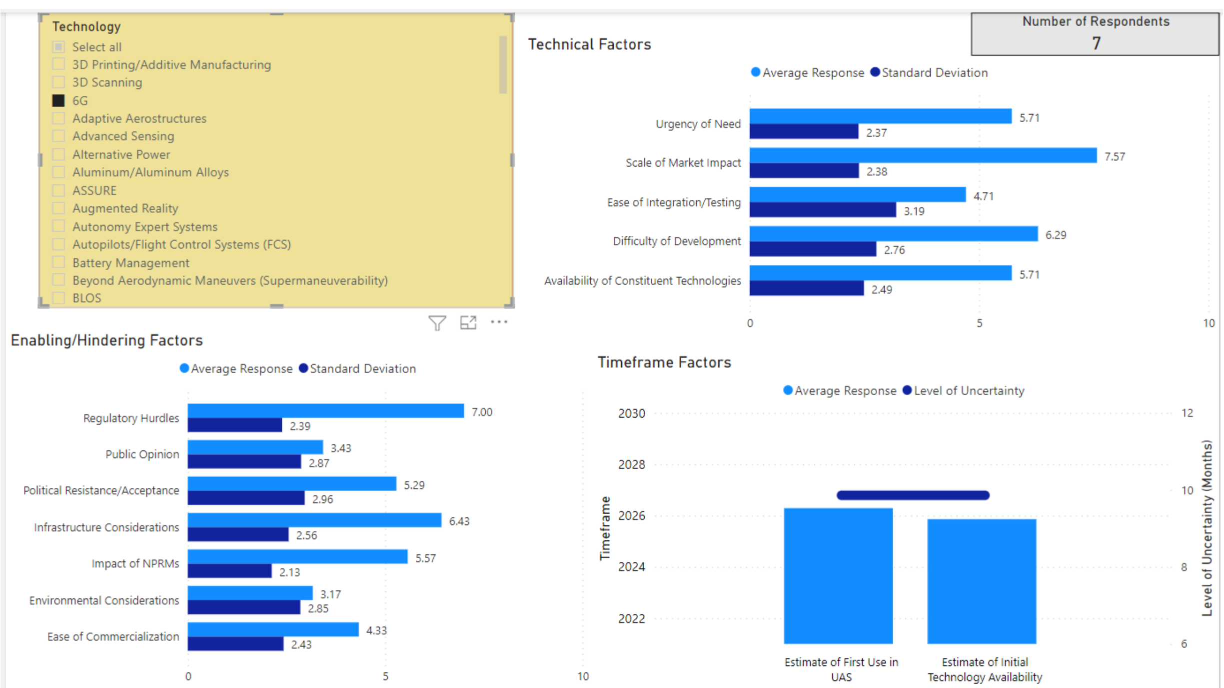

Figure 24. 6G Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2026.29 ± 9.86/12
    - **Estimate of Initial Technology Availability:** 2025.86 ± 9.86/12

7.3 Adaptive Aerostructures

Although many subscale aircraft regularly fly with adaptive materials in sensors and small components in secondary subsystems, only a handful have flown with adaptive aerostructures as flight critical, enabling components. Several families of adaptive aerostructures have enabled or significantly enhanced flightworthy UAVs, including rotary and fixed wing aircraft, missiles, and munitions. More than 40 adaptive aerostructures programs have had a direct connection to flight test and/or production UAVs, ranging from hover to hypersonic flight and sea-level to exo-stratospheric environments. Adaptive material type, design velocity range, test methods, aircraft configuration, and performance of each of the designs have been documented. A historical analysis shows the evolution of flightworthy adaptive aerostructures from the earliest staggering flights in 1994 to modern adaptive UAVs supporting live-fire exercises in harsh military environments (Barrett, 2004).

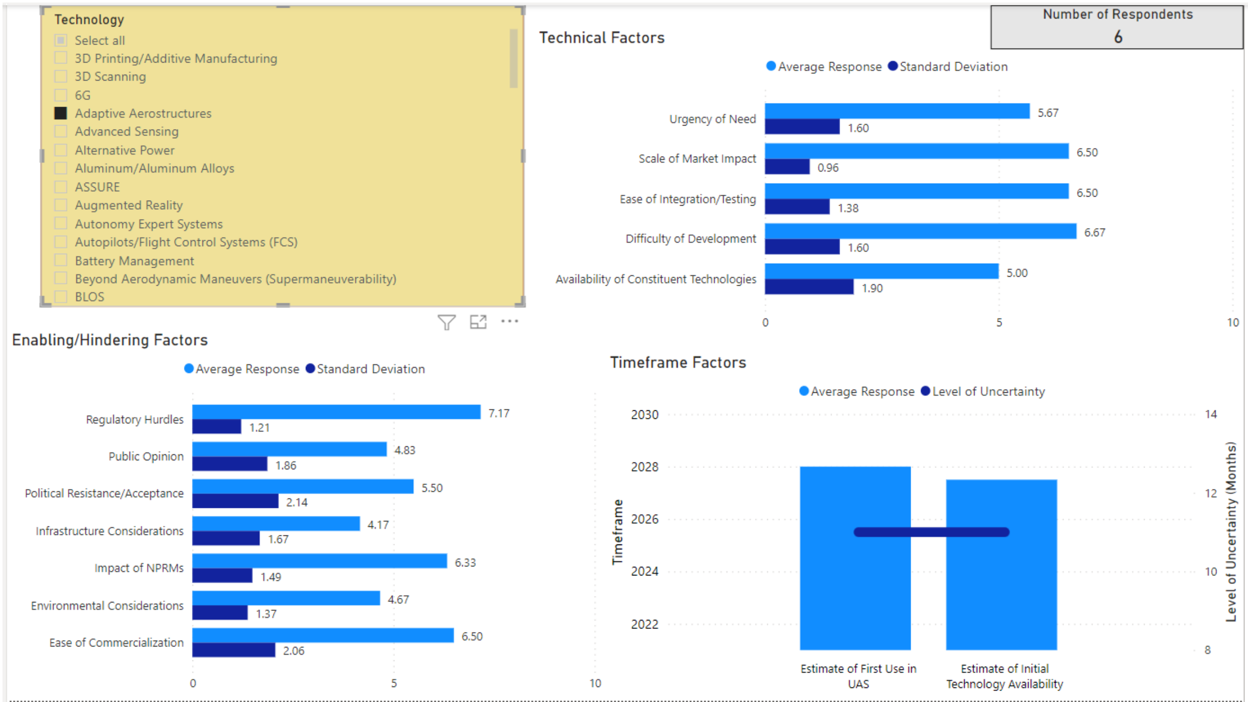

Figure 25. Adaptive Aerostructures Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2028.00 ± 11/12
  - **Estimate of Initial Technology Availability:** 2027.50 ± 11/1

7.4 Advanced Sensing

Advanced sensors such as thermal, multispectral, hyperspectral, and LiDAR are used to gather more detailed data than otherwise possible. They connect with compatible drones and can be swapped out to support a diverse set of business needs. Sensor outputs can be used to generate orthomosaic maps, 3D models, point clouds, and digital surface models. They can then be processed by algorithms to identify plant disease, assess water quality, produce volume measurements, detect heat signatures, create surface composition surveys, and more (PrecisionHawk, 2022).

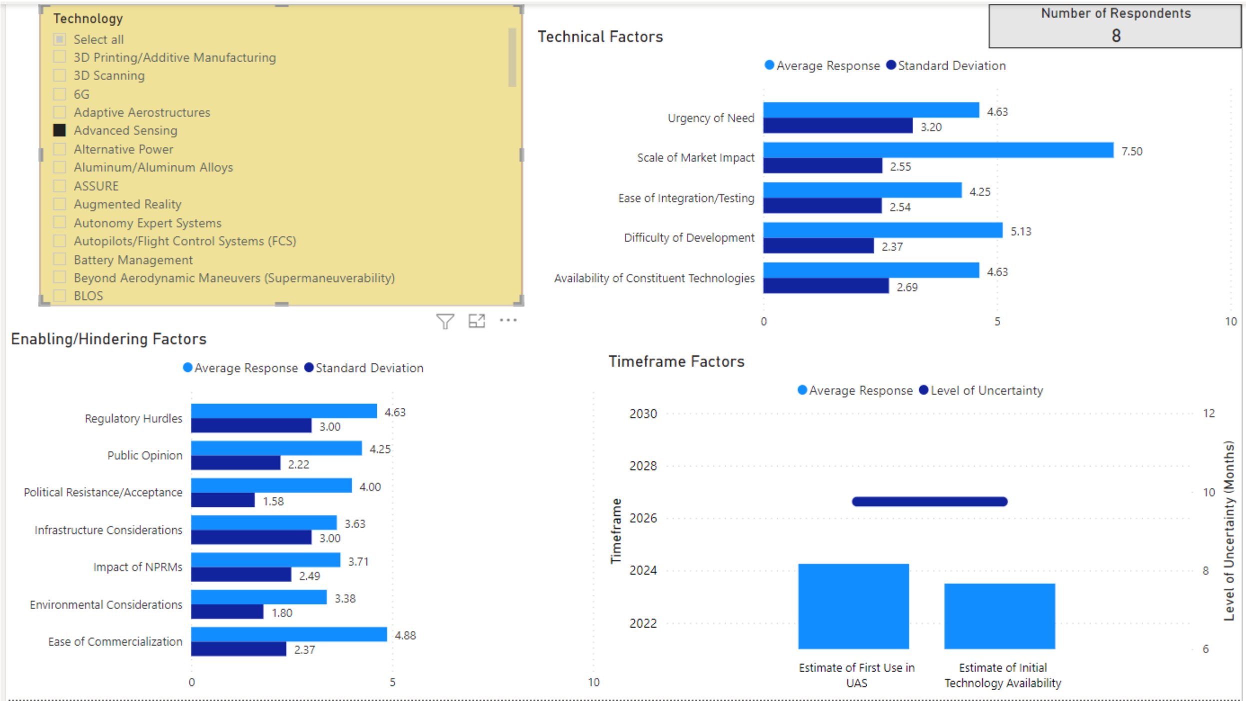

Figure 26. Advanced Sensing Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2024.25 ± 9.75/12
  - **Estimate of Initial Technology Availability:** 2023.50 ± 9.75/12

7.5 Alternative Power

Alternative power includes use of nonconventional power sources for UAS propulsion. Examples include hydrogen fuel cells, solar power, or laser power (Frink, 2012).

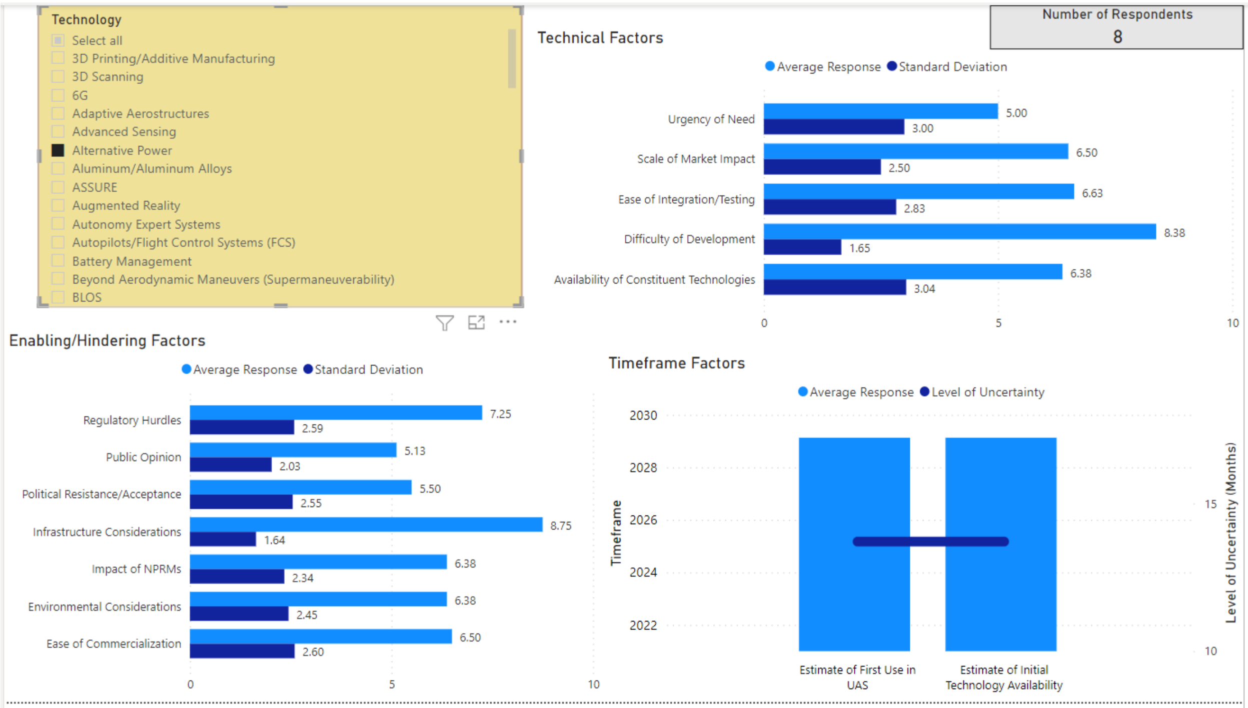

Figure 27. Alternative Power Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Extremely Difficult
- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Highly Concerned Regarding Infrastructure Requirements
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Substantially Concerned about Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2029.13 ± 13.71/12
  - **Estimate of Initial Technology Availability:** 2029.13 ± 13.71/12

7.6 Aluminum, Aluminum Alloys

To fly, drones must be able to generate enough upward thrust to overcome their own weight. Therefore, the selection of materials in a drone is dominated by minimizing the drone's mass while maximizing its structural integrity. Every gram of material used in manufacturing has an aerodynamic cost - every gram that can be saved improves performance in increased cargo capacity, extended flying time, and reduced inertia and improved maneuverability. Aluminum alloys are commonly used in aerospace structural design. Aluminum alloys are used in UAS motors because they have good strength to weight ratio. The alloys also have high thermal conductivity making them a good choice for electric motor housings (Lanning, 2019).

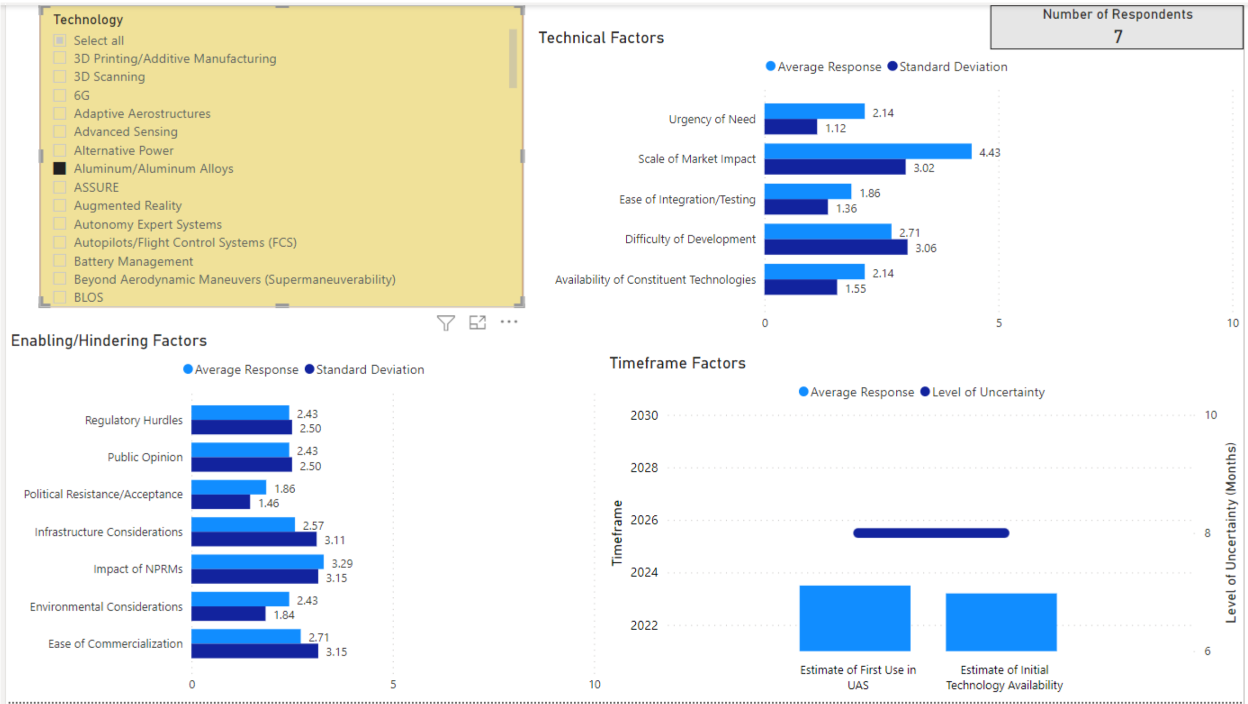

Figure 28. Aluminum, Aluminum Alloys Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Easy to Integrate
- **Difficulty of Development:** Slight Difficulty
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Minor Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Little/No Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

* Average Projected Times (Year ± Uncertainty):
    * **Estimated First Use in UAS:** 2023.50 ± 8/12
    * **Estimate of Initial Technology Availability:** 2023.20 ± 8/12

7.7 ASSURE

The Alliance for System Safety of UAS through Research Excellence (ASSURE) is comprised of twenty-four of the world's leading research institutions and more than a hundred leading industry/government partners. This alliance features expertise across a broad spectrum of research areas including air traffic control interoperability, UAS airport ground operations, control and communications, detect and avoid, human factors, UAS noise reduction, UAS wake signatures, unmanned aircraft pilot training and certification, low altitude operations safety, spectrum management and UAS traffic management. ASSURE provides the FAA with the research needed to integrate unmanned aerial systems quickly, safely, and efficiently into the National Airspace System with minimal changes to our current system (ASSURE, 2021).

ASSURE was considered in this analysis to account for the influence it has on the integration of UAS into the NAS (i.e., is the ASSURE program an enabling or hindering factor). According to the opinion of the SMEs, the ASSURE program is substantially difficult to develop and has moderate regulatory hurdles associated. Though this is the opinion of the SMEs interviewed, the UAH team speculates that potentially factors such as: 1) cost both monetary/time, 2) research needed and how that research translates to the advancement of UAS in the NAS, and 3) the fact that not all research translates to resolved issues in regulation could contribute to these responses.

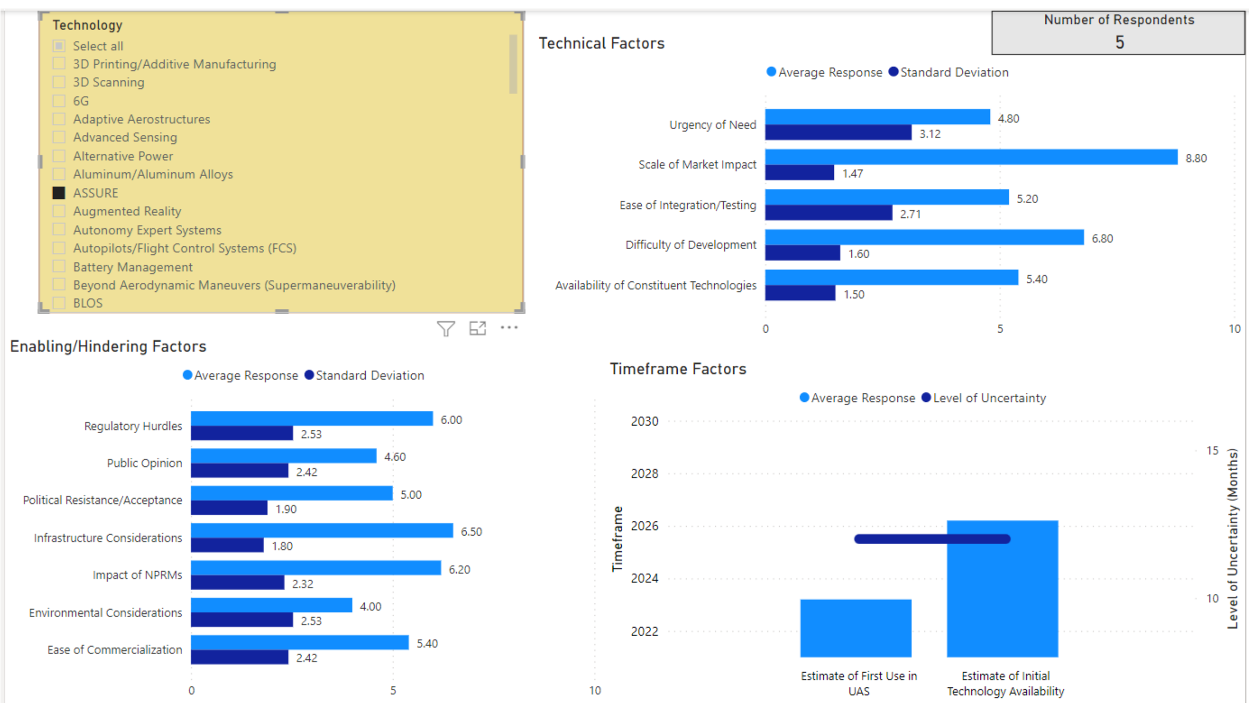

Figure 29. ASSURE Responses.

Technical Factors

* **Urgency of Need:** Moderately Urgent

- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

7.8 Augmented Reality

Unlike virtual reality, which creates its own cyber environment, augmented reality (AR) adds to the existing world. Augmented reality is an interactive experience between a human and computer where objects that reside in the real world are enhanced by a computer-generated output. This computer-generated perceptual information can be outputted across multiple sensory stimuli (e.g. visual, auditory, olfactory, etc.). Imagine you can see not only real objects as the drone sees them, but also some additional images, text, or marks over them. Those virtual objects can appear in response to some “triggers” – special images on real objects recognized by drone software on the fly. AR can be defined as a system that incorporates three basic features: a combination of real and virtual worlds, real-time interaction, and accurate 3D registration of virtual and real objects. The overlaid sensory information can be constructive (i.e. additive to the natural environment), or destructive (i.e. masking of the natural environment). This experience is seamlessly interwoven with the physical world such that it is perceived as an immersive aspect of the real environment (IT Craft, 2016).

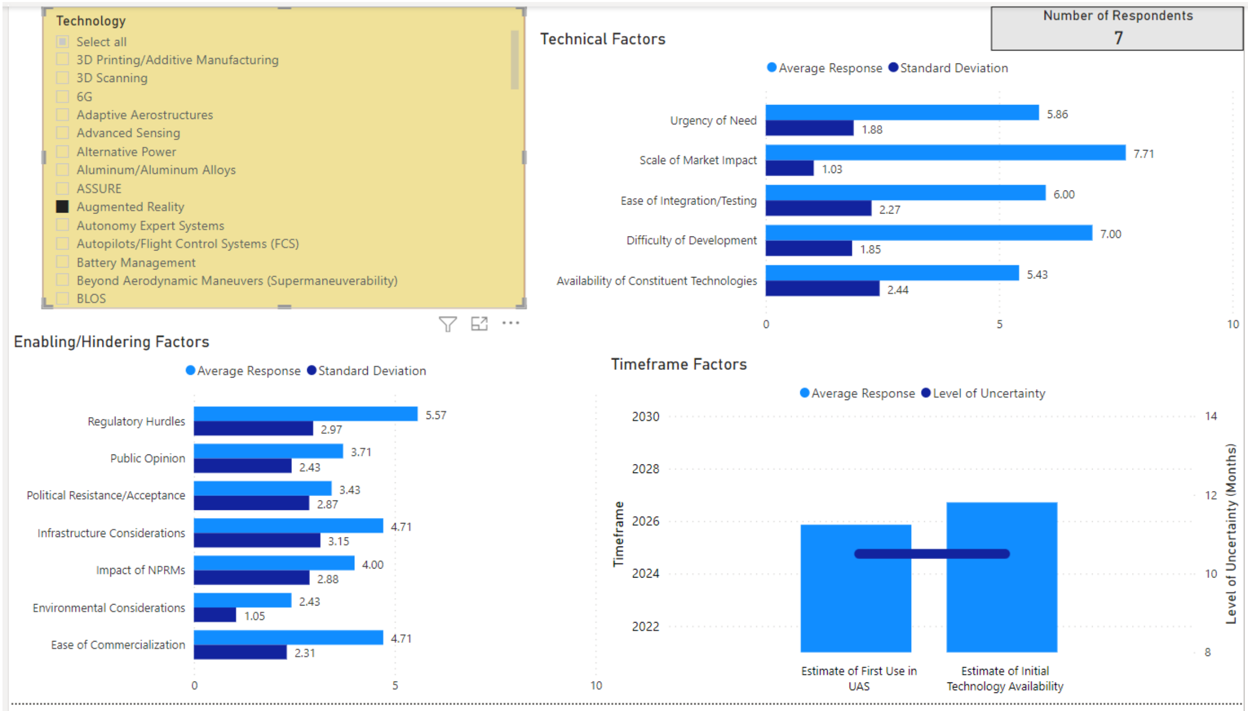

Figure 30. Augmented Reality Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2025.86 ± 10.5/12
  - **Estimate of Initial Technology Availability:** 2026.71 ± 10.5/12

7.9 Autonomy Expert Systems

In artificial intelligence, an expert system is a computer system emulating the decision-making ability of a human expert. Expert systems are designed to solve complex problems by reasoning through bodies of knowledge, represented mainly as if–then rules rather than through conventional procedural code. Recent developments of concepts related to high autonomy systems and the roles played by conventional control theory and artificial intelligence include the following (Zeigler, 1990):

1) Autonomy is shown to be an extended paradigm that subsumes both control and AI paradigms, each of which is limited by its own abstractions.

2) Autonomy, as a design goal, offers an arena where both control and AI paradigms must be applied as well as and a challenge to the viability of both as independent entities.

3) Architectures in which such paradigms can be integrated, with some focus on a model-based approach, have been addressed in several papers.

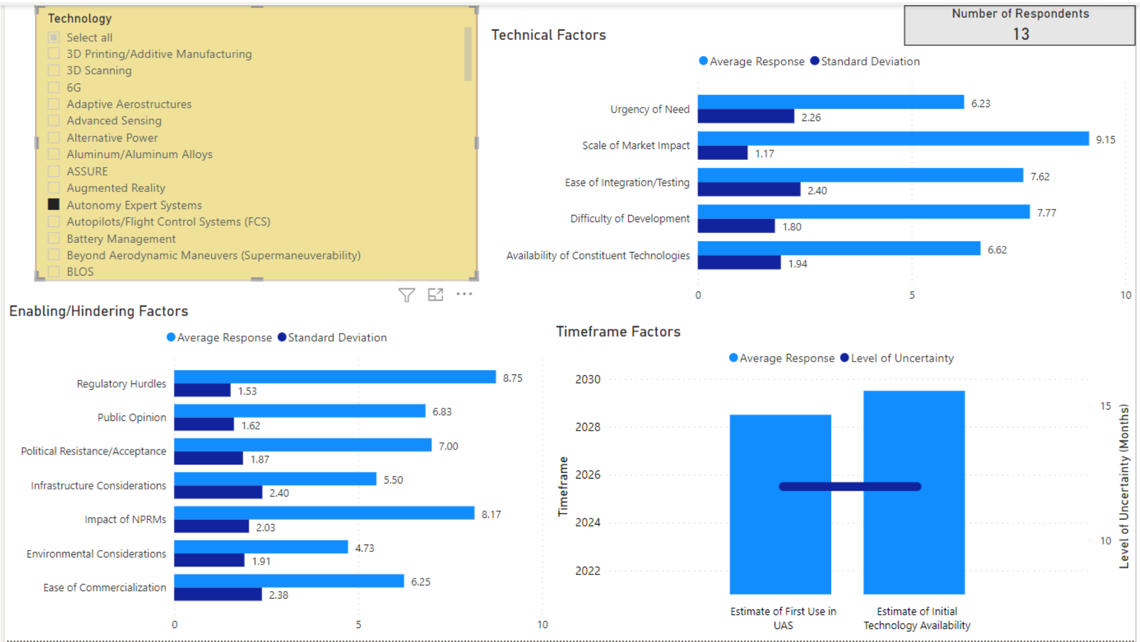

Figure 31. Autonomy Expert Systems Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Somewhat Unacceptable
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** High NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2028.50 ± 1

○ **Estimate of Initial Technology Availability:** 2029.50 ± 1

7.10 Autopilots/Flight Control Systems (FCS)

Several available on-line market reports predict "explosive" growth in the number, variety, and capabilities of drone flight control systems in the coming years. Autonomy will continue to advance. A recent market survey states, "Autonomous flight, while a few drones can already fly without a user directing their path, this technology is still emerging. Over the next five years, system-failure responses, dynamic routing, and handoffs between human and machine controllers should improve. With greater autonomous control, companies will be able to pursue uses that are now elusive, such as the repeated and unpiloted surveillance of pipelines, mines, and construction projects (Nonami, 2020)."

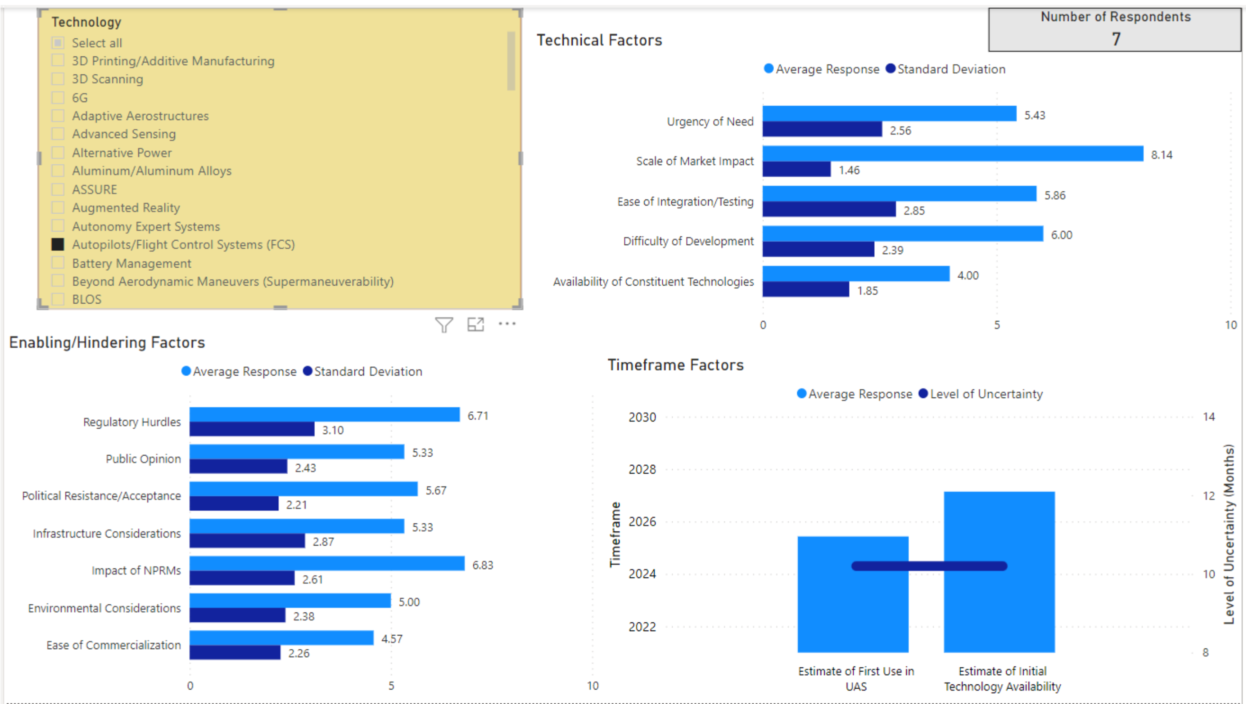

Figure 32. Autopilots/Flight Control Systems (FCS) Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues

- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2025.43 ± 10.2/12
    - **Estimate of Initial Technology Availability:** 2027.14 ± 10.2/12

7.11 Battery Management

A battery management system will continuously monitor important battery parameters, remedy varying operational power demands, and optimize the distribution of the aircraft's battery. The battery management system may monitor battery voltage, current, temperature, state of charge, state of health and other parameters, and may calculate additional information based on these. In addition to managing the battery usage, the battery management system can also protect the battery during charging safeguarding against conditions such as over-current or over-voltage (Unmanned Systems Technology, n.d.).

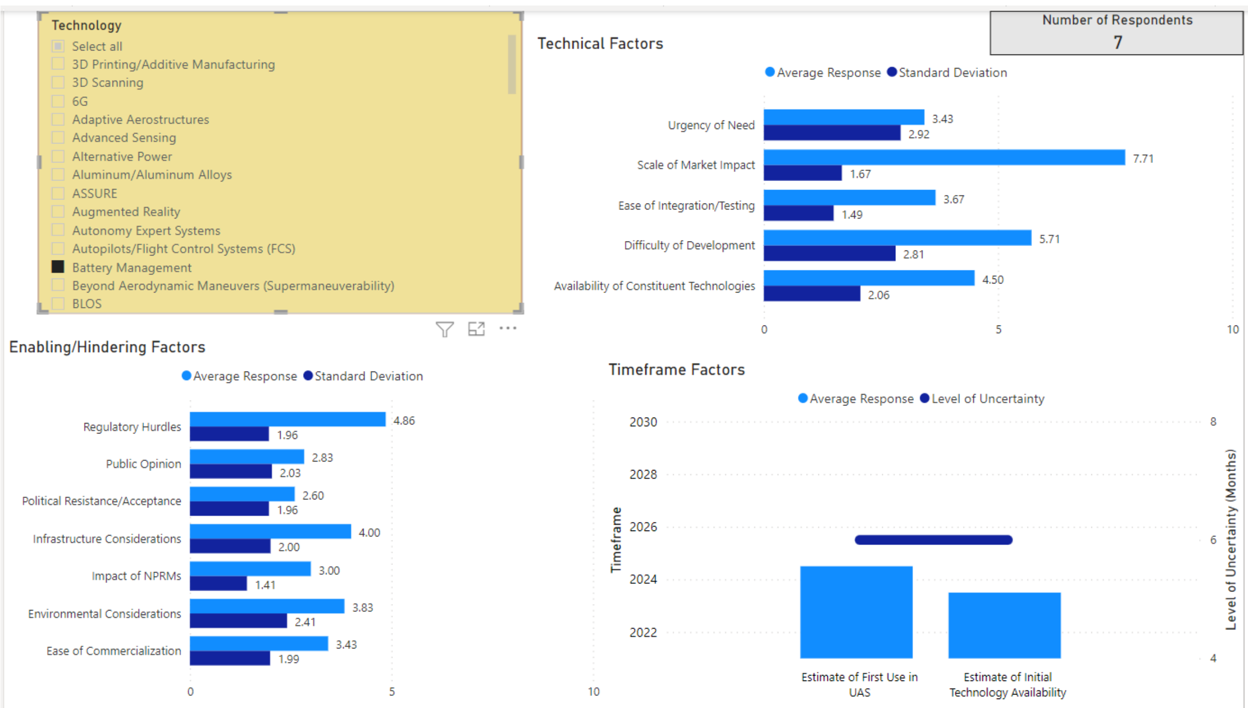

Figure 33. Battery Management Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges

- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2024.50 ± 6/12
  - **Estimate of Initial Technology Availability:** 2023.50 ± 6/12

7.12 Beyond Aerodynamic Maneuvers (Supermaneuverability)

In a supermaneuverable aircraft, the pilot can maintain a high degree of maneuverability below corner velocity, and at least limited altitude control without altitude loss below stall speed. Such an aircraft is capable of maneuvers that are impossible with a purely aerodynamic design. More recently, increased use of jet-powered, instrumented unmanned vehicles ("research drones") has increased the potential flyable angle of attack beyond 90 degrees and well into the post-stall safe flight domains, and has also replaced some of the traditional uses of wind tunnels. A supermaneuverable aircraft allows the pilot to maintain at least some control when the aircraft stalls, and to regain full control quickly. This is achieved largely by designing an aircraft that is highly maneuverable but will not deep stall (thus allowing quick recovery by the pilot) and will recover predictably and favorably (ideally to level flight; more realistically to as shallow a nose-down attitude as possible). To that design, features are then added that allow the pilot to actively control the aircraft while in the stall and retain or regain forward level flight in an extremely shallow band of altitude that surpasses the capabilities of pure aerodynamic maneuvering (Gal-Or, 2013).

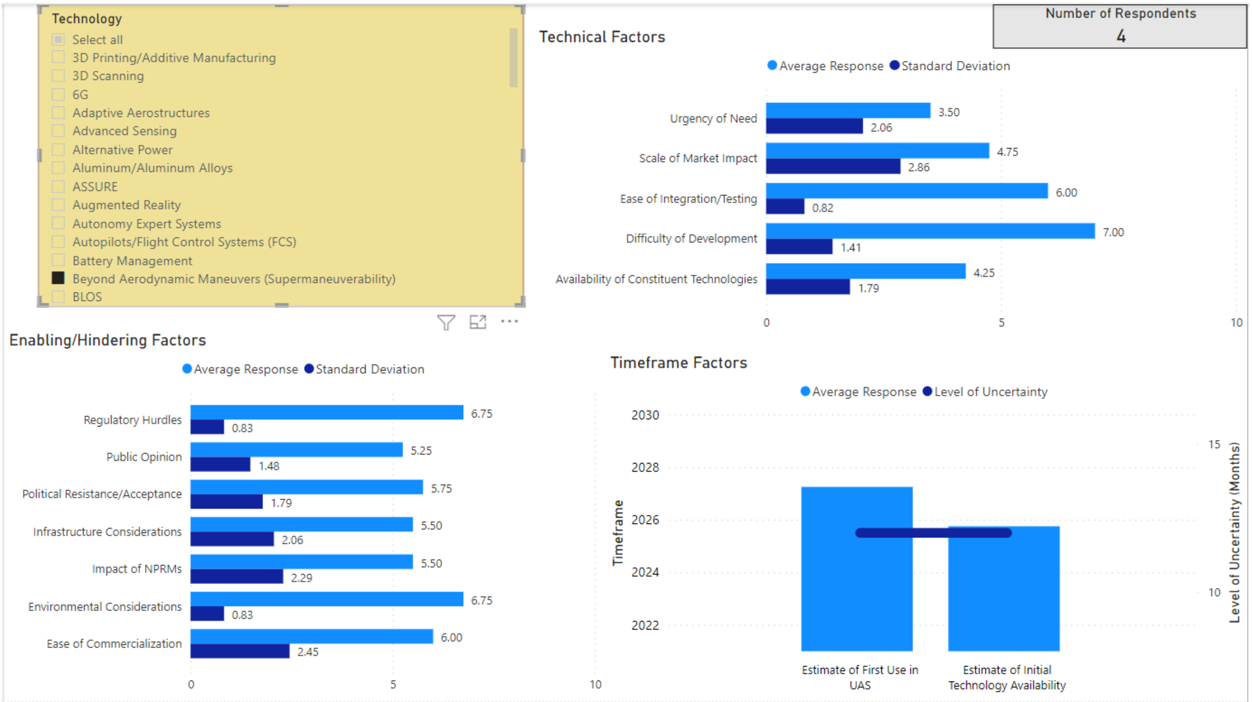

Figure 34. Beyond Aerodynamic Maneuvers Responses

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Substantially Concerned About Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2027.25 ± 1
  - **Estimate of Initial Technology Availability:** 2025.75 ± 1

7.13 BLOS

Jamming, spoofing, interference from the landscape or cityscape, interference from other flight equipment are snarls arise often enough with satellite signals to make it clear that routine UAS flight beyond the line of sight (BLOS) will likely never happen with traditional GPS technology alone. To ensure safe travel over long distances, unmanned aircraft systems need greater capability to ensure accurate positioning and routing. BLOS differs from Beyond Visual Line of Sight (BVLOS) in that BLOS refers to the line of sight of radar or communications signals rather than the visual spectrum (sUAS News, 2020).

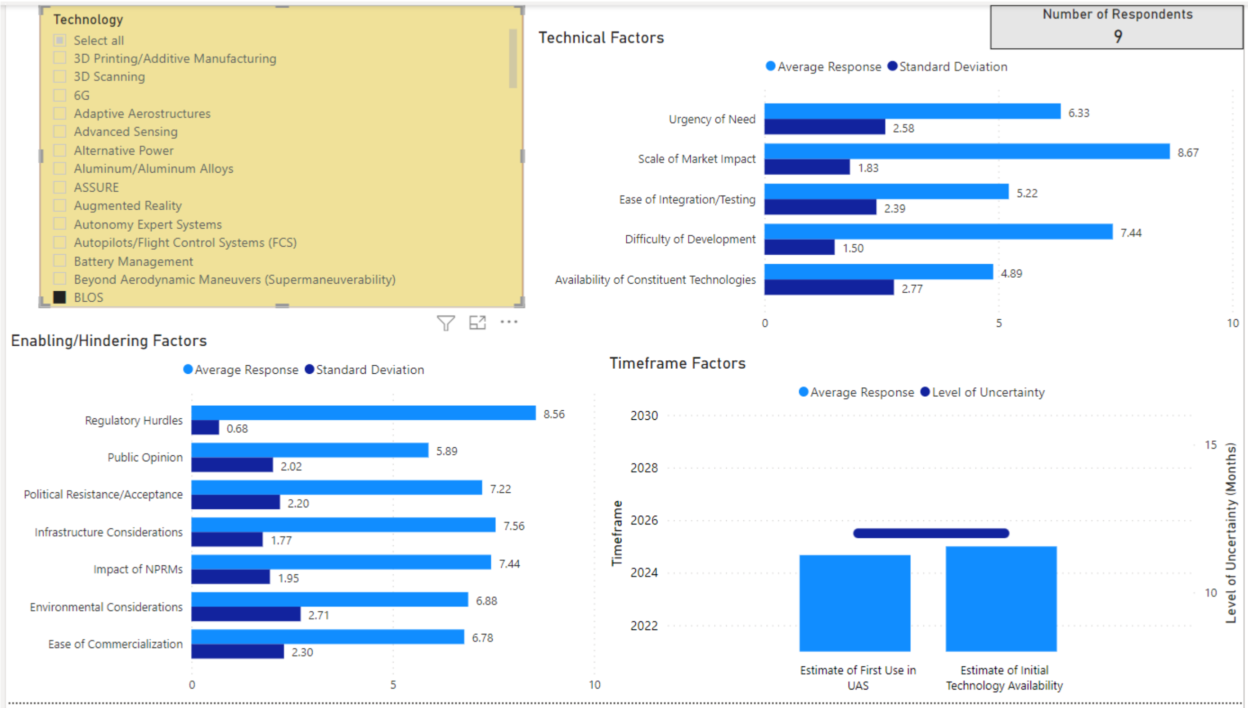

Figure 35. BLOS Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Substantially Concerned About Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2024.67 ± 1
  - **Estimate of Initial Technology Availability:** 2025.00 ± 1

7.14 Brain Control

Brain control is using electroencephalography (EEG) in the operator's brain for flight controls of a drone. the EEG looks for patterns of electricity on the surface of the brain and turns those into commands for the drone. The essential technology component of mind controlled UASs, or unmanned aircraft systems, is the interface: a combination of hardware and algorithms that maps one's brain activation to commands for a robotic system. Using electrodes placed on the scalp to record electrical activity, the non-invasive EEG method measures voltage fluctuations resulting from the neurons' ionic current. The hardware then measures brain activation as the subject thinks about an intended motion for the machine. The algorithms decode those activations to control commands for the robotic system (Hurley, 2017).

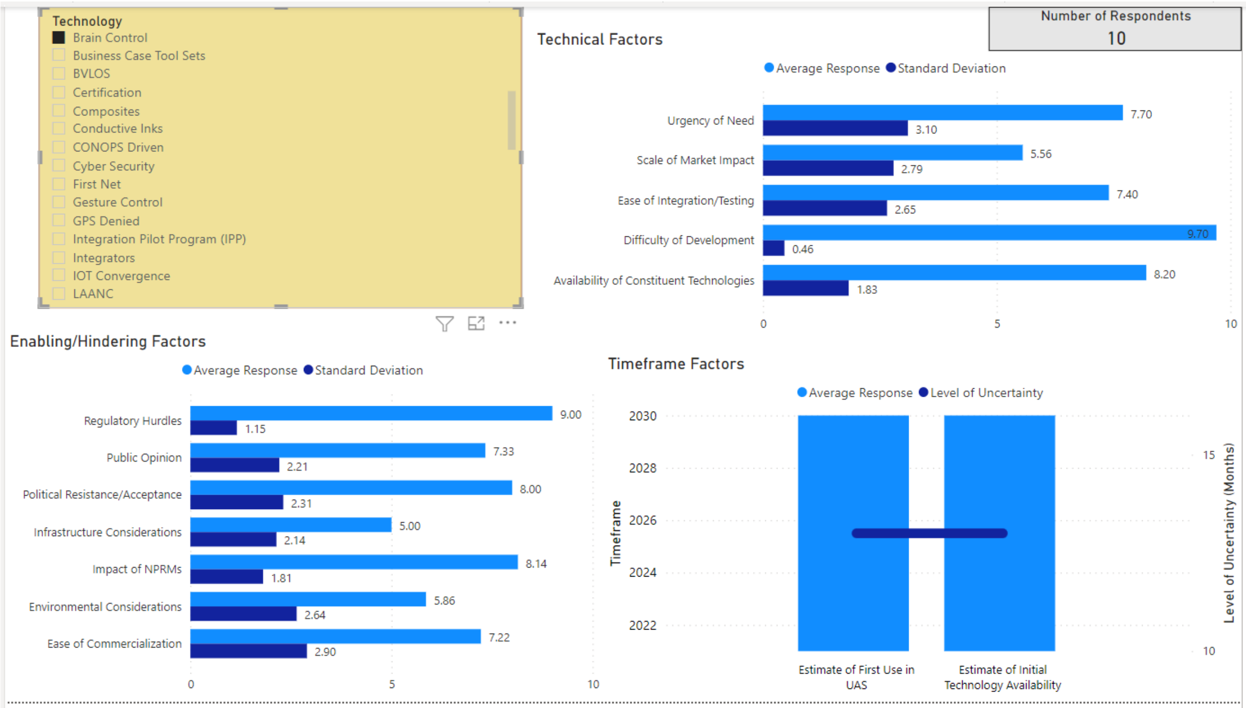

Figure 36. Brain Control Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Extremely Difficult
- **Availability of Constituent Technologies:** Unavailable

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Somewhat Unacceptable
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** High NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2031.00 ± 13/12
  - **Estimate of Initial Technology Availability:** 2031.00 ± 13/12

7.15 Business Case Tool Sets

The global drone market is expected to grow 57.5% by 2028. As businesses develop unique concept of operations (CONOPS) for specific needs, software and hardware developers respond with imaginative toolsets to serve the specific business model. Examples are agricultural and mapping industry specialized sensors and software and applications that enable close-up inspection of objects while avoiding collision (Ward, 2021).

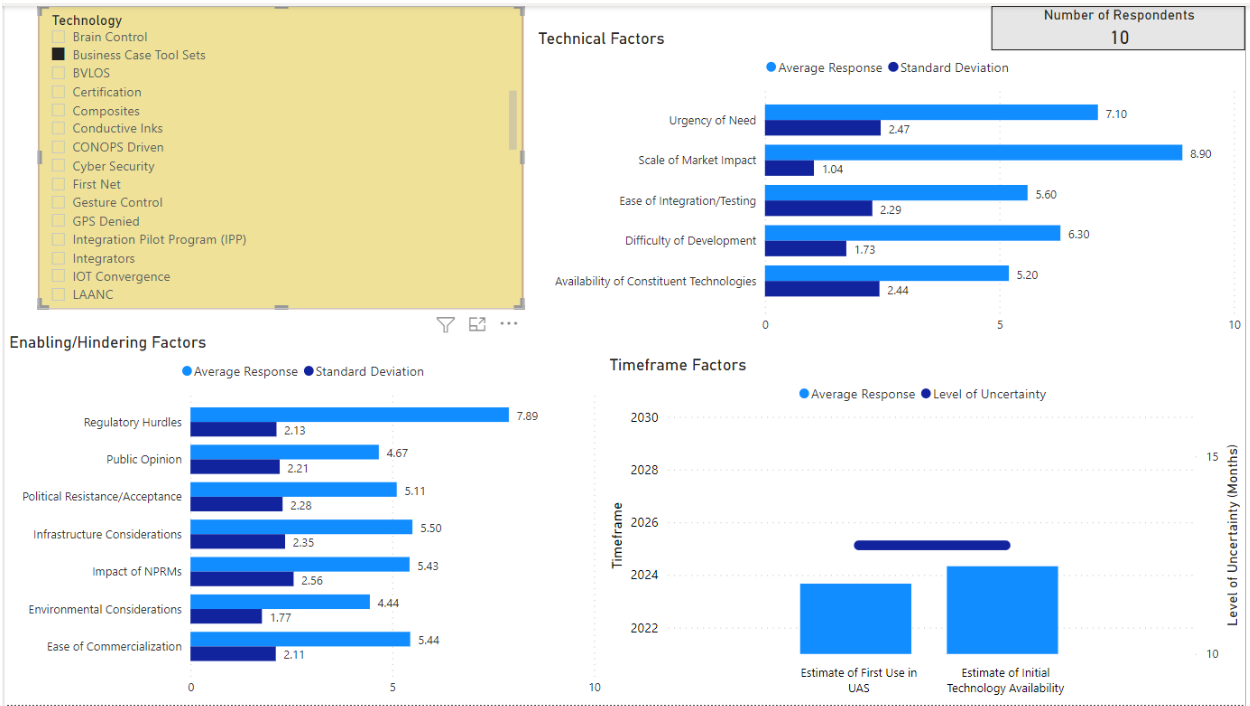

Figure 37. Business Case Tool Sets Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact

- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2023.67 ± 12.75/12
    - **Estimate of Initial Technology Availability:** 2024.33 ± 12.75/12

7.16 BVLOS

Unmanned aircraft flying beyond an operator's visual line-of-sight present unique challenges to the FAA's existing regulatory framework. Most aviation regulations that would apply to UAS operations besides Part 107 assuming the aircraft has an onboard pilot who is responsible for avoiding other aircraft. Not only do UAS lack an onboard pilot, but even a remote pilot pushes the boundaries of the traditional regulatory role of a pilot. However, the UAS capability to fly without the pilot onboard and beyond the pilot's visual line-of-sight is what offers the most economic and societal benefits. Today, companies, communities, and industrial sectors are eager to realize these benefits and have invested substantial resources developing UAS technologies. The FAA's existing regulatory framework must change to better support the long-term viability and sustainability of this evolving aviation sector. However, these are challenges the entire UAS community must confront together, because they have implications not only to safety, but also security and society at large. The FAA recognizes the significant safety, economic, and environmental value associated with BVLOS unmanned aircraft operations. Over the past five years, the FAA has engaged in multiple pilot programs and partnership arrangements – including the UAS Integration Pilot Program (IPP), Partnership for Safety Plans (PSPs), and currently BEYOND – to further both the Agency's and stakeholder community's collective understanding of the minimum performance criteria for safe BVLOS operations. The UAS BVLOS ARC will consider the various lessons and insights gained from these and other activities to inform the FAA on performance-based criteria to enable safe, scalable, economically viable, and environmentally advantageous BVLOS operations in the NAS (U.S. Department of Transportation Federal Aviation Administration, 2021).

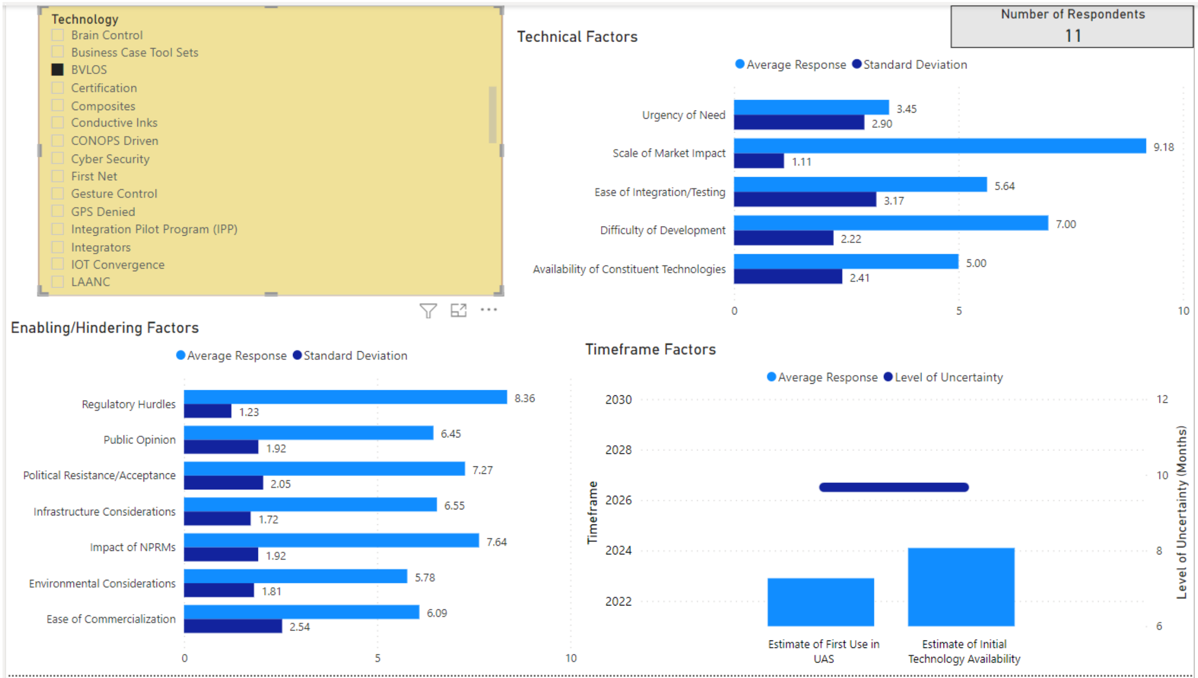

Figure 38. BVLOS Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Somewhat Unacceptable
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2022.90 ± 9.67/12
  - **Estimate of Initial Technology Availability:** 2024.10 ± 9.67/12

7.17 Certification

Certification is the process by which the FAA manages risk through safety assurance. It provides the FAA confidence that a proposed product or operation will meet FAA safety expectations to protect the public. Certification affirms that FAA requirements have been met. 14 CFR Part 21 defines three separate certifications: type, production, and airworthiness.

Type certification is the approval of the design of the aircraft and all component parts (including propellers, engines, control stations, etc.). It signifies the design follows applicable airworthiness, noise, fuel venting, and exhaust emissions standards. The Los Angeles Aircraft Certification Office (ACO) is the main ACO for unmanned aircraft systems (UAS) type certification.

Production certification is the approval to manufacture duplicate products under an FAA-approved type design. It signifies that an organization and its personnel, facilities, and quality system can produce a product or article that conforms to its approved design.

Airworthiness certification is necessary for operation of civil aircraft outside of 14 CFR Part 107 or without an exemption under the Special Authority for Certain Unmanned Systems (U.S.C. 44807). An airworthiness certificate can be either in the Standard or Special class and signifies that an aircraft meets its approved type design (if applicable) and is in a condition for safe operation (Federal Aviation Administration, 2022a).

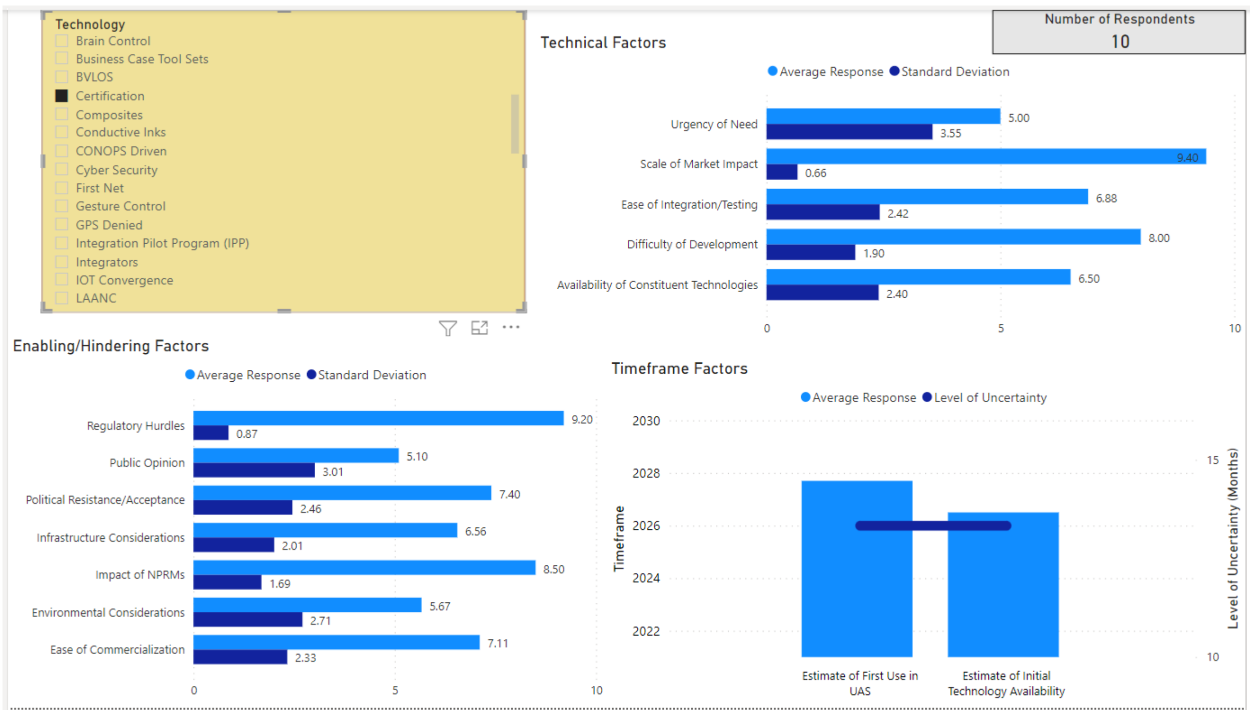

Figure 39. Certification Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns

- **Impact of NPRMs:** High NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2027.70 ± 13.33/12
    - **Estimate of Initial Technology Availability:** 2026.50 ± 13.33/12

7.18 Composites

A composite material (also called a composition material or shortened to composite, which is the common name) is a material which is produced from two or more constituent materials. These constituent materials have notably dissimilar chemical or physical properties and are merged to create a material with properties unlike the individual elements. Within the finished structure, the individual elements remain separate and distinct, distinguishing composites from mixtures and solid solutions. Typical engineered composite materials include (Fazeli et al., 2018):

- Reinforced concrete and masonry

- Composite wood such as plywood

- Reinforced plastics, such as fiber-reinforced polymer or fiberglass

- Ceramic matrix composites (composite ceramic and metal matrices)

- Metal matrix composites and other advanced composite materials

There are various reasons where new material can be favored. Typical examples include materials that are less expensive, lighter, stronger, or more durable when compared with common materials. More recently researchers have also begun to actively include sensing, actuation, computation, and communication into composites, which are known as robotic materials or smart materials.

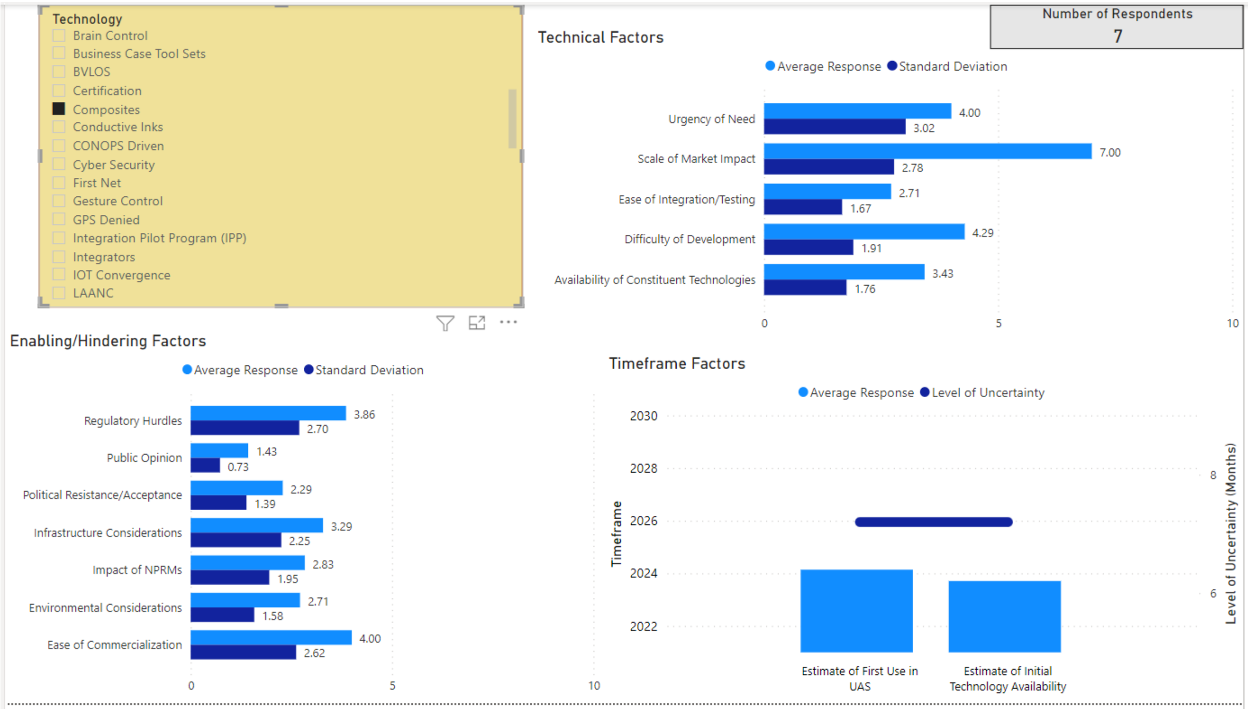

Figure 40. Composites Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Minor Regulatory Hurdles
- **Public Opinion:** Completely Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2024.14 ± 7.2/12
  - **Estimate of Initial Technology Availability:** 2023.71 ± 7.2/12

7.19 Conductive Inks

Conductive ink results in a printed object which conducts electricity. This replaces the need to use wires to create the circuits to power or control a drone. The Ink has the property of providing EMI shielding. Conductive ink can be drop-deposited easily on polyethylene terephthalate film to develop a highly efficient EMI shielding coating that achieves an ultrahigh EMI shielding effectiveness (EMI SE) of 74.5 dB at only 10 µm thickness. At present, the material is not as conductive as traditionally used wiring or copper etched circuit boards (McFadden, 2019).

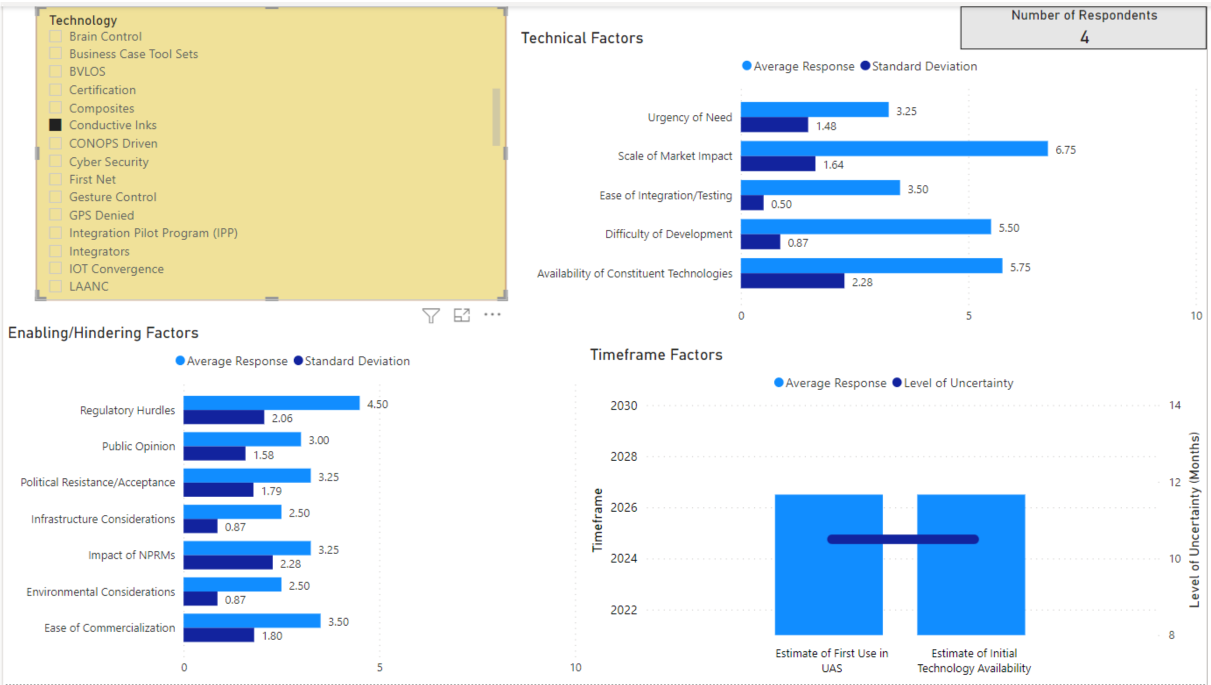

Figure 41. Conductive Inks Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2026.50 ± 10.5/12
    - **Estimate of Initial Technology Availability:** 2026.50 ± 10.5/12

7.20 CONOPS Driven

This category refers to advances in any aspect of UAS technology that is driven by a particular CONOPS (i.e., technology driven by a need). The CONOPS describes a proposed system in terms of the user needs it will fulfill, its relationship to existing systems or procedures, and the way it will be used. The CONOPS is used to obtain consensus among the inquirer, developer, support, and user agencies on the operational concept of a proposed system. Depending on its use, a CONOPS may focus on communicating the user's needs to the developer or the developer's ideas to the user and other interested parties. The term "system" may be interpreted to apply to a portion of a system (MITRE, n.d.).

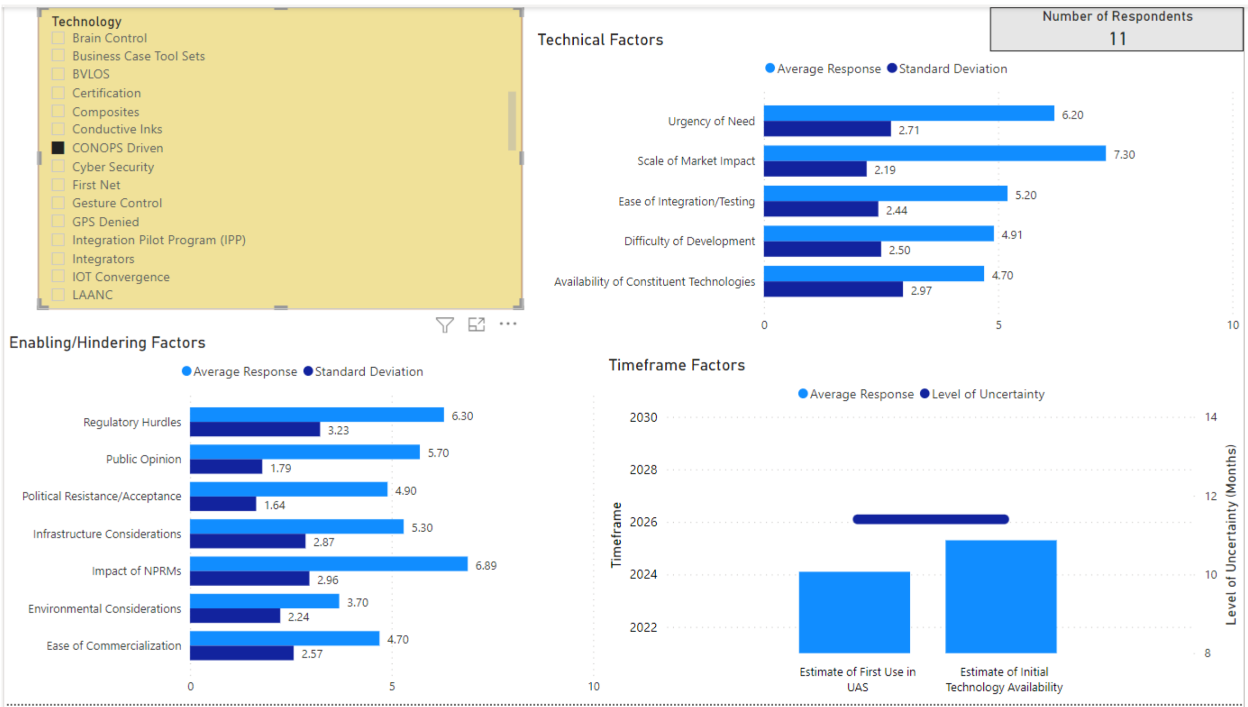

Figure 42. CONOPS-Driven Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2024.10 ± 11.4/12
    - **Estimate of Initial Technology Availability:** 2025.30 ± 11.4/12

7.21 Cyber Security

Cyber security refers to the body of technologies, processes, and practices designed to protect networks, devices, programs, and data from attack, damage, or unauthorized access. Cyber security is important because government, military, corporate, financial, and medical organizations collect, process, and store unprecedented amounts of data on computers and other devices. A significant portion of that data can be sensitive information, whether that be intellectual property, financial data, personal information, or other types of data for which unauthorized access or exposure could have negative consequences. Organizations transmit sensitive data across networks and to other devices while doing businesses, and cyber security describes the discipline dedicated to protecting that information and the systems used to process or store it. As the volume and sophistication of cyber-attacks grow, companies and organizations, especially those that are tasked with safeguarding information relating to national security, health, or financial records, need to take steps to protect their sensitive business and personnel information. As early as March 2013, the nation's top intelligence officials cautioned that cyber-attacks and digital spying are the top threat to national security, eclipsing even terrorism (De Groot, 2020).

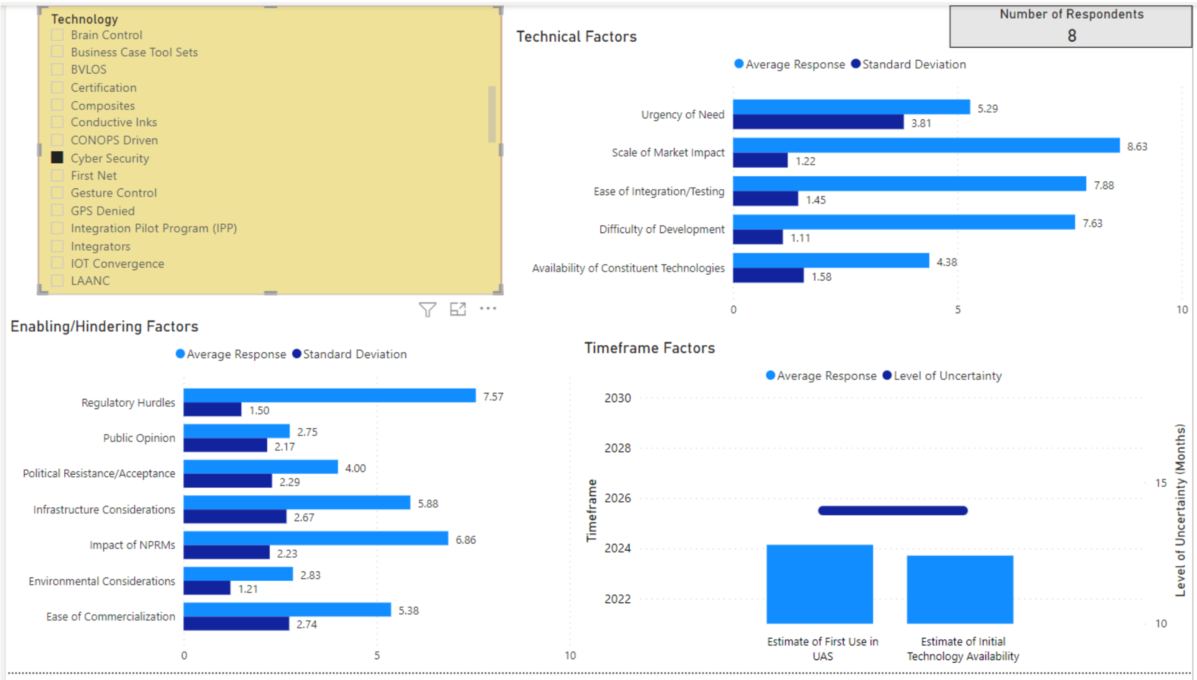

Figure 43. Cyber Security Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult

- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2024.14 ± 14/12
    - **Estimate of Initial Technology Availability:** 2023.71 ± 14/12

7.22 First Net

First Net aims to deploy, operate, maintain, and improve the first high-speed, nationwide, wireless broadband network dedicated to public safety. This reliable, highly secure, interoperable, and innovative public safety communications platform will bring 21st century tools to public safety agencies and first responders, allowing them to get more information quickly and helping them to make faster and better decisions. Due to communications challenges during the response to the 9/11 terrorist attacks, the 9/11 Commission recommended the establishment of a single, interoperable network for public safety. For years, public safety organizations lobbied congress to make this recommendation a reality. Therefore, when congress established the First Responder Network Authority (FirstNet) in 2012, missions were based on expressed public safety concerns and desires. To truly design the FirstNet network for public safety by public safety – a distinction that makes it unique in American telecommunications history – FirstNet continuously consults with local, state/territory, tribal and federal public safety agencies across the country. Over the past several years, FirstNet has collaborated with public safety stakeholders and leadership from each state and territory. Never before has the public safety community had the opportunity to provide input towards the creation of a nationwide broadband network tailored specifically to meet their needs as they save lives and protect communities across the nation (AT&T, n.d.).

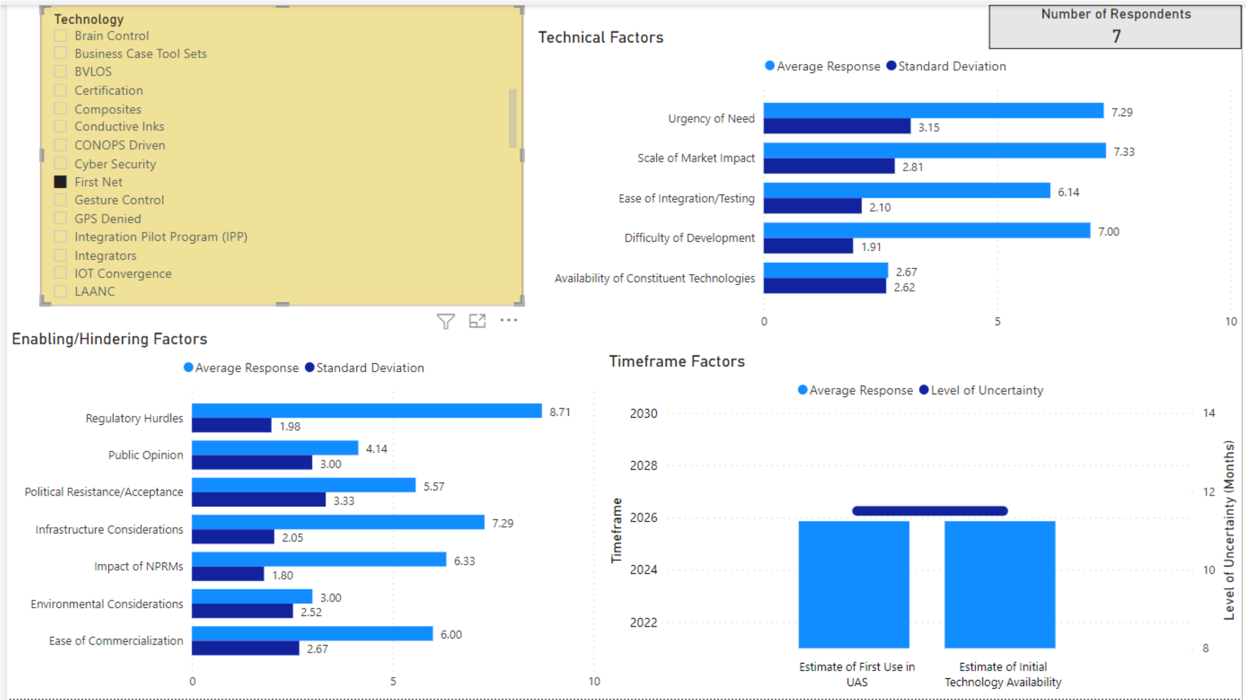

Figure 44. First Net Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2025.86 ± 11.5/12
    - **Estimate of Initial Technology Availability:** 2025.86 ± 11.5/12

7.23 Gesture Control

Gesture control is the use of hand and muscle movements to create flight command inputs. MIT's Computer Science and Artificial Intelligence Lab (CSAIL) has released a video of their ongoing work using input from muscle signals to control devices. Their research involves full and fine control of drones, using just hand and arm gestures to navigate through a series of rings. This work is impressive not just because they're using biofeedback to control the devices instead of optical or other kinds of gesture recognition, but also because of how specific the controls can be, setting up a range of different potential applications for this kind of remote tech (Etherington, 2020).

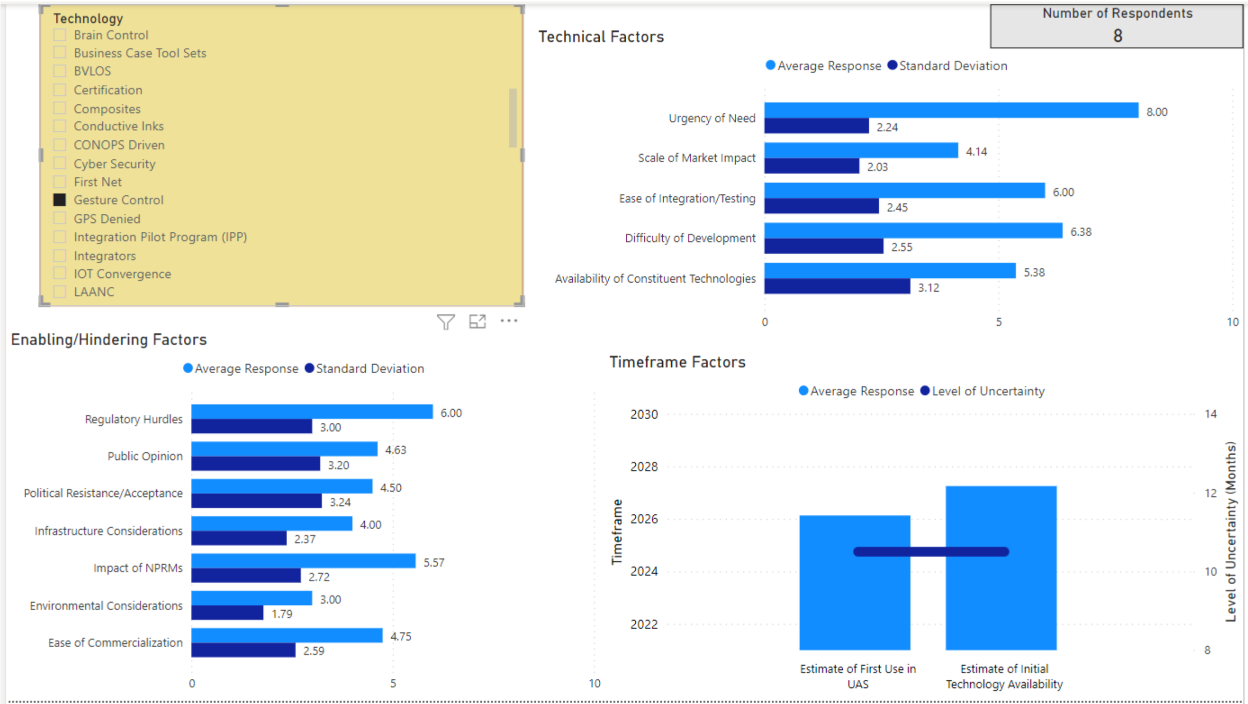

Figure 45. Gesture Control Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2026.13 ± 10.5/12
  - **Estimate of Initial Technology Availability:** 2027.25 ± 10.5/12

7.24 GPS Denied

Drones typically orient themselves using GPS, which helps keep them stable while in flight, hover in place, and ensures they don't fly above the 400-foot ceiling required by the FAA's Part 107 rules. But if one is flying in a mine—or in a variety of other scenarios, a GPS signal may simply not be available. Systems that lose access to GPS signals are referred to as "GPS Denied." Some situations that call for GPS-denied drones include:

- Indoor inspections. When flying inside of assets like huge oil storage tanks or industrial boilers, accessing GPS may be hard, if not impossible.

- Mining. Mines present the same kinds of challenges for GPS as flying inside huge above-ground assets—the signal just doesn't reach.

- Bridge inspections. Flying near or under a metal bridge can interfere with your drone's ability to connect to GPS.

- Critical infrastructure. Some governmental agencies may prefer to use a drone that doesn't rely on GPS near critical infrastructure, such as military bases or power plants, due to an apparent misperception that GPS is vulnerable to security risks. Although GPS does not rely on an external connection and therefore this concern seems to be unfounded, security risks do linger for some who oversee sensitive sites.

- Search and rescue. When looking for a missing person in a forest, the GPS signal can weaken if the drone is required to operate under tree cover. Similar considerations apply for other natural obstructions you might encounter while on a Search and Rescue mission.

- Surveying disaster sites. Rubble and other obstructions may get in the way of a GPS signal when operating at a disaster site.

GPS denied drones fly by using sensors and images and inertial real-time kinematic (RTK) systems instead of GPS information to navigate. Onboard visual sensors can help stabilize a drone while in flight, and obstacle avoidance sensors can provide a drone with reference points, allowing it to hover in place without GPS. These sensors can help the drone to determine key information for staying stable and in the air, including altitude, location, and tilt (Dukowitz, 2020).

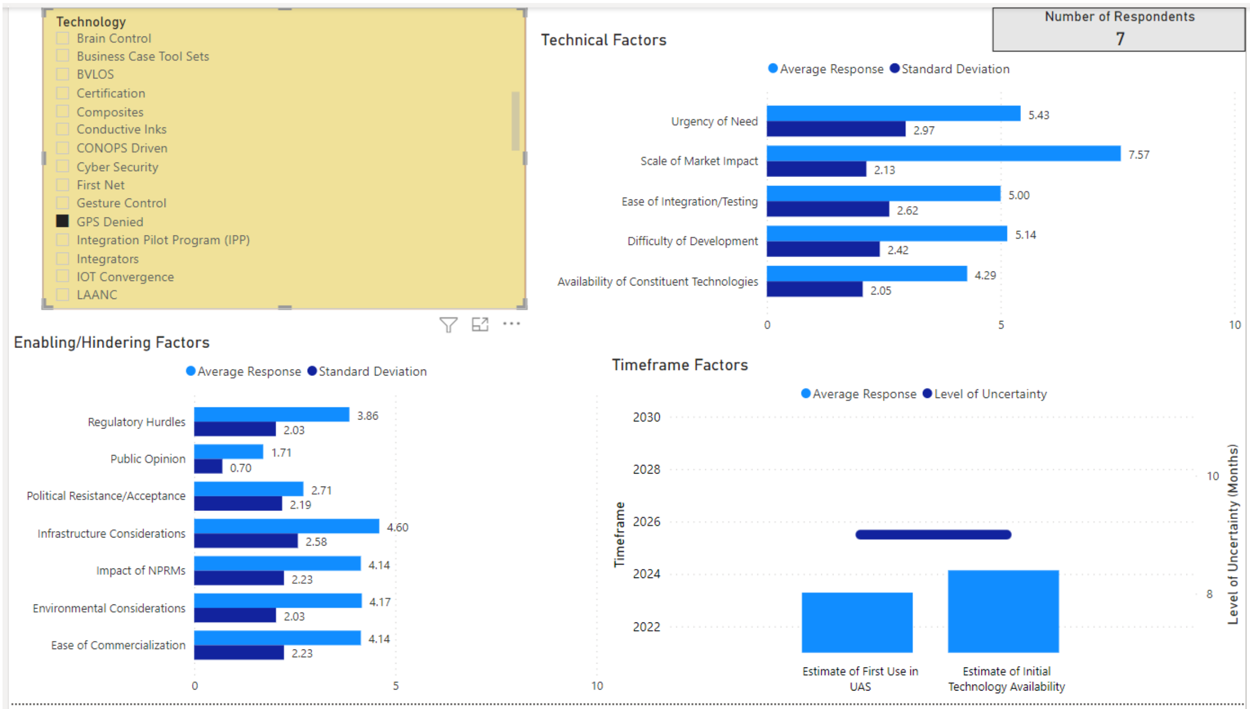

Figure 46. GPS Denied Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Minor Regulatory Hurdles
- **Public Opinion:** Completely Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2023.29 ± 9/12
  - **Estimate of Initial Technology Availability:** 2024.14 ± 9/12

7.25 Integration Pilot Program (IPP)/Beyond

Since it began in 2017, the UAS Integration Pilot Program has brought state, local, and tribal governments together with private sector entities, such as drone operators and manufacturers, to accelerate safe drone integration. The overarching goal of the IPP is to help the U.S. Department of Transportation and the FAA craft new rules, policies, and guidance that support more complex low-altitude operations. Specifically, the program is outlined in (Federal Aviation Administration, 2020) as:

- Identifying ways to balance local and national interests related to drone integration
- Improving communications with local, state, and tribal jurisdictions
- Addressing security and privacy risks
- Accelerating the approval of operations that currently require special authorizations
- Engaging people where they live and work to understand community sentiment.

In November 2017, the FAA solicited applications from state, local and tribal governments to participate in the IPP for a three-year period. Those entities enlisted the help of industry, academic, and other government partners to support their proposed operations. In May 2018, the agency selected 10 lead participants from 149 applications submitted, to represent a variety of operations, geographic locations and government partners. The IPP lead participants conducted their first operations in August and September 2018 and have achieved many successful milestones since then. The state, local and tribal governments have all worked closely with their industry partners to tackle challenges to safe and secure integration, including night operations, flights over people, operations beyond the pilot's line of sight, package delivery, detect-and-avoid technologies, remote identification and the reliability and security of data links between pilot and aircraft. Data the FAA has collected during the program will help inform future policy, guidance, and rulemaking. It already has influenced current and future activities in the areas of package delivery, emergency management, disaster damage assessment, agricultural support, and infrastructure inspections. One of the IPP’s objectives is to determine community acceptance of drones operating near neighborhoods and businesses. Many of the lead participants are conducting surveys to gauge community sentiment, and all of them have engaged their communities through public meetings, briefings, website updates and traditional and social media. Overall, the response has been generally positive. Most of the technical data the Lead Participants have collected in their IPP flights relates to how well their drones perform compared to original plans. The data includes information about flight paths, communications connectivity, and any deviations from original plans. Once the participants collect and report the data, the FAA will be able to see how well their risk mitigations worked. This information is vital to developing future FAA regulations and guidance on safe and secure drone use. The IPP concluded in October of 2020 and is now referred to as the BEYOND program. The data in the preceding section is utilized to make judgement on the BEYOND program.

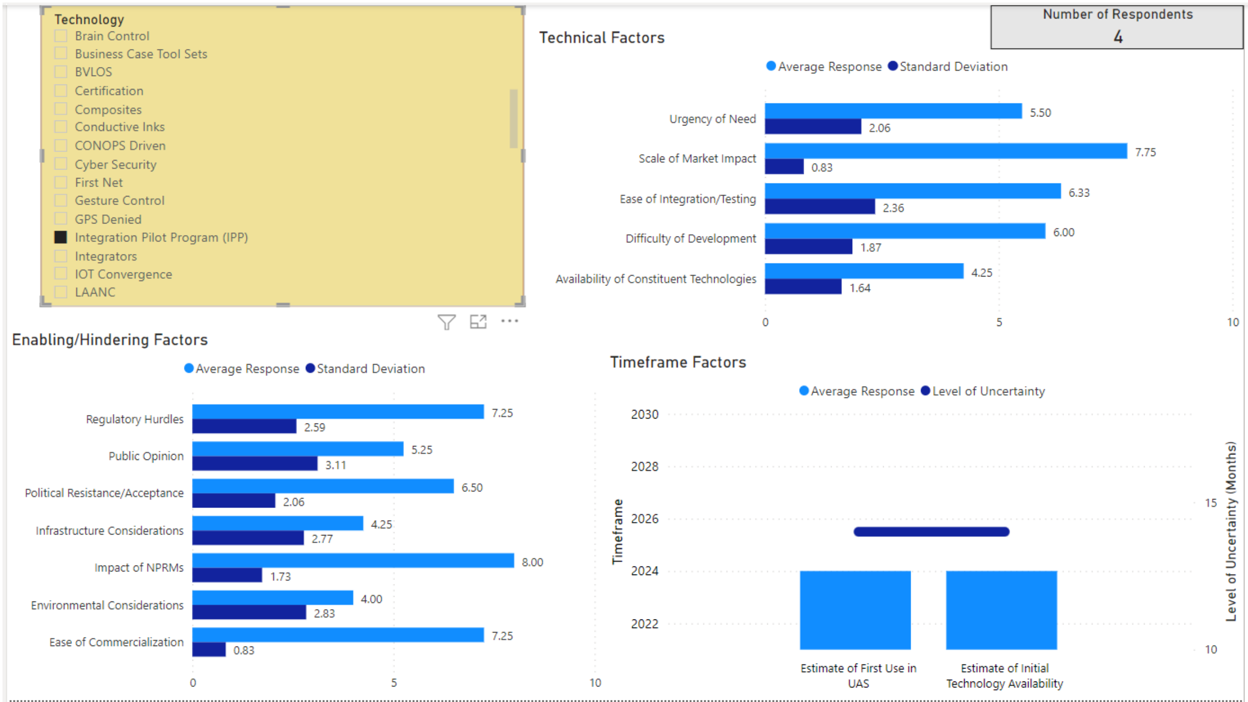

Figure 47. IPP/BEYOND Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Significant Commercialization Challenges

7.26 Integrators

UASs are complex systems of hardware, software, firmware, and procedures. The system also includes interfaces to human operators and external sources of information, such as communications data, navigation data, and imagery. As these systems become ever more complex, the function of integrators will be more relevant to their integration into the NAS. Integrators might include both the intellectual effort of systems integration specialists as well as software programs and hardware devices that enable the integration process. Systems integrators specialize in comprehending available technologies and delivering combinations of them, sometimes including custom engineering, to provide a complete (but often non-reusable) turnkey solution for a manufacturer's specific need (Cazaurang, 2020).

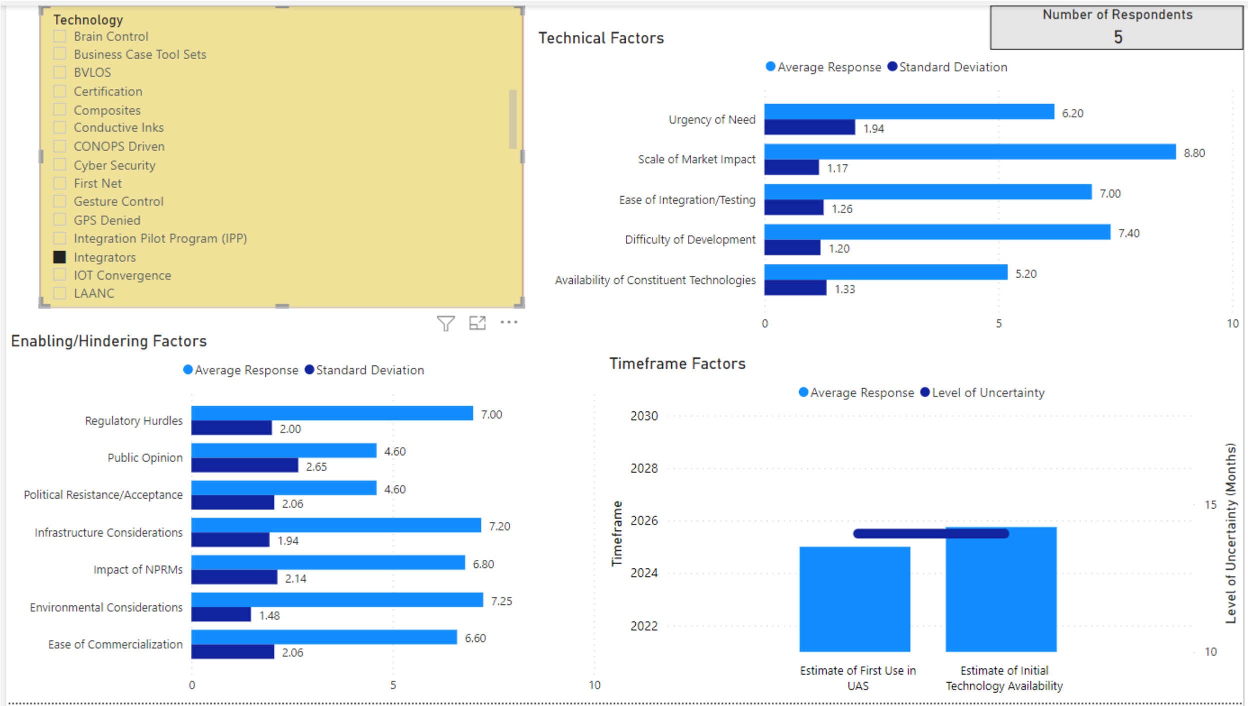

Figure 48. Integrators Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Substantially Concerned About Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2025.00 ± 14/12
    - **Estimate of Initial Technology Availability:** 2025.75 ± 14/12

7.27 IOT Convergence

The next big leap in the Internet of Things (IOT) evolution will be the coherence of efforts on all levels towards innovation. In case of the IoT community this would mean that out of many possible “coherence horizons” the following will likely provide the foundation for a step forward:

• Coherence of object capabilities and behavior: the objects in the Internet of Things will show a huge variety in sensing and actuation capabilities, in information processing functionality and their time of existence. In either case it will be necessary to generally apprehend object as entities with a growing “intelligence” and patterns of autonomous behavior (Vermesan & Friess, 2013).

• Coherence of application interactivity: the applications will increase in complexity and modularization, and boundaries between applications and services will be blurred to a high degree. Fixed programmed suites will evolve into dynamic and learning application packages. Besides technical, semantic interoperability will become the key for context aware information exchange and processing.

• Coherence of corresponding technology approaches: larger concepts like smart cities, cloud computing, future internet, robotics, and others will evolve in their own way, but because of complementarity also partly merge with the Internet of Things. Here a creative view on potential synergies can help to develop new ecosystems.

• Coherence of real and virtual worlds: today real and virtual worlds are perceived as two antagonistic concepts. At the same time virtual worlds grow exponentially with the amount of stored data and ever-increasing network and information processing capabilities. Understanding both paradigms as complementary and part of human evolution could lead to new synergies and exploration of living worlds.

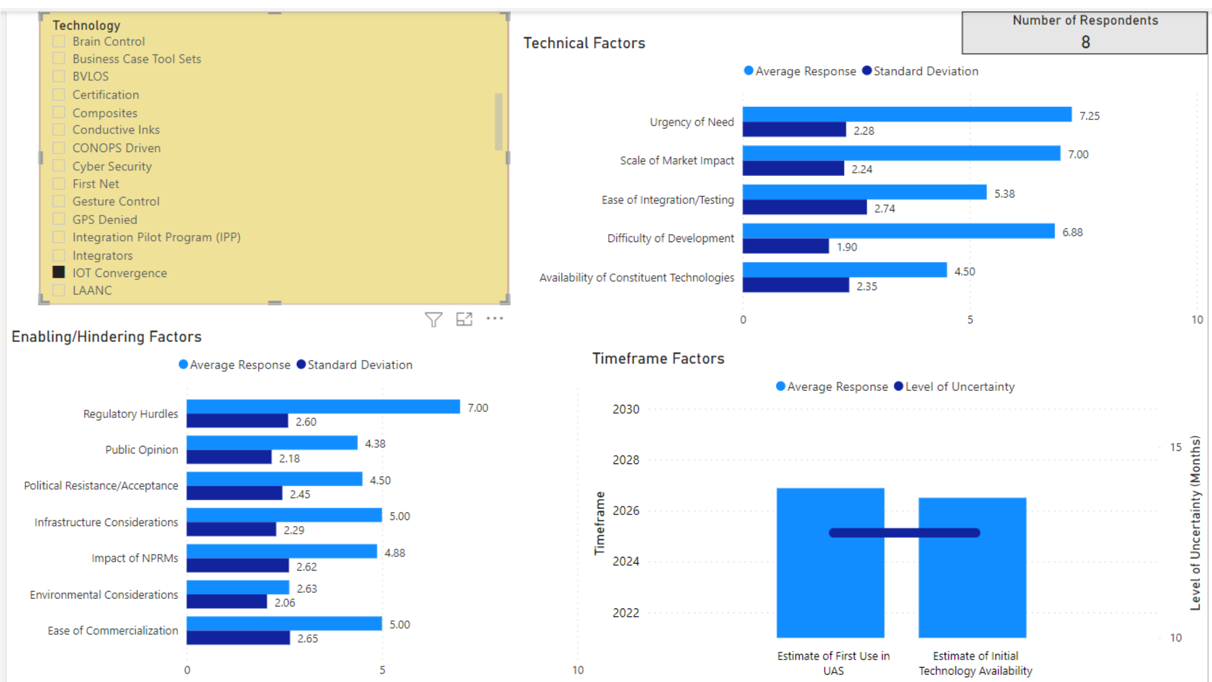

Figure 49. IOT Convergence Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2026.88 ± 12.75/12
  - **Estimate of Initial Technology Availability:** 2026.50 ± 12.75/12

7.28 LAANC

The FAA UAS Data Exchange is an innovative, collaborative approach between government and private industry facilitating the sharing of airspace data between the two parties. Under the FAA UAS Data Exchange umbrella, the agency will support multiple partnerships, the first of which is the LAANC. LAANC is the Low Altitude Authorization and Notification Capability, a collaboration between FAA and Industry. It directly supports UAS integration into the airspace. LAANC provides:

- Drone pilots with access to controlled airspace at or below 400 feet.

- Awareness of where pilots can and cannot fly.

- Air traffic professionals with visibility into where and when drones are operating.

- Through the UAS Data Exchange, the capability facilitates the sharing of airspace data between the FAA and companies approved by the FAA to provide LAANC services. The companies are known as UAS Service Suppliers — and the desktop applications and mobile apps to utilize the LAANC capability are provided by the UAS Service Suppliers (USS) (Federal Aviation Administration, 2022c).

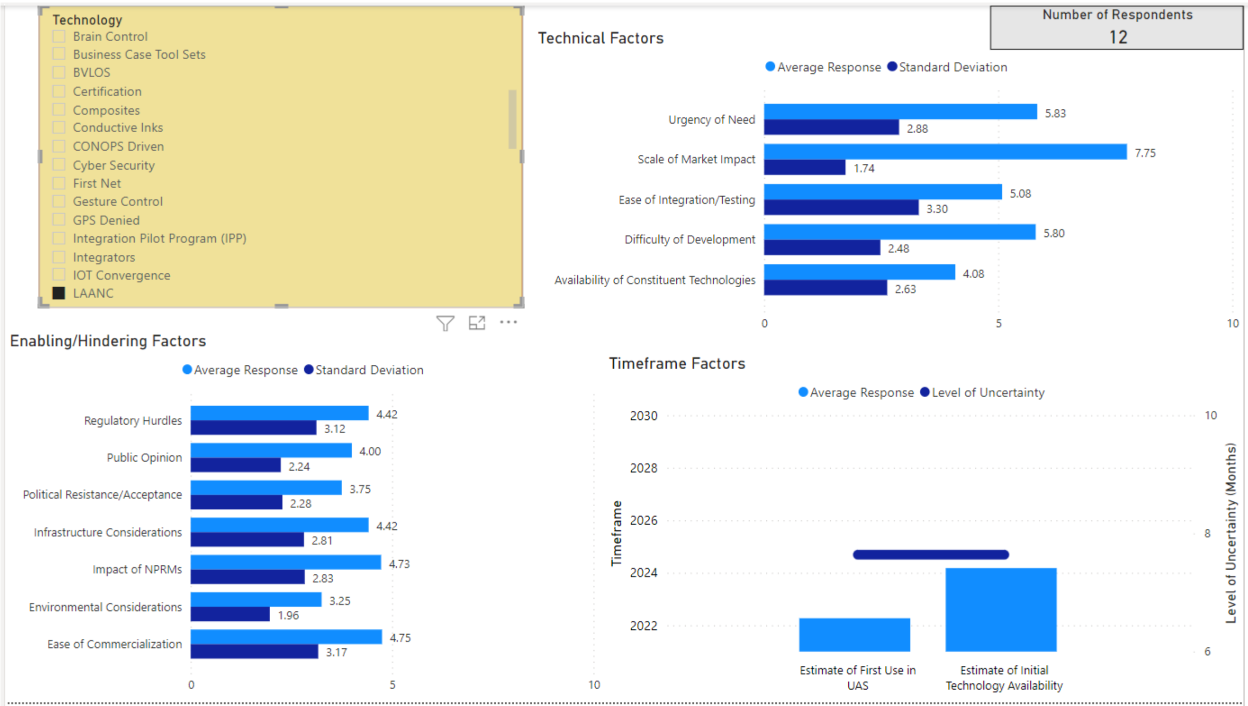

Figure 50. LAANC Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderately Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

7.29 Live Map

Live Map is a tool for creating maps while a drone is still flying so one can act immediately. Live Map is a real-time mapping product available as part of DroneDeploy's mobile iOS app. With Live Map, one can produce a low-resolution 2D map on your iOS device as the drone is flying - even without a cellular or data connection. The entire workflow is on your mobile device. This feature is available to all paying customers. During the mission, Live Map will use the live video feed from your drone to populate a map as the drone flies each leg of the mission. Once the flight is completed, one will be able to see the Live Map icon on the dashboard, while offline, and review the 2D map layers (B., 2022).

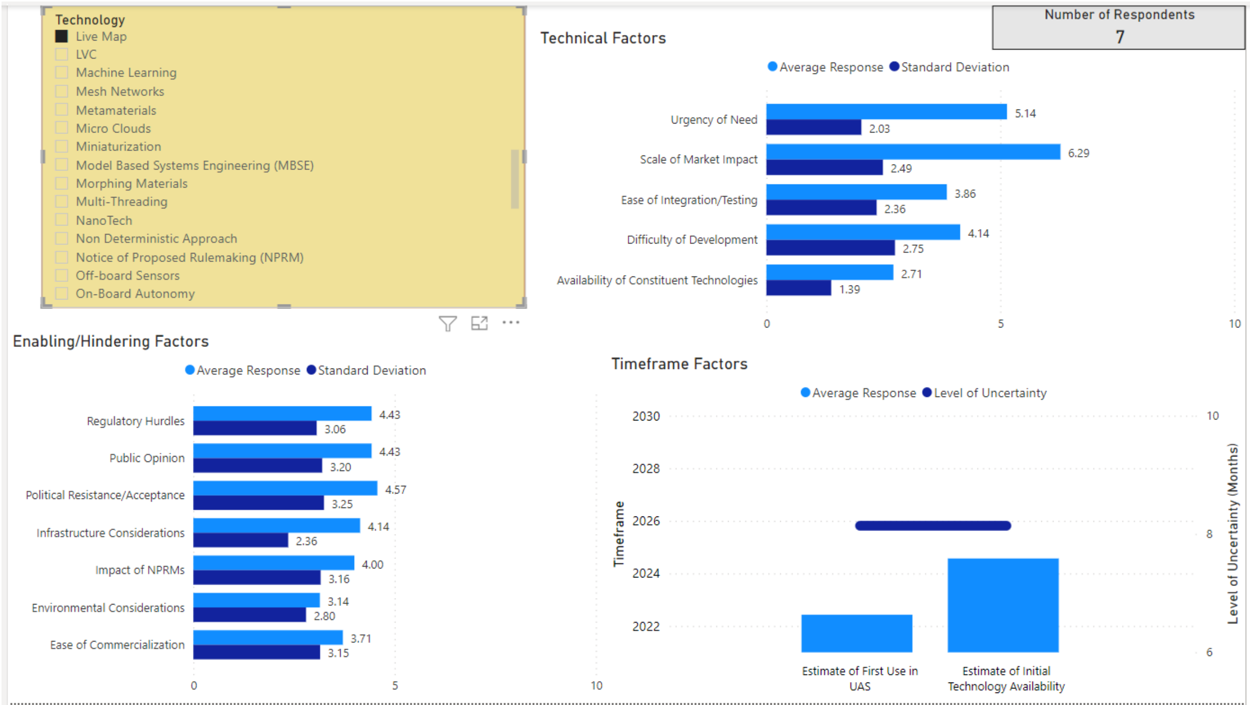

Figure 51. Live Map Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2022.43 ± 8.14/12
  - **Estimate of Initial Technology Availability:** 2024.57 ± 8.14/12

7.30 LVC

LVC or Live, Virtual, & Constructive Simulation is a broadly used taxonomy for classifying models and simulation. LVC is being used by the military for more comprehensive training of UAVs. It simulates flight data which creates the feeling of flying a UAV, therefore, reducing costs while developing more competent pilots. NASA's Unmanned Aircraft Systems Integration in the

National Airspace System Project is conducting human in the loop simulations and flight testing intended to reduce barriers associated with enabling routine airspace access for unmanned aircraft. The primary focus of these tests is interaction between the unmanned aircraft pilot and the display of detect and avoid alerting and guidance information. The project's integrated test and evaluation team was charged with developing the test infrastructure. As with any development effort, compromises in the underlying system architecture and design were made to allow for the rapid prototyping and open-ended nature of the research. In order to accommodate these design choices, a distributed test environment was developed incorporating LVC concepts. The LVC components form the core infrastructure support simulation of UAS operations by integrating live and virtual aircraft in a realistic air traffic environment. This LVC infrastructure enables efficient testing by leveraging the use of existing assets distributed across multiple NASA centers. The use of standard LVC concepts enable future integration with existing simulation infrastructure (Otto, 2018).

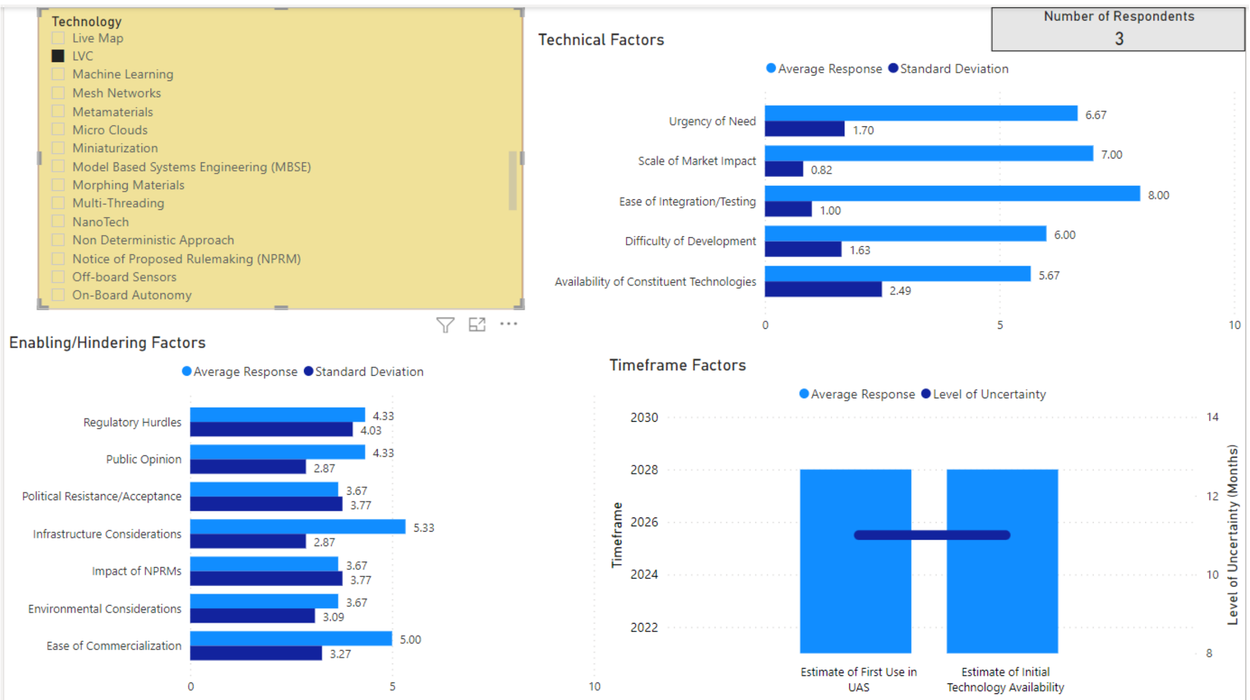

Figure 52. LVC Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact

- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2028.00 ± 11/12
    - **Estimate of Initial Technology Availability:** 2028.00 ± 11/12

7.31 Machine Learning

Machine learning will take existing drones to even greater heights. There are already extremely useful tools for observing our surroundings, but machine learning will allow drones to perceive and interpret their surroundings. Here are three major ways machine learning is already enabling change:

1) Improving Pattern Recognition for Automated Inspections - Machine learning gives drones pattern recognition abilities. With programming and the right cameras and sensor equipment, UAS can safely, efficiently, and even automatically provide ongoing and detailed inspections for large construction and infrastructure projects.

2) Optimizing and Planning Construction Site Activities - Using machine learning and trained models, construction drones could monitor all a construction site's operations. They'll be able to "understand" how the site changes daily and over the course of the project, deliver cost and timeline projections and help optimize the order and way tasks are completed.

3) Predicting and Interdicting Poaching and Other Crimes - For example, the Lindbergh Foundation and a drone technology company called Neurala has an ongoing partnership to fight elephant poaching in Africa. Neurala's software is powered by machine learning and can process in 20 minutes equivalent surveillance footage that would take days or hours with previous-generation technology. In the fight against poaching, the implication is that these "air shepherds" can automatically patrol vast amounts of natural landscape with very little guidance. Therefore, identifying poaching activities early. Additionally, this level of intelligence is useful for finding and predicting the movements of protected animal populations or those with research potential (Folk, n.d.).

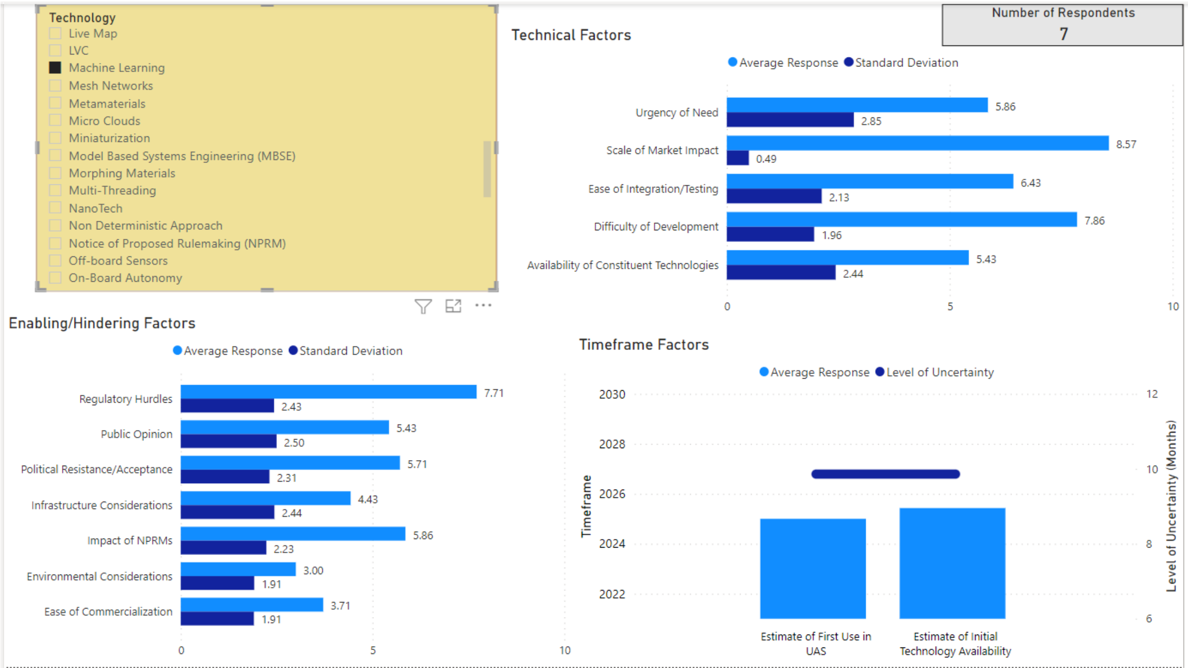

Figure 53. Machine Learning Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2025.00 ± 9.86/12
  - **Estimate of Initial Technology Availability:** 2025.43 ± 9.86/12

7.32 Mesh Networks

Operating in remote areas can present challenges in communications. In areas with weak or non-existing communication networks, large changes in elevation, or obstacles one must look for other purposes of establishing communications. In locations with no towers, drones can be used to set up temporary communication networks. However, the limited flight time of drones denies prolonged operations. A drone tethering system provides a solution to this limitation. The tethered drone system uses an intelligent winch system that powers the drone from the ground. This allows the drone to stay airborne for extended periods of time as the system is no longer reliant on a battery charge. Mesh networks can be used to quickly establish a multi-node grid using drones. These systems allow for the distribution of flight data as well as video stream to a ground control station operator from multiple drone operators in the field (UgCS, n.d.).

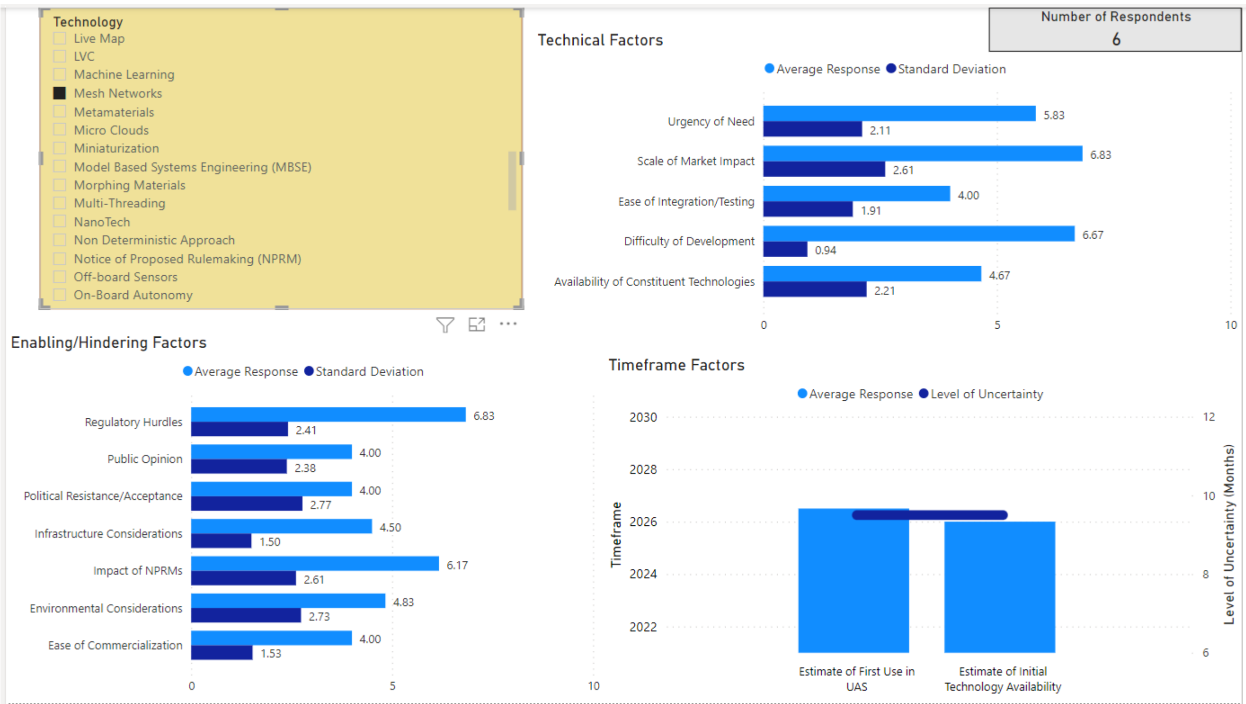

Figure 54. Mesh Networks Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Impact
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2026.50 ± 9.5/12
    - **Estimate of Initial Technology Availability:** 2026.00 ± 9.5/12

7.33 Metamaterials

A metamaterial is any material engineered to have a property that is not found in naturally occurring materials. They are made from assemblies of multiple elements fashioned from composites, metals, and plastics. The materials are usually arranged in repeating patterns, at scales that are smaller than the wavelengths of the phenomena they influence. Metamaterials derive their properties not from the properties of the base materials, but from their newly designed structures. Their precise shape, geometry, size, orientation, and arrangement gives them their smart properties capable of manipulating electromagnetic waves: by blocking, absorbing, enhancing, or bending waves, to achieve benefits that go beyond what is possible with conventional materials. Appropriately designed metamaterials can affect waves of electromagnetic radiation or sound in a manner not observed in bulk materials. Those that exhibit a negative index of refraction for specific wavelengths have been the focus of a large amount of research. These materials are known as negative-index metamaterials. Potential applications of metamaterials are diverse and include optical filters, medical devices, remote aerospace applications, sensor detection and infrastructure monitoring, smart solar power management, crowd control, high-frequency battlefield communication and lenses for high-gain antennas, improving ultrasonic sensors, and even shielding structures from earthquakes (Nader et al., 2006), (Research Group of David R. Smith, 2006), and (Smith, 2001).

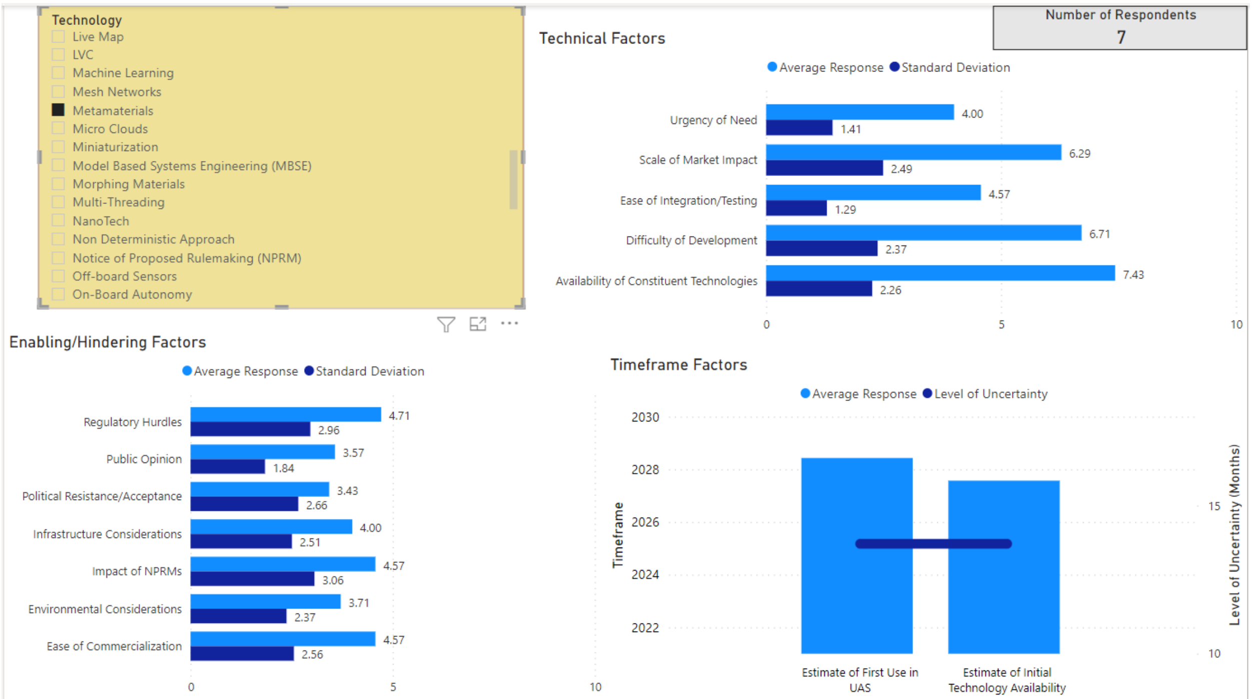

Figure 55. Metamaterials Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult

- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2028.43 ± 13.71/12
  - **Estimate of Initial Technology Availability:** 2027.57 ± 13.71/12

7.34 Micro Clouds

Today's predominantly centralized cloud services that are in remote datacenters will evolve. Our expectation is that it will be necessary for local cloud-like infrastructures to be established to facilitate communication between sensors and other devices. For example, cars will "talk" to each other when they are in close proximity, creating dynamic local transient clouds – perhaps for safety reasons or to exchange other data (road conditions, traffic density, alerts and the like). These transient clouds will exhibit autonomous swarm-like behavior. These local "micro clouds" are likely to have some form of gateway to the centralized cloud. Therefore, some processing tasks will take place locally, whilst others will make more sense to do centrally on aggregated data. This will enable scalable infrastructures. The UAH research team believes the IoT gateway will require additional features such as enhanced processing power. Additionally, by leveraging concepts from software-defined networking micro clouds can be governed by a set of logical controllers. This will allow them to host virtualized computing functions and assist a set of objects in mutual operation and cooperation. This will create autonomous systems that constitute the IoT applications. The Micro Cloud must provide a means to protect data against unintended use. IoT Micro Clouds can help to implement effective monitoring and secure software lifecycle management. The rise of this concept is dependent largely on how quickly a standard for IoT devices emerges. IoT devices are built with the intention of being inexpensive and long-lasting; it may not be practical to perform system updates and patching (Smith, 2017).

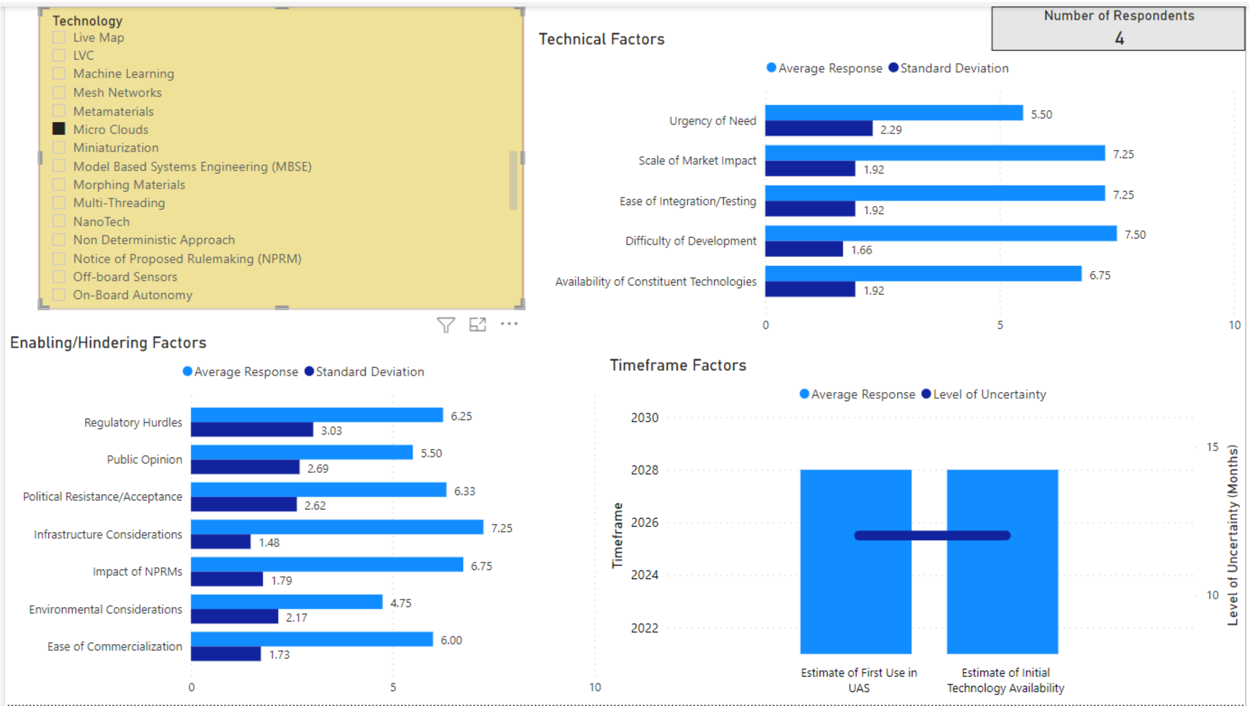

Figure 56. Micro Clouds Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2028.00 ± 1
  - **Estimate of Initial Technology Availability:** 2028.00 ± 1

7.35 Miniaturization

Miniaturization became a trend in the last fifty years and came to cover not just electronic but also mechanical devices. By 2004, electronic companies were producing silicon integrated circuit chips with switching MOS transistors that had feature size as small as 130 nanometers (nm) and development was also underway for chips that are merely few nanometers in size through the nanotechnology initiative. The focus is to make components smaller to increase the number of chips that can be integrated into a single wafer. This requires critical innovations including increasing wafer size, development of sophisticated metal connections between the chip's circuits, and improvement in the polymers used for masks (photoresists) in the photolithography processes. These last two innovation areas are where miniaturization has moved into the nanometer range. Miniaturization in electronics is advancing rapidly due to the comparative ease in miniaturizing electrical devices. The process for mechanical devices, however, is more complex due to the change in structural properties of parts as they shrink. It is said that the so-called Third Industrial Revolution is based on economically viable technologies that can shrink three-dimensional objects (Ghosh, 2015), (Guston, 2010), (Jha, 2004), and (Van Riper, 2002).

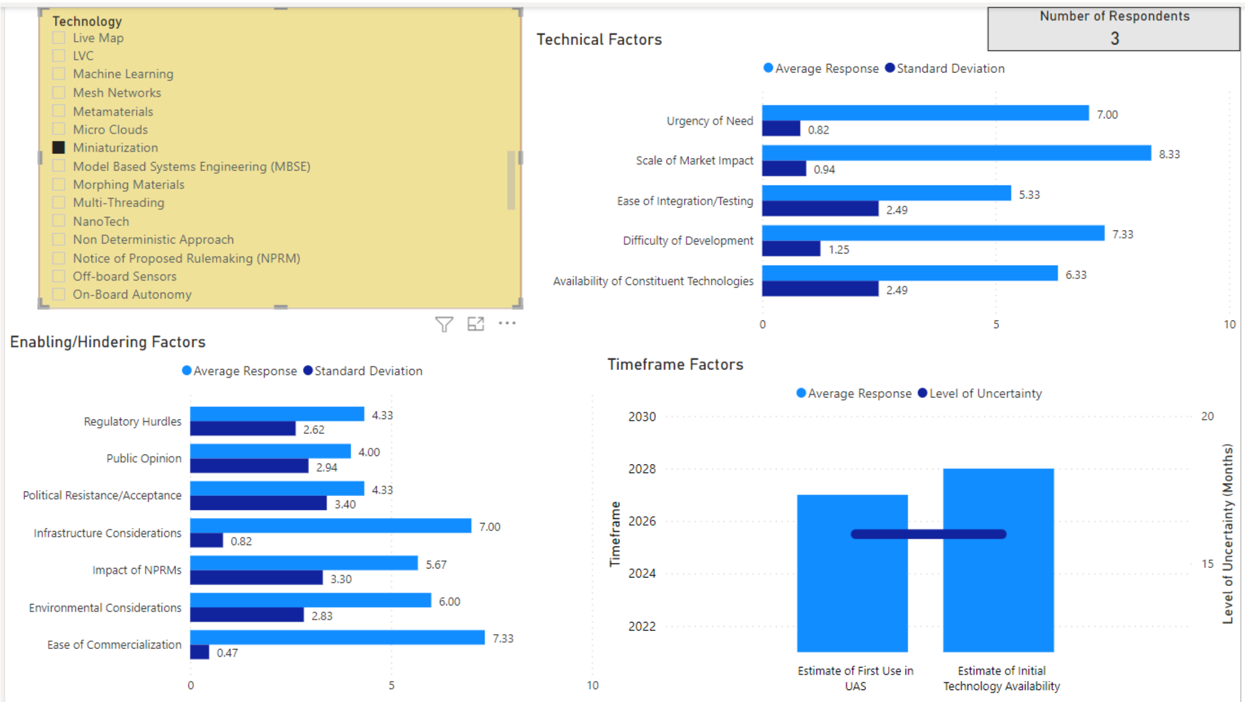

Figure 57. Miniaturization Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):

- **Estimated First Use in UAS:** 2027.00 ± 16/12
- **Estimate of Initial Technology Availability:** 2028.00 ± 16/12

7.36 Model Based Systems Engineering (MBSE)

MBSE or model-based system engineering is performed during the design process to ensure issues do not arise during development. This allows proper data flow, control flow, and component-level reliability properties. A tool recently developed for MBSE is SysML, or Systems Modeling Language. It supports the specification, analysis, design, verification, and validation of a broad range of systems and systems-of-systems. The goal of MBSE in UAS is to allow for seamless creation of new drones without issues arising during development (Steurer et al. 2018).

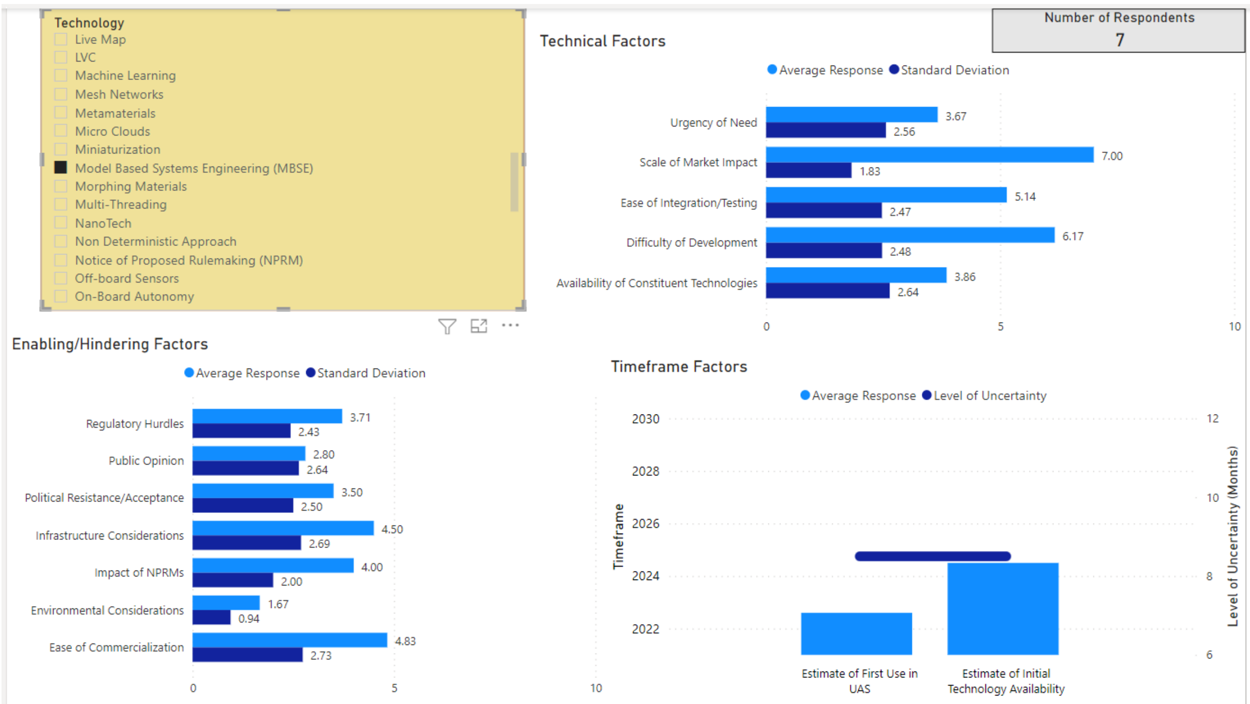

Figure 58. MBSE Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Minor Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Little to No Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2022.60 ± 8.5/12
  - **Estimate of Initial Technology Availability:** 2024.50 ± 8.5/12

7.37 Morphing Materials

Shape-changing materials open an entirely new solution space for a wide range of disciplines: from architecture that responds to the environment and medical devices that unpack inside the body, to passive sensors and novel robotic actuators. While synthetic shape-changing materials are still in their infancy, studies of biological morphing materials have revealed key paradigms and features which underlie efficient natural shape-change (Oliver et al., 2016).

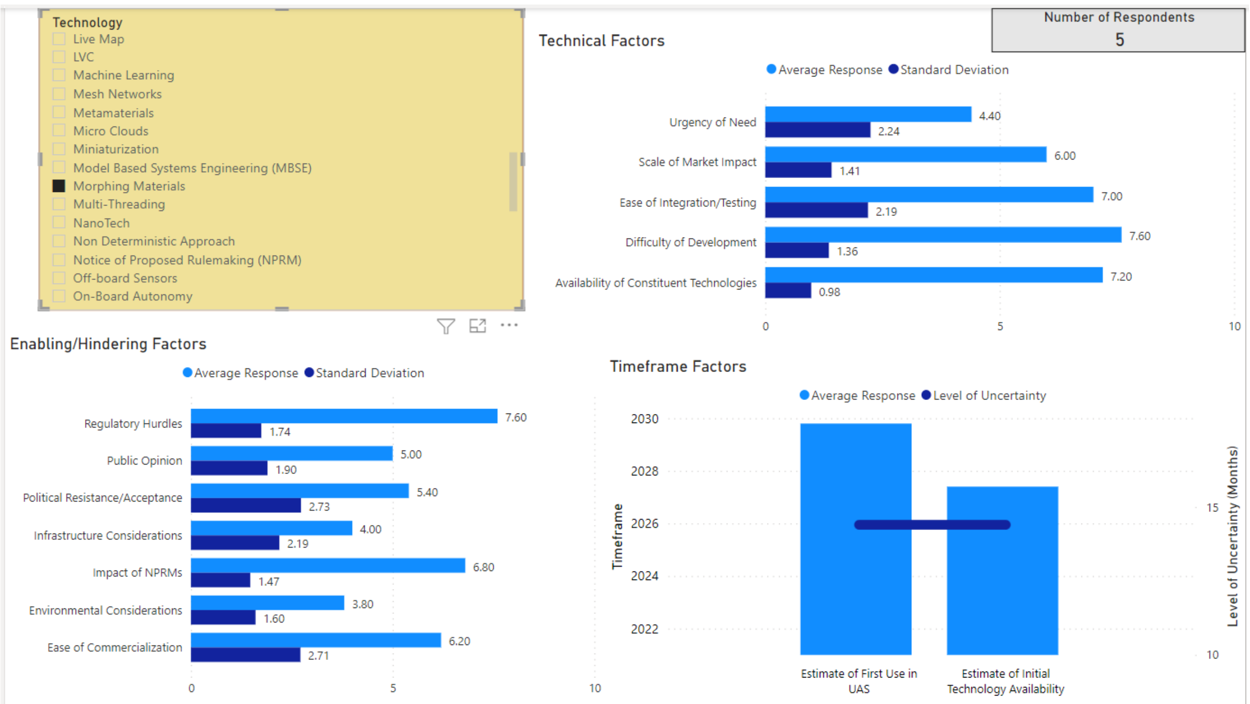

Figure 59. Morphing Materials Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact

- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2029.80 ± 14.4/12
  - **Estimate of Initial Technology Availability:** 2027.40 ± 14.4/12

7.38 Multi-Threading

A multithreading system aims to fill the idle time of polling I/O with other threads. Therefore, it can optimize the efficiency of a microcontroller. Because some processing tasks must be completed in series (e.g. PWM output values are processed before being sent to motors) and other tasks can be completed in parallel. Multithreading can organize tasks and threads to be executed concurrently (Randu, n.d.).

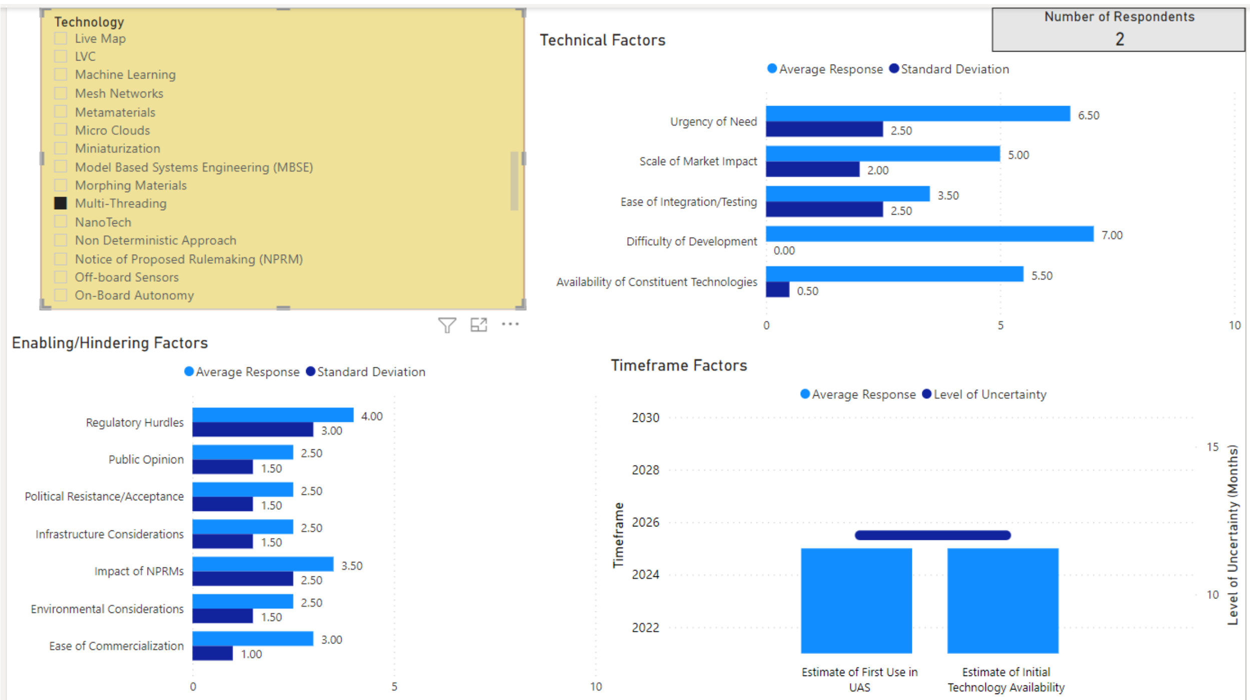

Figure 60. Multithreading Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Moderate to Easy Integration
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Minor Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns

- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2025.00 ± 1
    - **Estimate of Initial Technology Availability:** 2025.00 ± 1

7.39 Nano Tech

Nanotechnology, or nanotech, is the use of matter on an atomic, molecular, and supramolecular scale for industrial purposes. The earliest, widespread description of nanotechnology refers to the technological goal of precisely manipulating atoms and molecules for fabrication of macroscale products. This process is also known as molecular nanotechnology. A more generalized description of nanotechnology was subsequently established by the National Nanotechnology Initiative, which defined nanotechnology as the manipulation of matter with at least one dimension sized from 1 to 100 nanometers. This definition reflects the fact that quantum mechanical effects are important at this quantum-realm scale. Therefore, the definition shifted from a particular technological goal to a research category inclusive of all types of research and technologies that deal with the special properties of matter which occur below the given size threshold. It is therefore common to see the plural form "nanotechnologies" as well as "nanoscale technologies" to refer to the broad range of research and applications whose common trait is size. Nanotechnology as defined by size is naturally broad, including fields of science as diverse as surface science, organic chemistry, molecular biology, semiconductor physics, energy storage, engineering, microfabrication, and molecular engineering. The associated research and applications are equally diverse, ranging from extensions of conventional device physics to completely new approaches based upon molecular self-assembly, from developing new materials with dimensions on the nanoscale to direct control of matter on the atomic scale (Drexler, 1986) and (Gustin, 2010).

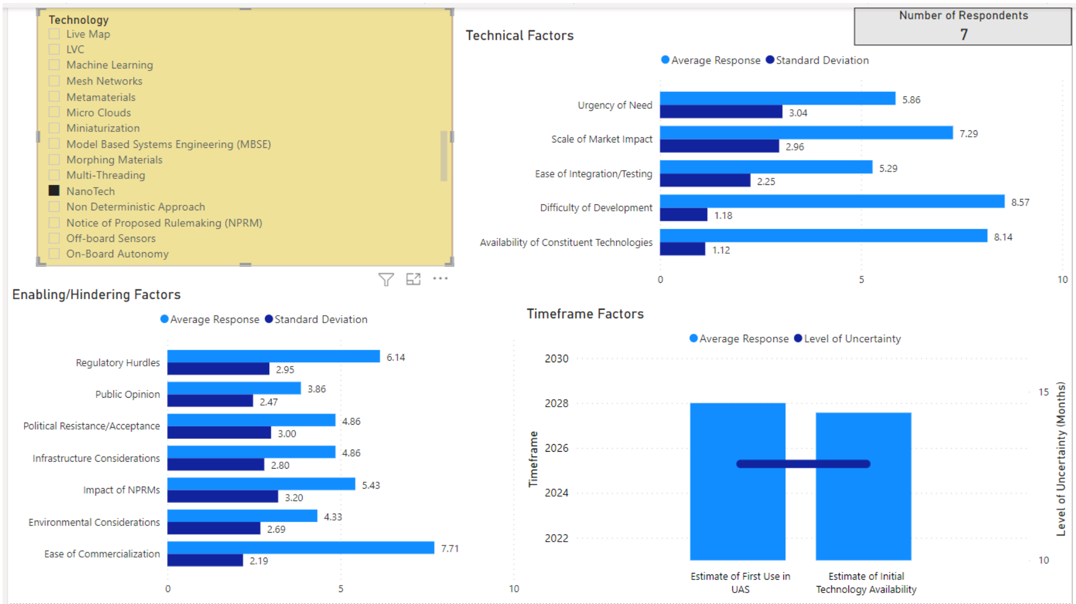

Figure 61. Nano Tech Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Extremely Difficult
- **Availability of Constituent Technologies:** Unavailable

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2028.00 ± 12.86/12
  - **Estimate of Initial Technology Availability:** 2027.57 ± 12.86/12

7.40 Non-Deterministic Approach

Aviation is currently experimenting with strong AI This includes systems capable of independent machine learning. Complex engineered products are more likely to meet performance requirements when Non-Deterministic Approaches (NDA) are used. Aircraft structural health management has always relied upon NDA, with systems investigating root causes and identifying solutions. Management of the Next Generation Air Transportation System (NextGen) will use NDA for trajectory-based operations (TBO) to account for aircraft position and weather uncertainty. Carbonell, a Carnegie Mellon University, Aerospace Data Analytics Laboratory researcher working with Boeing, is working on an artificial intelligence system that can identify holes in aircraft security, cross-check references from multiple aircraft, and dig for data to solve the issue, all autonomously. Future flight decks may contain, or be expected to interact with, software "intelligent agents." The characteristics of these agents may differ significantly from most software tools in use today. The increasing complexity of technology drives the need for such NDA. Projects like the Defense Advanced Research Projects Agency's (DARPA), Aircrew Labor In-Cockpit Automation System (ALIAS) was created to help overcome the challenges associated with high levels of automation (NLR, 2017).

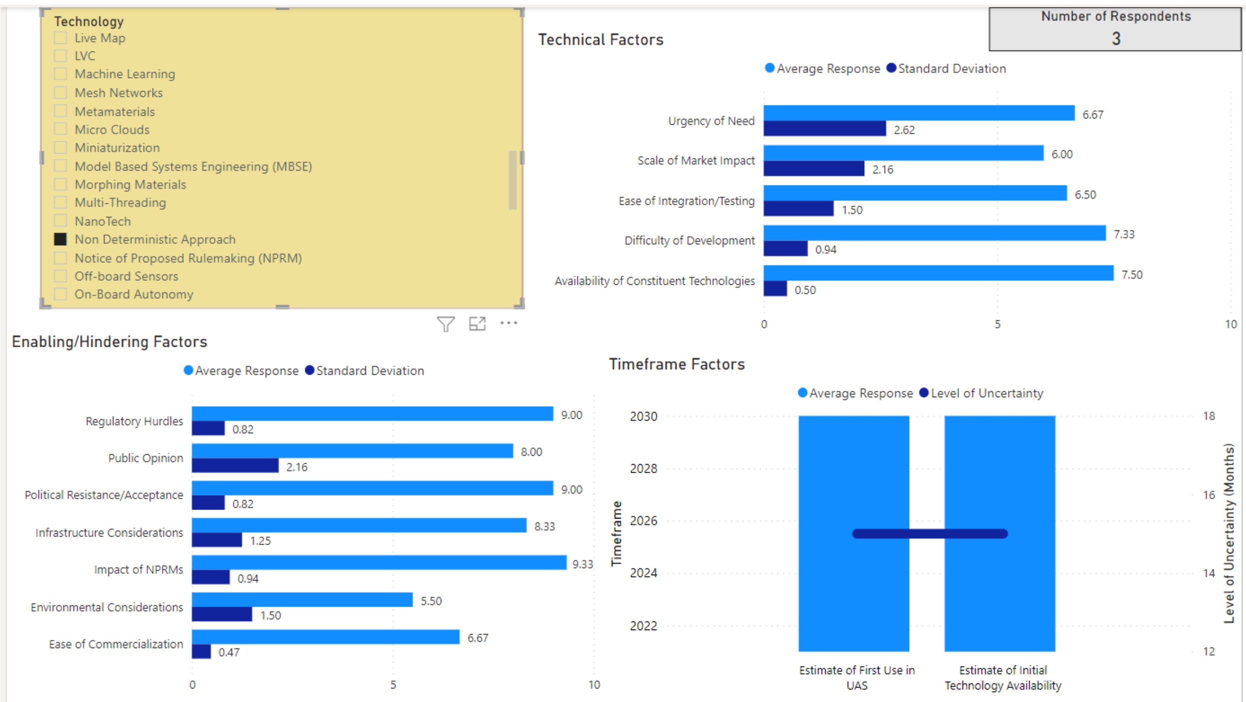

Figure 62. Non-Deterministic Approach Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Somewhat Unacceptable
- **Political Resistance/Acceptance:** Extreme Political Challenges
- **Infrastructure Considerations:** Highly Concerned Regarding Infrastructure Requirements
- **Impact of NPRMs:** High NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2032.00 ± 15/12
  - **Estimate of Initial Technology Availability:** 2030.00 ± 15/12

7.41 Notices of Proposed Rulemaking (NPRM)

A Notice of Proposed Rulemaking (NPRM) is a public notice that is issued by law when an independent agency of the US government wishes to add, remove, or change a rule or regulation. The notice is an important part of US administrative law. The FAA follows the Administrative Procedure Act for rules; definitions are contained in 14 CFR 11. An example of such a notice is the NPRM on Remote Identification of UAS. The Remote Identification proposed rule provides a framework for remote identification of all UAS operating in the airspace of the United States. The rule will facilitate the collection and storage of certain data such as identity, location, and altitude regarding an unmanned aircraft and its control station (Federal Aviation Administration, 2022b).

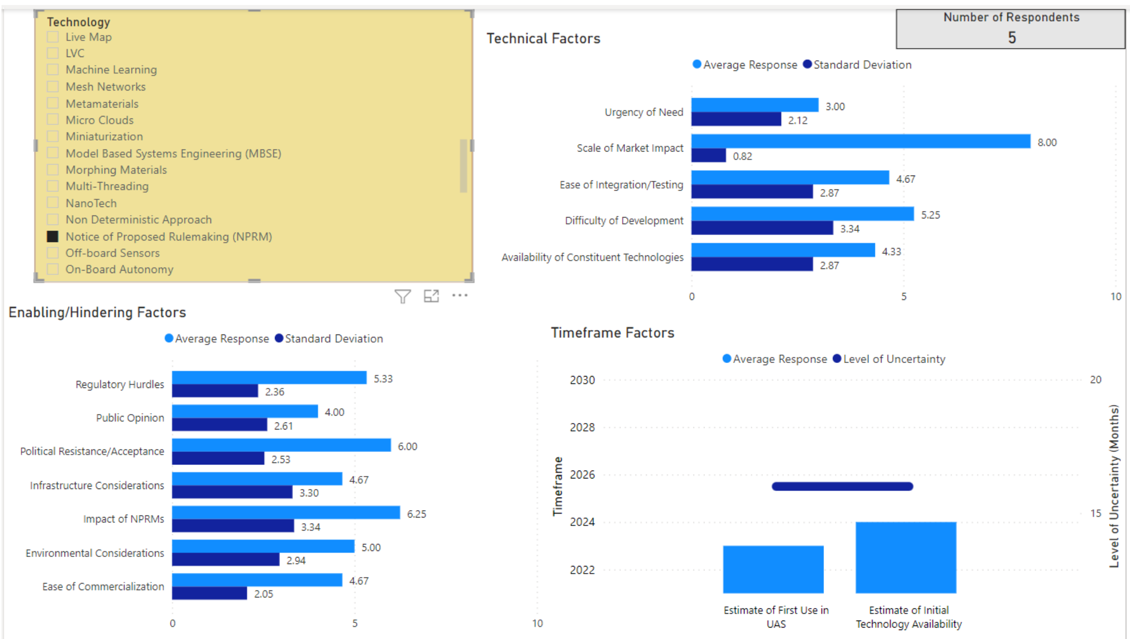

Figure 63. NPRM Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues

- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2023.00 ± 16/12
    - **Estimate of Initial Technology Availability:** 2024.00 ± 16/12

7.42 Off-board Sensors

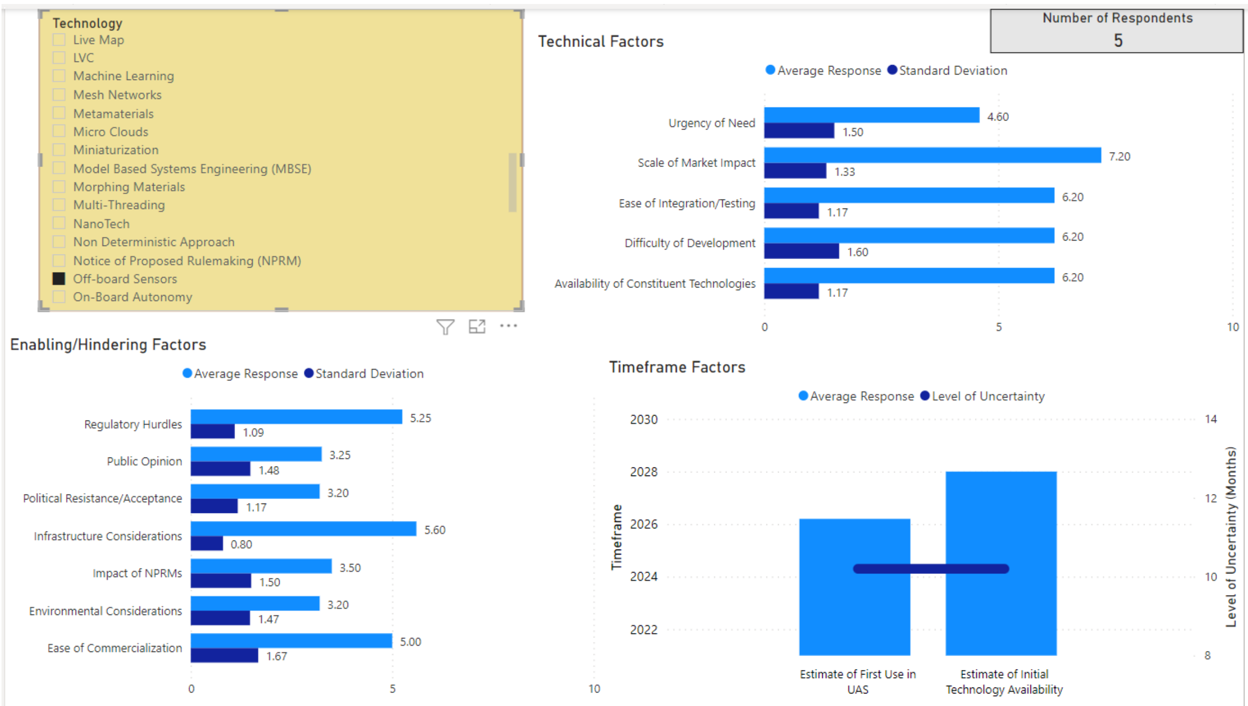

Figure 64. Off-board Sensor Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):

- ○ **Estimated First Use in UAS:** 2026.20 ± 10.2/12
- ○ **Estimate of Initial Technology Availability:** 2028.00 ± 10.2/12

7.43 On-Board Autonomy

Under the traditional data-processing model, raw video would be fed from an UAV to the ground control station for processing. The processing system can be embedded along with the sensor aboard the aircraft. On-board autonomy is a technology in which the drone detects potential objects in real-time through analysis of aerial surveillance video. The data is analyzed in its purest form, without degradation, enabling autonomous detection systems to find very small objects across much wider areas than previously possible. The drone can autonomously and persistently detect movement within electro-optical (EO) and infrared (IR) video, picking up objects that would be too small or slow-moving for the human eye to see (sUAS News, 2018).

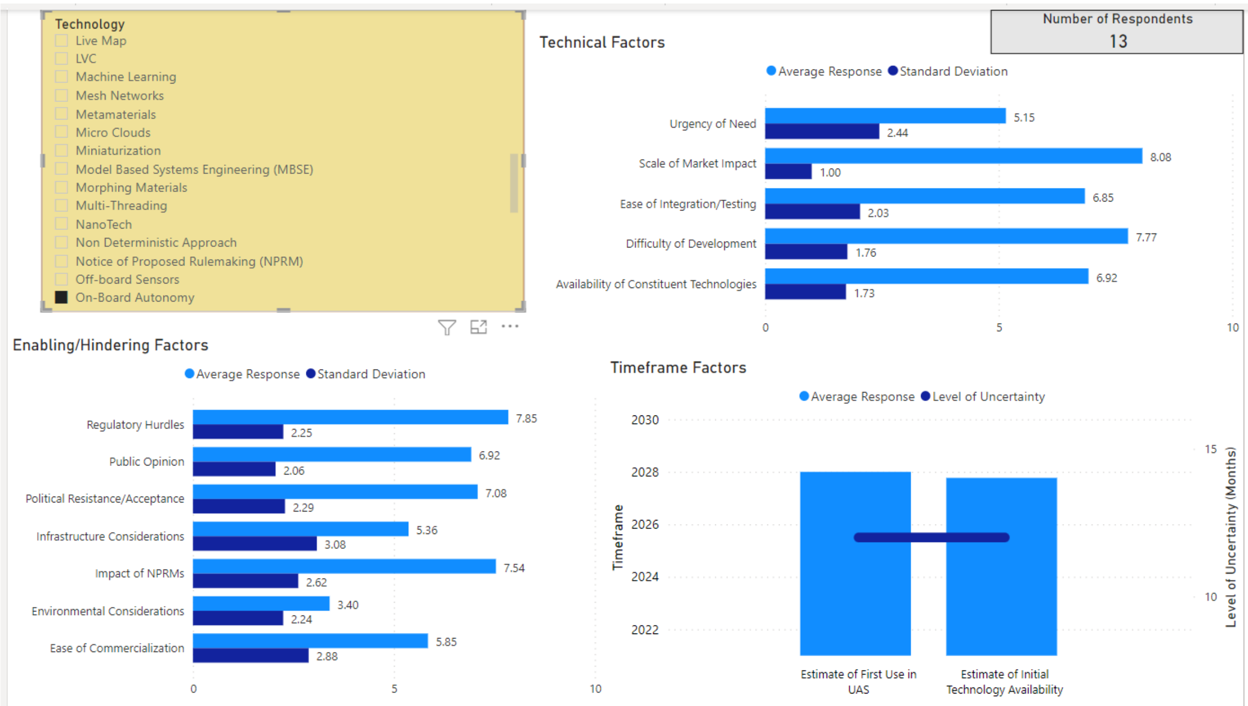

Figure 65. On-Board Autonomy Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Somewhat Unacceptable
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact

- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2028.00 ± 1
  - **Estimate of Initial Technology Availability:** 2027.77 ± 1

7.44 Part 135

As drones are introduced into everyday life in the U.S. — from recreational flying to commercial uses — FAA's number one priority remains safety. Whether manned or unmanned aircraft, FAA requires that all operators follow specific guidelines for the operations they request. The FAA is encouraging innovation and working with industry, state, local, and tribal governments to realize the benefits of drones and inform future rules and regulations. From 2017 through 2020 the UAS IPP focused on testing and evaluating the integration of civil and public drone operations into our national airspace system. This work continues under the UAS BEYOND program which focuses on the remaining challenges of UAS integration, including BVLOS operations, societal and economic benefits of UAS operations, and community engagement. Participants in these programs are among the first to prove their concepts, including package delivery by drone through part 135 air carrier certification. Part 135 certification is the only path for small drones to carry the property of another for compensation beyond visual line of sight. As participants in these programs move to prove their concepts, they must use FAA's existing Part 135 certification process, some of which FAA has adapted for drone operations by granting exemptions for rules that don't apply to drones, such as the requirement to carry the flight manuals on board the aircraft. All part 135 applicants must go through the full five phases of the certification process. The FAA issues air carrier certificates to U.S. applicants based on the type of services they plan to provide and where they want to conduct their operations. Operators must obtain airspace authorizations and air carrier or operating certificates before they can begin operations. Certificates are available for four types of Part 135 operations:

- Part 135 Single Pilot. A single-pilot operator is a certificate holder that is limited to using only one pilot for all part 135 operations.

- A Single Pilot in Command certificate is a limited part 135 certificate. It includes one pilot in command certificate holder and three second pilots in command. There are also limitations on the size of the aircraft and the scope of the operations.

- A Basic operator certificate is limited in the size and scope of their operations. Maximum of five pilots, including second in command. Maximum of five aircraft can be used in their operation.

- A Standard operator holds a certificate with no limits on the size or scope of operations. However, the operator must be granted authorization for each type of operation they want to conduct.

The FAA issued the first Part 135 Single pilot air carrier certificate for drone operations to Wing Aviation, LLC in April 2019. The FAA later issued Wing a Standard Part 135 air carrier certificate to operate a drone aircraft in October 2019. Wing Aviation is part of the Integration Pilot Program (IPP), delivering food and over-the-counter pharmaceuticals directly to homes in Christiansburg, VA. UPS Flight Forward, Inc., another participant in the IPP, was the first company to receive a Standard Part 135 air carrier certificate to operate a drone aircraft. On September 27, 2019, UPS Flight Forward conducted its first package delivery by drone with its part 135 certification when it flew medical supplies at WakeMed's hospital campus in Raleigh, NC. The FAA is currently working on six additional part 135 air carrier certificate applications that have been submitted by IPP operators and one 135 application that was submitted by an FAA Partnership for Safety Plan (PSP) participant (Federal Aviation Administration, 2021d).

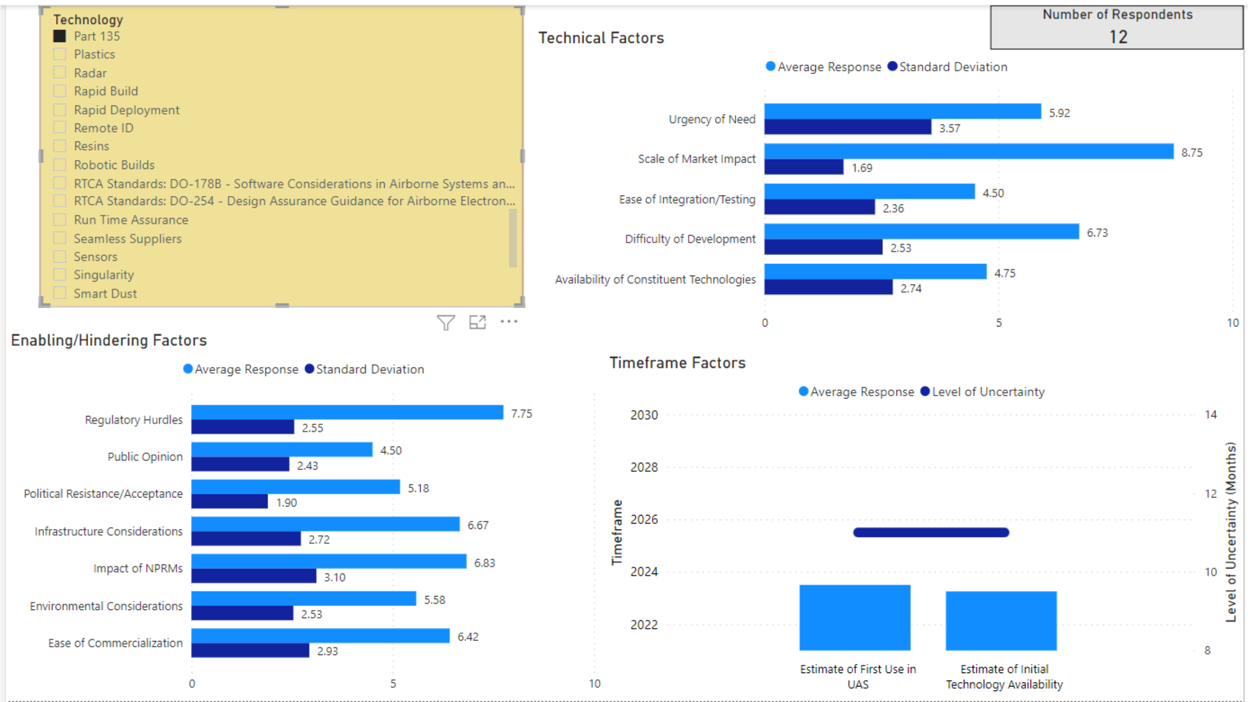

Figure 66. Part 135 Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2023.50 ± 11/12
  - **Estimate of Initial Technology Availability:** 2023.25 ± 11/12

7.45 Plastics

Thermoplastics, such as variants of nylon, polyester, and polystyrene, are popular choices for commercial drones because they are inexpensive to make into complex parts using injection molding processes. Plastics offer good strength and low density. Plastics also can come in a filament allowing the production of experimental drones using 3D printing. Along with the body of the drone, most rotors are made of plastic because they are inexpensive to replace in the event of failure (Lanning, 2019).

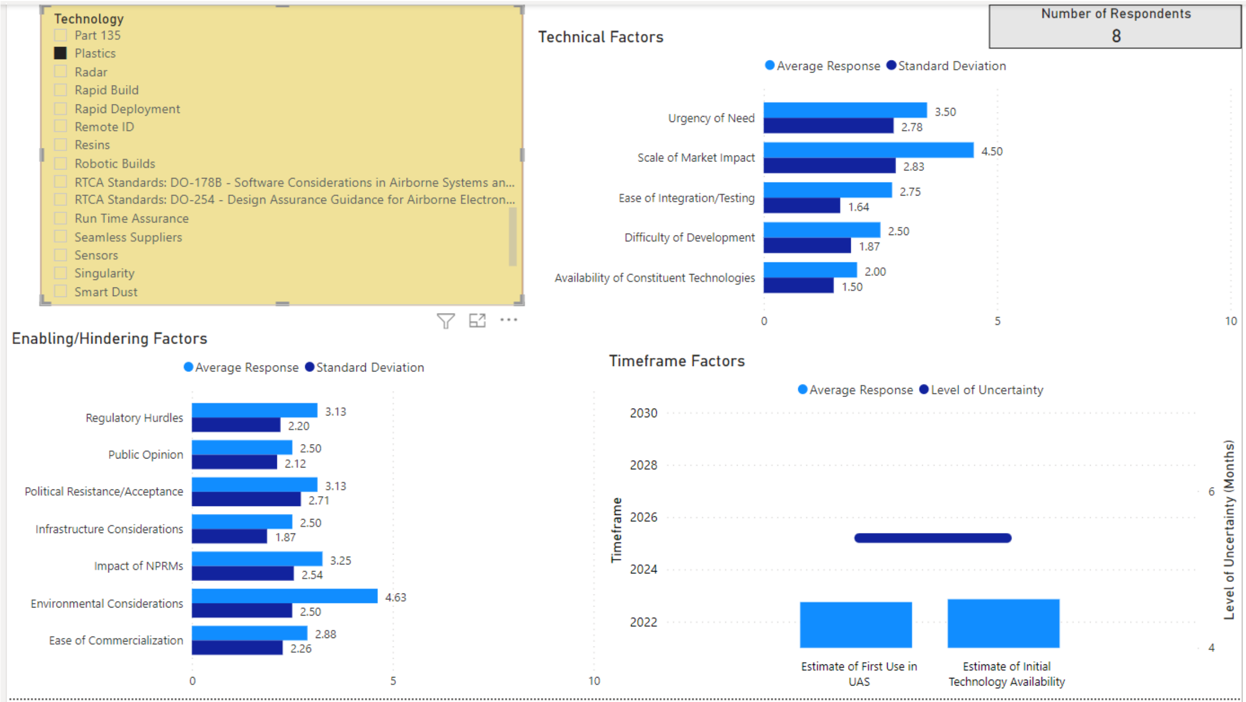

Figure 67. Plastics Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Slight Difficulty
- **Availability of Constituent Technologies:** Currently Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Minor Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2022.75 ± 5.4/12
  - **Estimate of Initial Technology Availability:** 2022.86 ± 5.4/12

7.46 Radar

Certain high-resolution radars are specifically designed for drone detection and tracking. Reflected signals are analyzed and compared to a database for drone characterization. The stored signatures can also be used to eliminate objects that are not drone-like much like how radars are used to detect birds. Radar can also provide real-time tracking by providing the GPS location of the drone detected (911 Security, 2020).

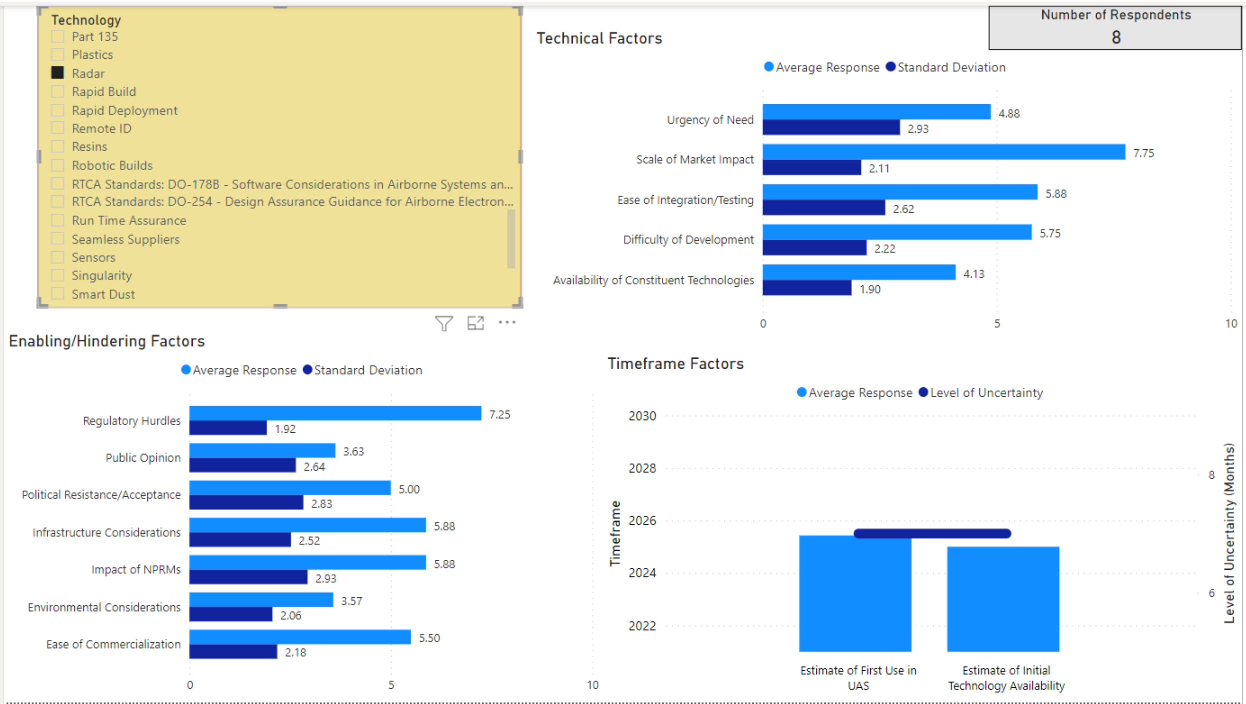

Figure 68. Radar Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2025.43 ± 7/12
  - **Estimate of Initial Technology Availability:** 2025.00 ± 7/12

7.47 Rapid Build

Rapid prototyping is the fast fabrication of a physical part, model or assembly using 3D CAD. The creation of the part, model or assembly is usually completed using additive manufacturing, or more commonly known as 3D printing. Rapid prototyping (RP) includes a variety of manufacturing technologies, although most utilize layered additive manufacturing. However, other technologies used for RP include high-speed machining, casting, molding and extruding (TWI, n.d.).

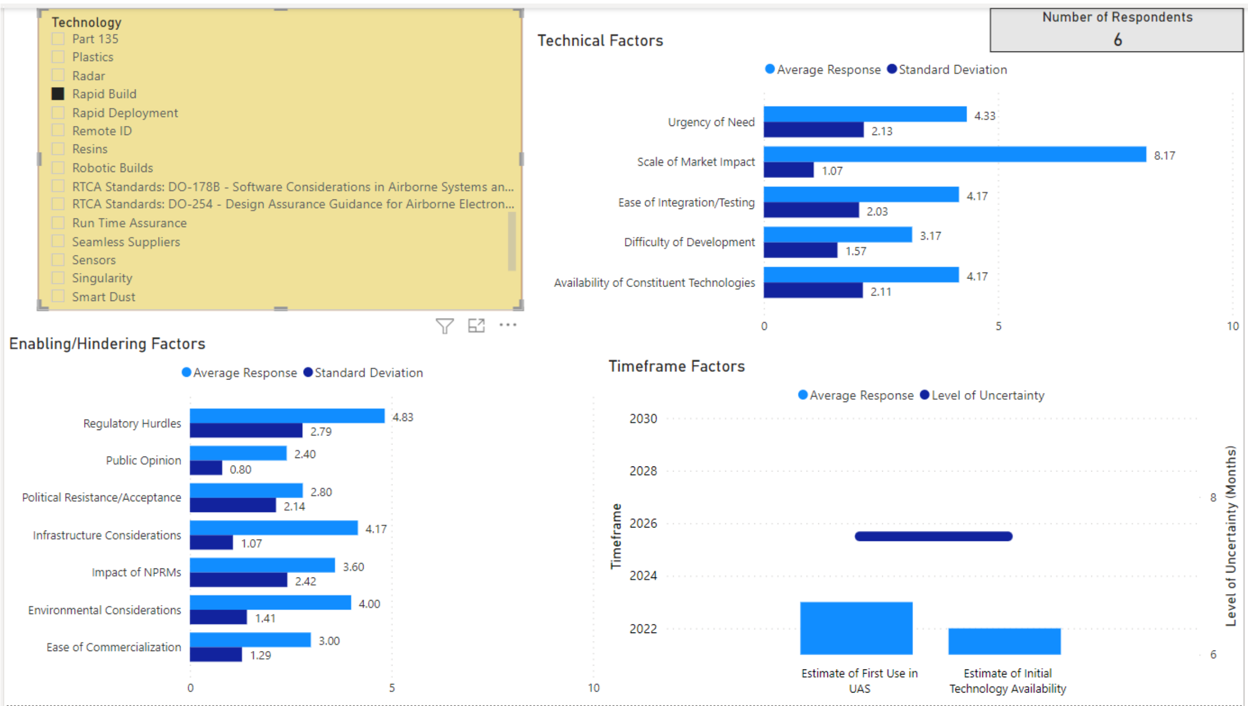

Figure 69. Rapid Build Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Slight Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2023.00 ± 7.5/12

- **Estimate of Initial Technology Availability:** 2022.00 ± 7.5/12

7.48 Rapid Deployment

Rapid deployment is the ability to set equipment up for operations swiftly. For example, Echodyne has produced a rapid deployment kit for field agents, law-enforcement, and security personnel charged with temporarily or intermittently securing ground and airspace perimeters. The kit takes 5 minutes to set up and has a high performing radar (Cleghorn, 2019).

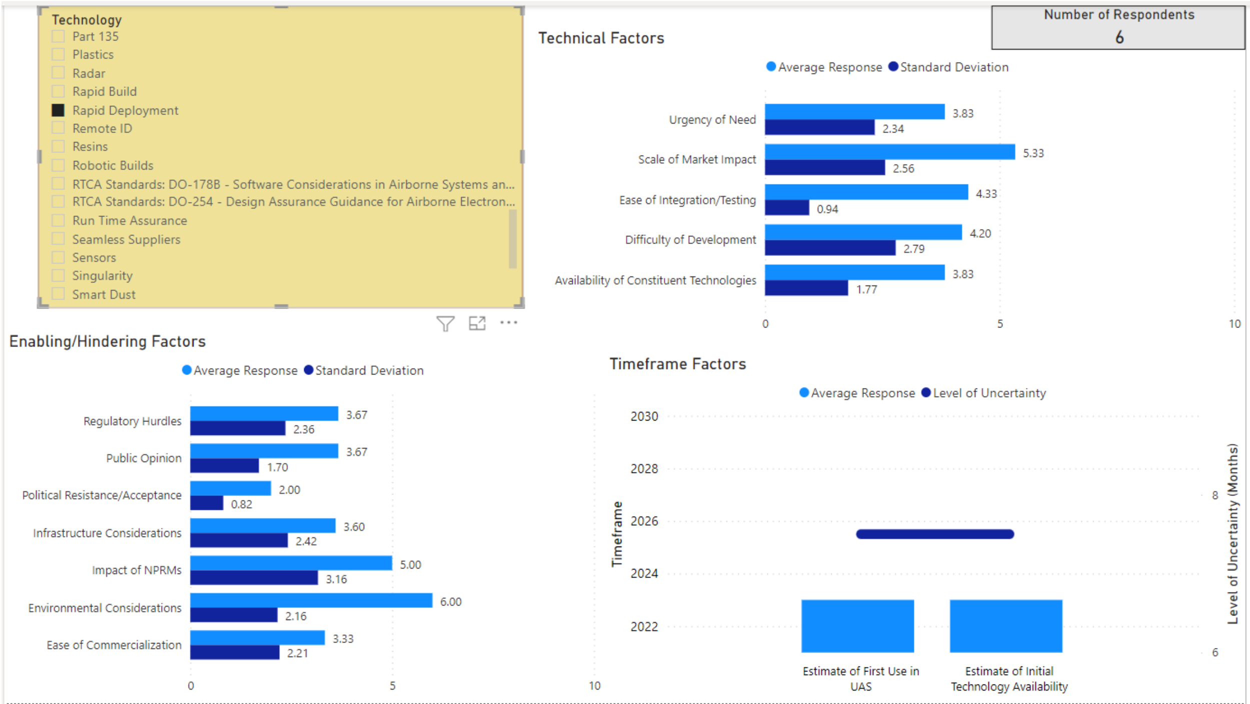

Figure 70. Rapid Deployment Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Minor Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Little/No Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):

- **Estimated First Use in UAS:** 2023.00 ± 7.5/12
- **Estimate of Initial Technology Availability:** 2023.00 ± 7.5/12

7.49 Remote ID

Remote ID allows governmental and civil identification of UAS for safety, security, and compliance purposes. The objective remote ID regulation is to increase UAS Remote Pilot accountability by removing anonymity while preserving operational privacy for remote pilots, businesses, and their customers. In the United States, the FAA defines Remote ID as the ability of a UAS in flight to provide identification and location information that other parties can receive. It also establishes the foundation for information sharing for future operational concepts such as BVLOS operations and addresses safety and security concerns which will be become more significant when expanded UAS operations become a reality (McNabb, 2020).

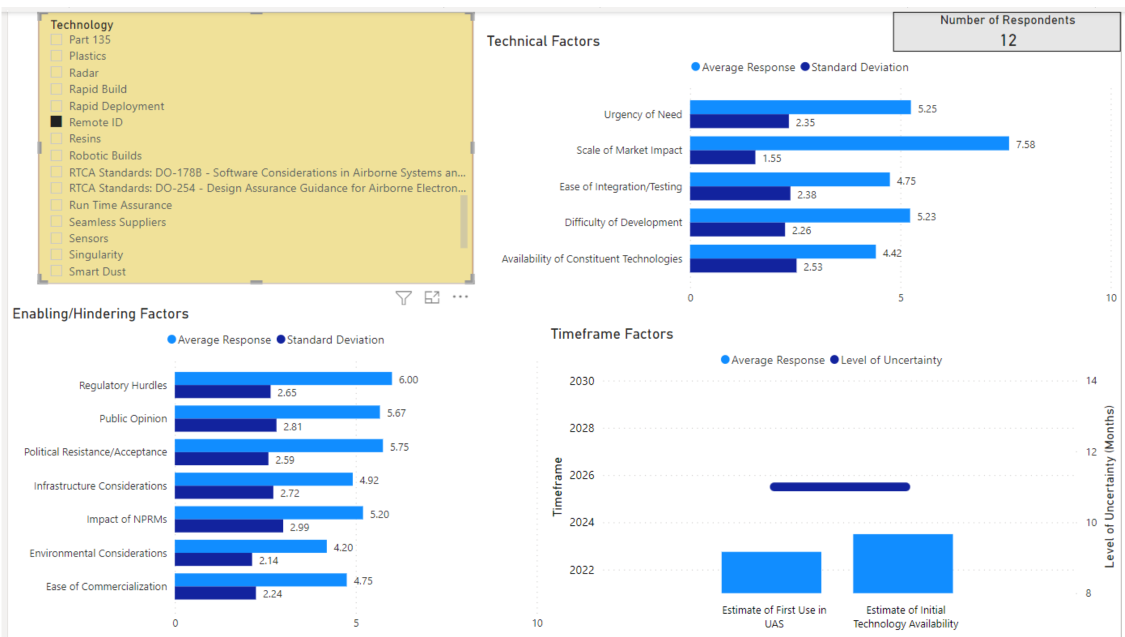

Figure 71. Remote ID Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues

- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2022.75 ± 11/12
    - **Estimate of Initial Technology Availability:** 2023.50 ± 11/12

7.50 Resins

Resins are a solid or highly viscous substance of plant or synthetic origin that is typically convertible into polymers. Resins are widely used as adhesives, coatings, or as a construction material. Synthetic resins are divided into two classes: thermoplastic and thermosetting. Thermoplastic resins remain plastic after heat treatments. However, thermosetting resins become insoluble and infusible upon heating. Different resins can produce inconsistent tolerances for the same part, so sometimes a tradeoff must be made between tolerance expectations and the physical properties of the resin. Holding tight tolerances can be a challenge with many resins because they have different shrink rates and high thermal expansion rates, will absorb moisture, and—in crystalline materials—may continue to grow crystals after the molding process (Bishop, 2018).

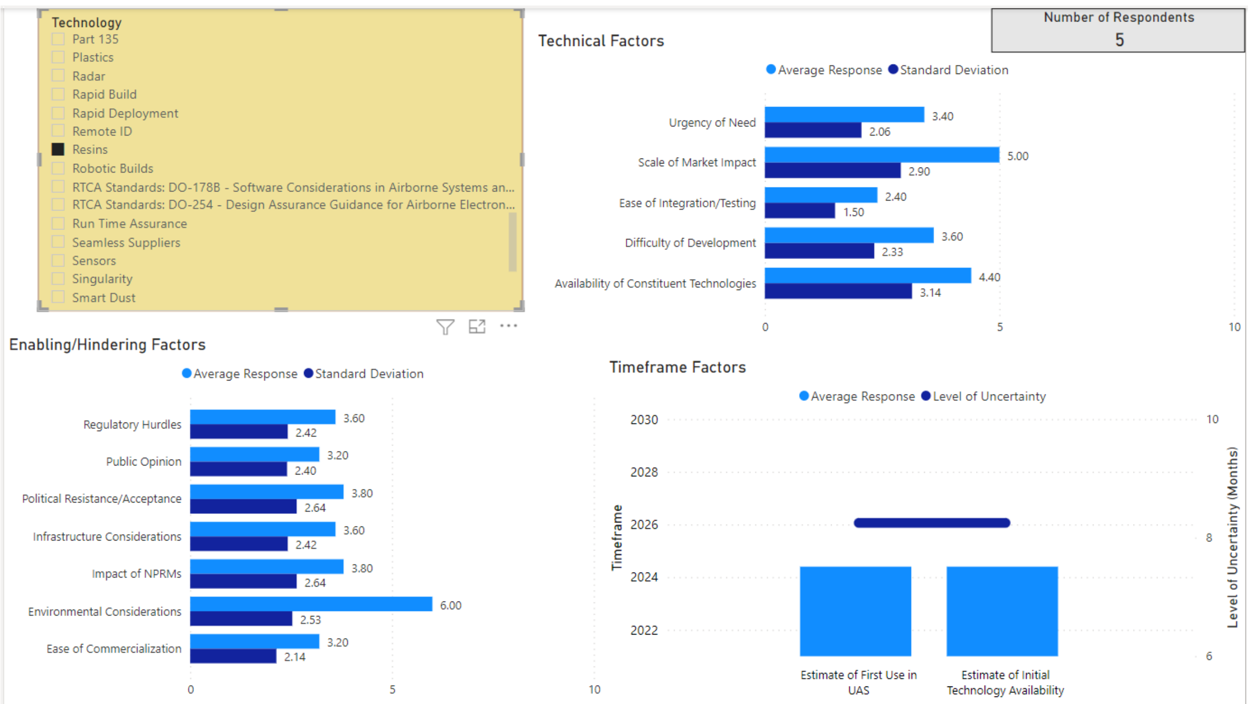

Figure 72. Resins Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Slight Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Minor Regulatory Hurdles

- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2024.40 ± 8.25/12
  - **Estimate of Initial Technology Availability:** 2024.40 ± 8.25/12

7.51 Robotic Builds

Robotic builds combine the principles of engineering, mechanics, manufacturing materials, sensors, dynamics, and controls into one discipline. Robotics can be defined as the science or study of the technology primarily associated with the design, fabrication, theory, and application of robots. The use of drone and other unmanned technology in performing robotic fabrication or construction activities would be particularly useful in remote, inaccessible, or dangerous locations (Built In, n.d.).

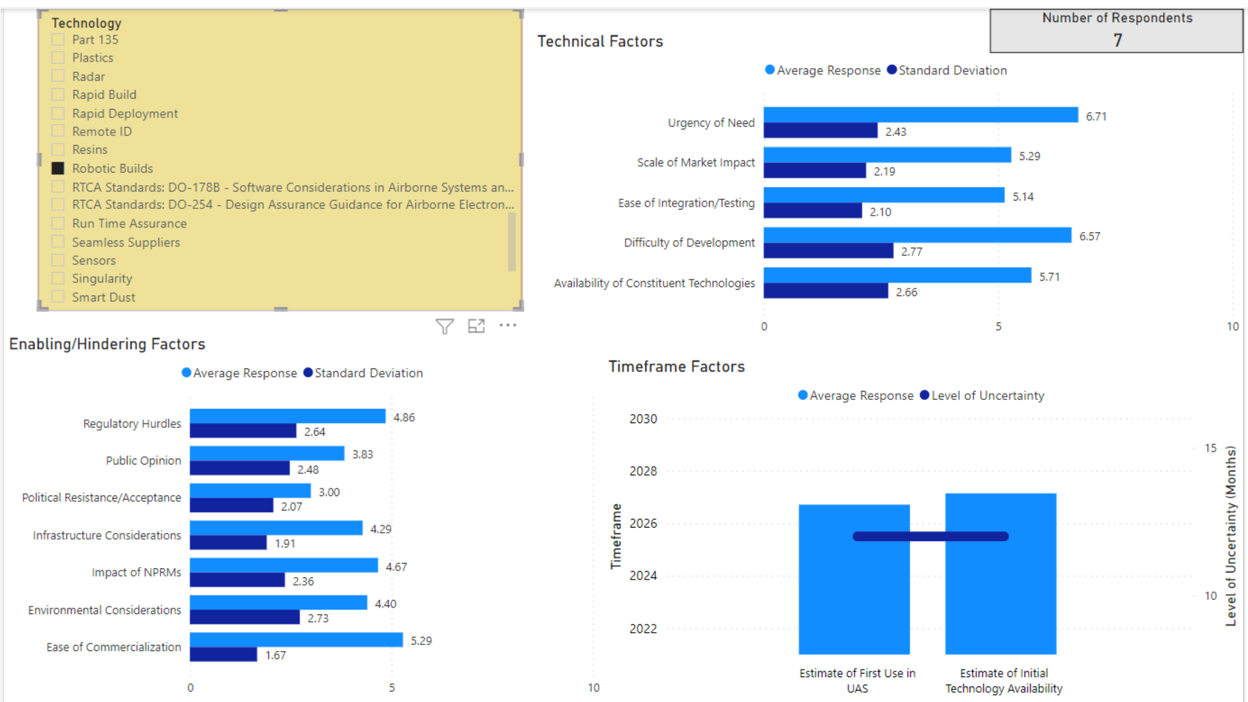

Figure 73. Robotic Builds Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2026.71 ± 1
  - **Estimate of Initial Technology Availability:** 2027.14 ± 1

7.52 RTCA Standards: DO-178B, Software Considerations in Airborne Systems and Equipment

DO-178B, Software Considerations in Airborne Systems and Equipment Certification is a guideline dealing with the safety of safety-critical software used in certain airborne systems. It was jointly developed by the safety-critical working group RTCA SC-167 of the Radio Technical Commission for Aeronautics (RTCA) and WG-12 of the European Organization for Civil Aviation Equipment (EUROCAE). RTCA published the document as RTCA/DO-178B, while EUROCAE published the document as ED-12B. Although technically a guideline, it was a de facto standard for developing avionics software systems until it was replaced in 2012 by DO-178C. The FAA applies DO-178B as the document it uses for guidance to determine if the software will perform reliably in an airborne environment, when specified by the Technical Standard Order (TSO) for which certification is sought. In the United States, the introduction of TSOs into the airworthiness certification process, and by extension DO-178B, is explicitly established in Title 14: Aeronautics and Space of the Code of Federal Regulations (CFR), also known as the Federal Aviation Regulations, Part 21, Subpart O (Federal Aviation Administration, n.d.-b).

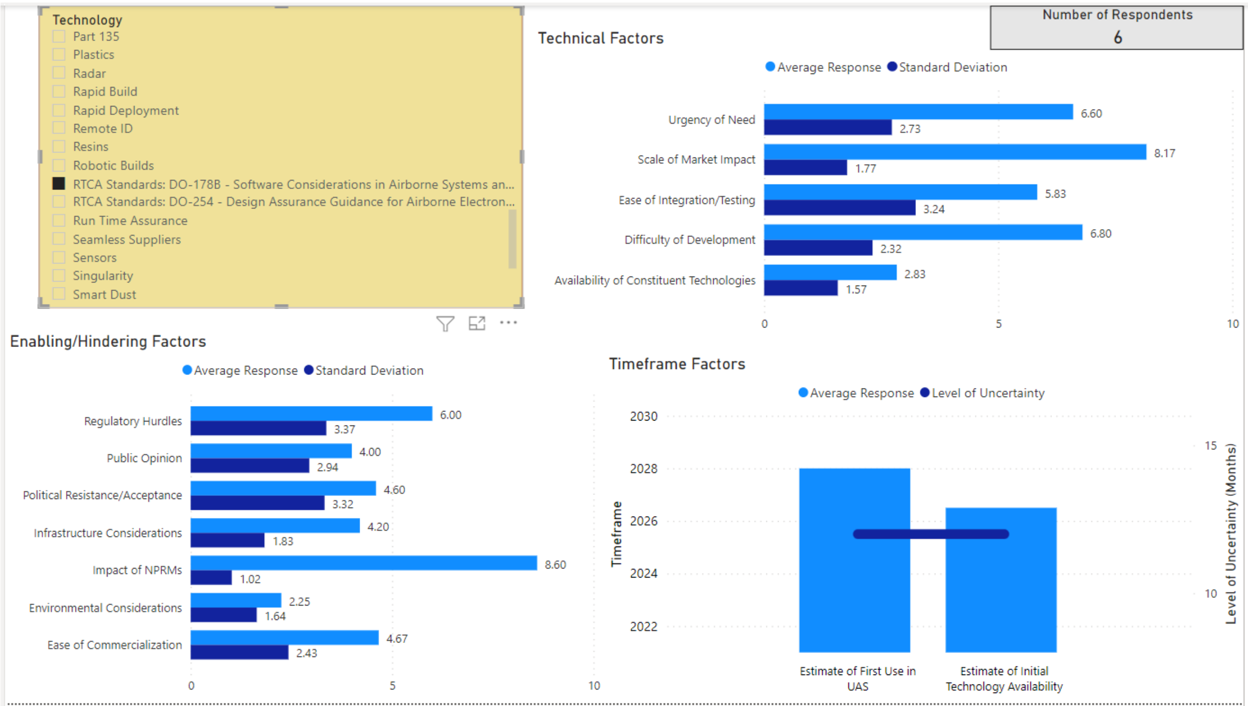

Figure 74. RTCA Standards: DO-178B Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** High NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2028 ± 1
    - **Estimate of Initial Technology Availability:** 2026.50 ± 1

7.53 RTCA Standards: DO-254, Design Assurance Guidance for Airborne Electronic Hardware

RTCA DO-254 / EUROCAE ED-80, Design Assurance Guidance for Airborne Electronic Hardware is a document providing guidance for the development of airborne electronic hardware, published by RTCA, Incorporated and EUROCAE. The DO-254/ED-80 standard was formally recognized by the FAA in 2005 via AC 20-152 as a means of compliance for the design assurance of electronic hardware in airborne systems. The guidance in this document is applicable, but not limited, to such electronic hardware items as Line Replaceable Units (quickly replaceable components) Circuit board assemblies (CBA) Custom micro-coded components such as field programmable gate arrays (FPGA), programmable logic devices (PLD), and application-specific integrated circuits (ASIC), including any associated macro functions Integrated technology components such as hybrid integrated circuits and multi-chip modules Commercial off-the-shelf (COTS) components. The document classifies electronic hardware items into simple or complex categories. An item is simple "if a comprehensive combination of deterministic tests and analyses appropriate to the design assurance level can ensure correct functional performance under all foreseeable operating conditions with no anomalous behavior." Conversely, a complex item is one that cannot have correct functional performance ensured by tests and analyses alone; so, assurance must be accomplished by additional means. The body of DO-254/ED-80 establishes objectives and activities for the systematic design assurance of complex electronic hardware, generally presumed to be complex custom micro-coded components, as listed above. However, simple electronic hardware is within the scope of DO-254/ED-80 and applicants propose and use the guidance in this standard to obtain certification approval of simple custom micro-coded components, especially devices that support higher level (A/B) aircraft functions (Federal Aviation Administration, 2007).

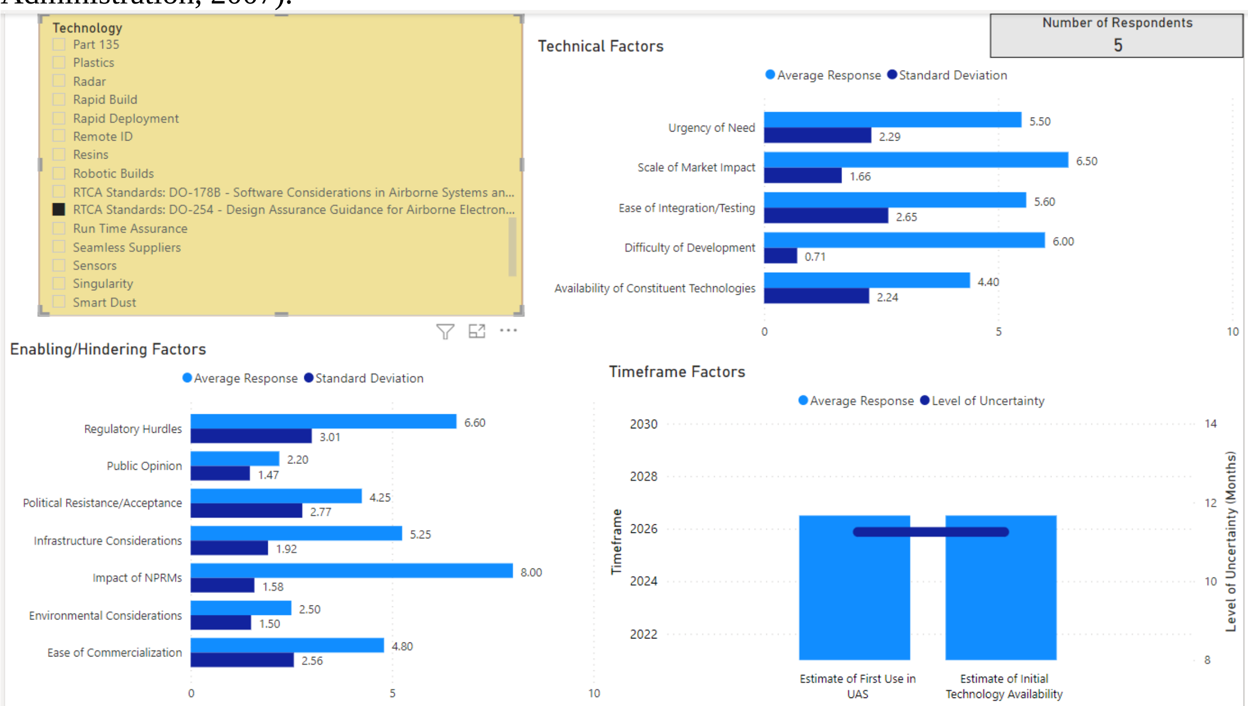

Figure 75. RTCA Standards: DO-254 Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2026.50 ± 11.25/12
    - **Estimate of Initial Technology Availability:** 2026.50 ± 11.25/12

7.54 Run Time Assurance

Runtime verification is a computing system analysis and based on extracting information from a running system and using it to detect and possibly react to observed behaviors satisfying or violating certain properties. There is guidance available in a safety architecture based on the ASTM F3269-17 standard for bounded behavior of complex systems, diverse run-time monitors of system safety, and formal synthesis of critical high-assurance components. This technology has implications for all autonomous systems including drones (Cofer et al., 2020).

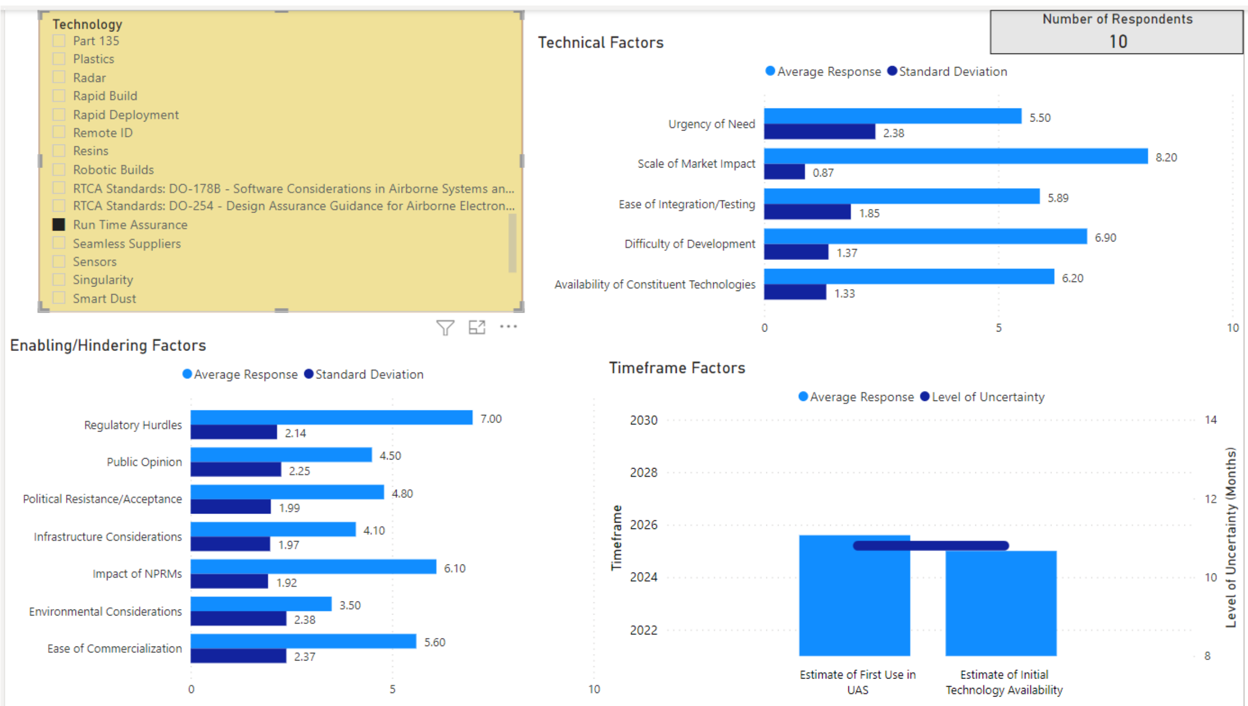

Figure 76. Run Time Assurance Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult

- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2025.60 ± 10.8/12
  - **Estimate of Initial Technology Availability:** 2025.00 ± 10.8/12

7.55 Seamless Suppliers

The seamless supply chain is an organizational initiative that requires an amalgamation of people, process, governance, and best-of-breed technology, as well as strong executive leadership and commitment. Best-of-breed systems have come a long way, and leading companies are now leveraging decision support technology to enable seamless supply chains. Essentially, they are leveraging the same physical assets to create multiple virtual supply chains that match different value propositions to different clusters with corresponding costs-to-serve. This helps them orchestrate a differentiated supply chain posture (planning for demand, inventory, manufacturing, allocation, order promising, etc.) for different clusters based on their strategic business objectives. They can use the same physical supply chain assets, plants, distribution centers and warehouses much more effectively, instead of deploying additional assets. Thus, technology supports the seamless union of the digital connected consumer with the physical supply chain. It leverages the profitable customer commerce tenet, seamlessly propagating demand across value chain partners using adaptable manufacturing, then delivering synchronized planning and execution across the extended supply chain through intelligent fulfillment (MD Logistics, 2016).

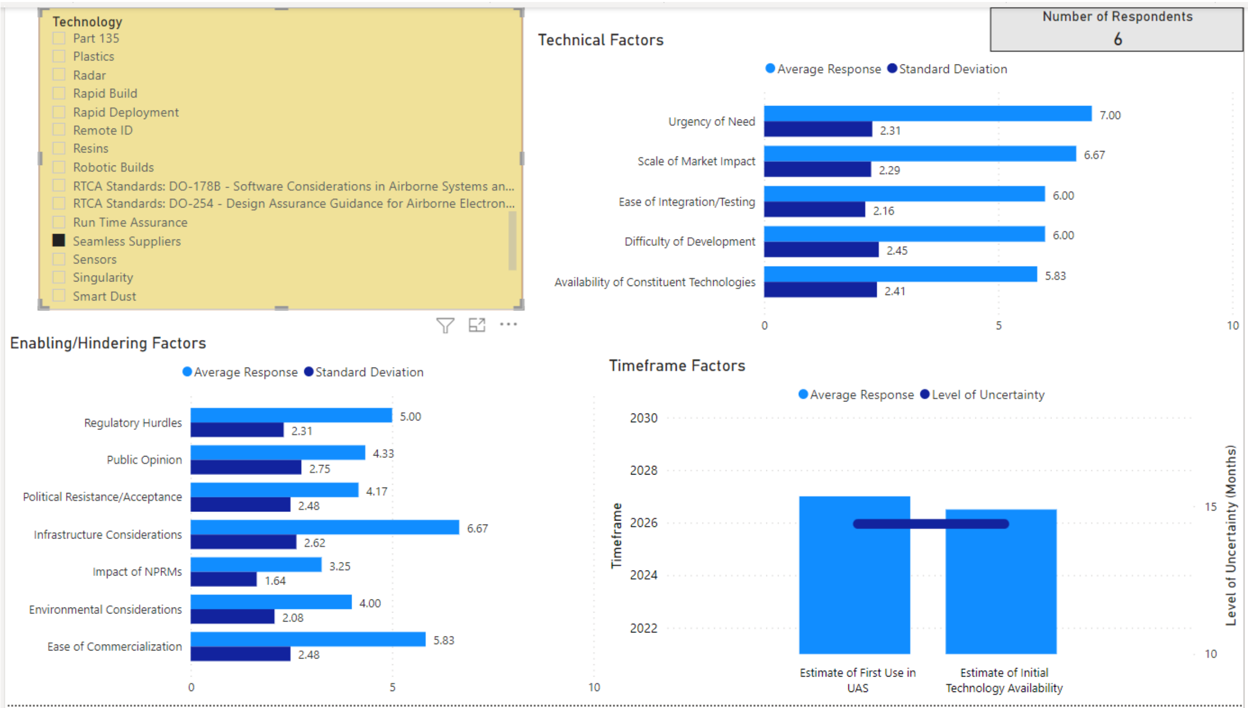

Figure 77. Seamless Suppliers Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2027.00 ± 14.4/12
  - **Estimate of Initial Technology Availability:** 2026.50 ± 14.4/12

7.56 Sensors

A sensor is a device which detects or measures a physical property and records, indicates, or otherwise responds to it. UAS carry sensors of various wavelength sensitivity (thermal, multispectral, hyperspectral, and light detection and ranging (LiDAR), for example) to record imagery. Drones also utilize air pressure sensors to stabilize altitude, allowing hover capabilities needed for videography or photography. Combined with the accelerometer and gyroscope, barometric pressure sensors enable drones to fly with precision. A digital humidity sensor with temperature output accurately measures temperature and humidity (TE Connectivity, n.d.).

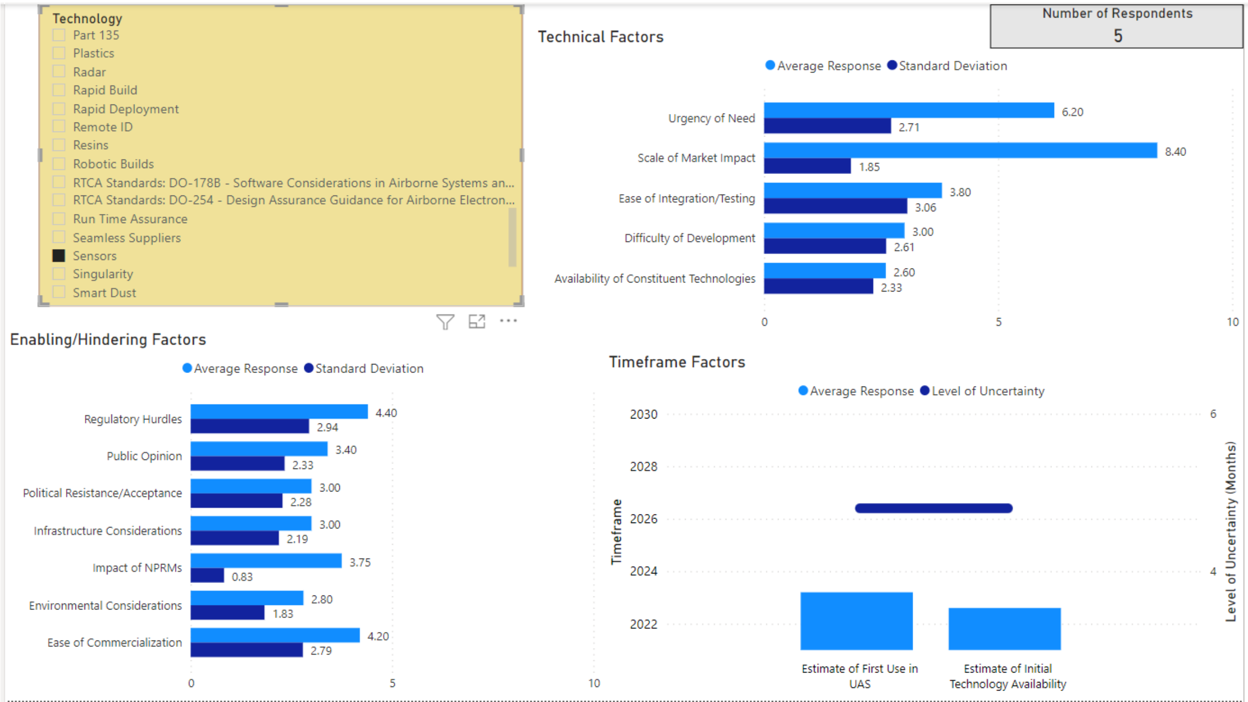

Figure 78. Sensors Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Slight Difficulty
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2023.20 ± 4.8/12
    - **Estimate of Initial Technology Availability:** 2022.60 ± 4.8/12

7.57 Singularity

The technological singularity is a hypothetical point in time at which technological growth becomes uncontrollable and irreversible, resulting in unforeseeable changes to human civilization.

Drones will be used for surveillance, delivery, and in the construction sector as it moves towards automation. Drones will require landing pads, charging points, and drone ports. They could usher in new styles of building, and lead to more sustainable design. This will change how cities are designed to help accommodate for these new aircraft (SingularityHub, 2020).

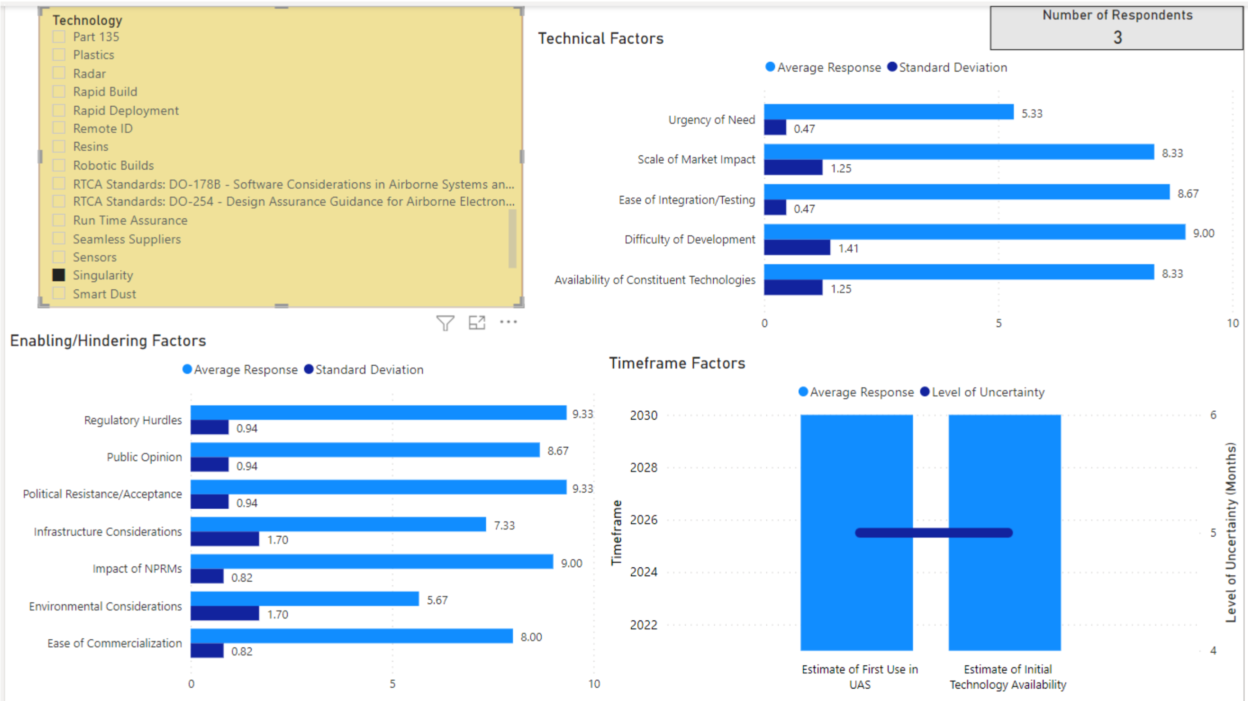

Figure 79. Singularity Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Difficult to Integrate
- **Difficulty of Development:** Extremely Difficult
- **Availability of Constituent Technologies:** Unavailable

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Unacceptable
- **Political Resistance/Acceptance:** Extreme Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** High NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2032.00 ± 5/12
  - **Estimate of Initial Technology Availability:** 2032.00 ± 5/12

7.58 Smart Dust

Smart dust is a small, millimeter-sized device that can operate as an individual component using a very small power supply. It consists of multiple small wireless microelectromechanical systems (MEMS) of 20 micrometers, 1 millimeter in size. MEMS are also known as motes which are equipped with sensors, cameras, and other communication mechanisms. These are ultimately connected to a computer network wirelessly to process the data procured through RFID (radio-frequency identification) technology. These minuscule devices are constructed using conventional silicon microfabrication techniques and can remain suspended in an environment similar to dust (Bose, 2020).

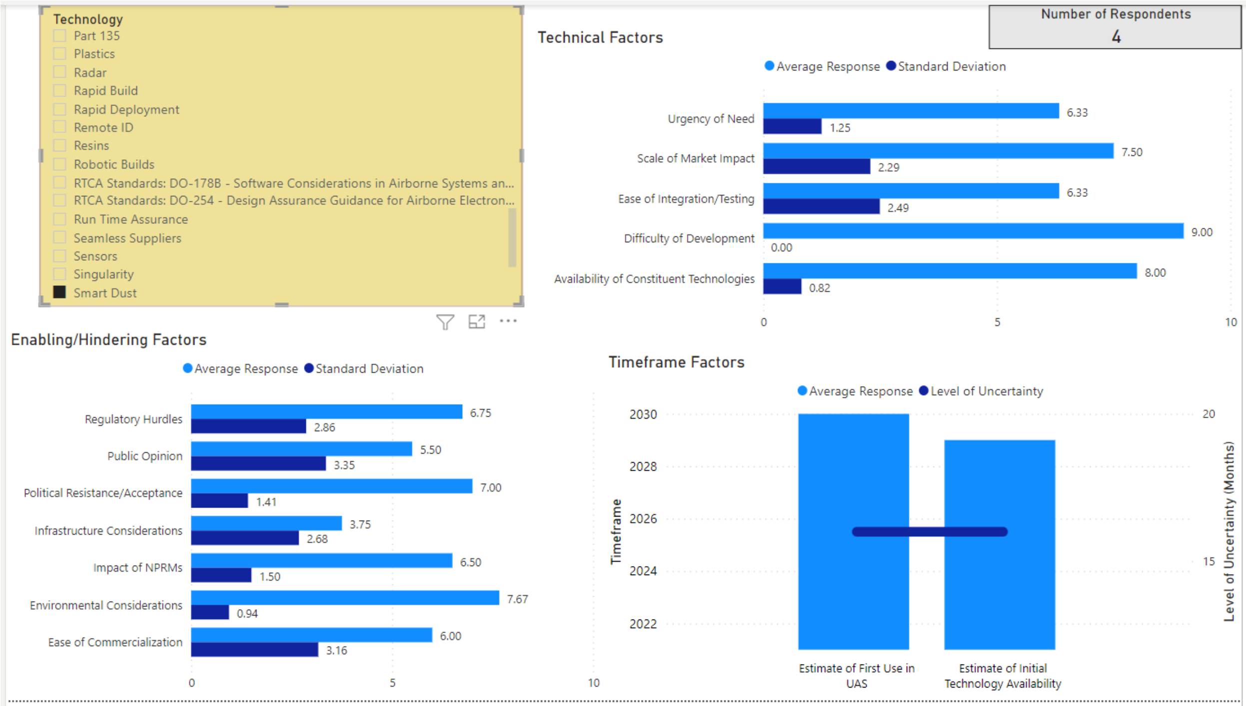

Figure 80. Smart Dust Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Extremely Difficult
- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Substantially Concerned About Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):

- **Estimated First Use in UAS:** 2030.00 ± 16/12
- **Estimate of Initial Technology Availability:** 2029.00 ± 16/12

7.59 Swarm

According to U.S. Army Training and Doctrine Command's Pamphlet 525-92, "Unmanned systems, including advanced battlefield robotic systems acting both autonomously and as part of a wider trend in man-machine teaming, will account for a significant percentage of a combatant force. Swarms of small, cheap, scalable, and disposable unmanned systems will be used both offensively and defensively, creating targeting dilemmas for sophisticated, expensive defensive systems. Swarming systems on the future battlefield will include not only unmanned aerial systems (UAS) but also swarms across multiple domains with the self-organizing, self-reconstituting, autonomous, ground, maritime (sub and surface), and subterranean unmanned systems." This technology will not be limited to the battlefield. One could envision swarms of autonomous fire suppressant delivery drones, for example, or swarms used in search-and-rescue (SAR) missions (Miller, 2020).

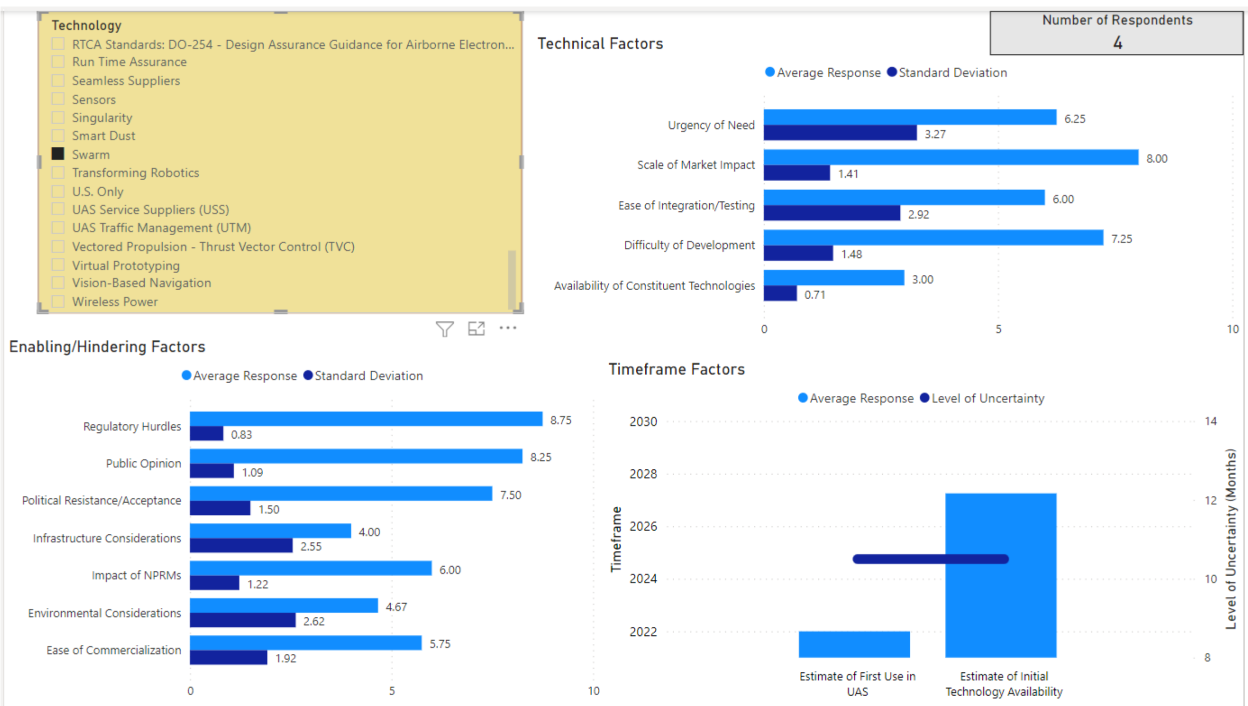

Figure 81. Swarm Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Unacceptable
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2022.00 ± 10.5/12
  - **Estimate of Initial Technology Availability:** 2027.25 ± 10.5/12

7.60 Transforming Robotics

A transforming robot is a robot that can change its form as needed. This technology is still in its early stages, but the applications are vast. The Army S&T investment areas for ground combat includes development of individual systems capable of 4D transformation, which can change the system's shape, modality, and function. For example, a swarm of unmanned systems will be capable of moving to an obstacle, such as a river, and then forming a structure to span the gap (U.S. Army CCDC Army Research Laboratory Public Affairs, 2020).

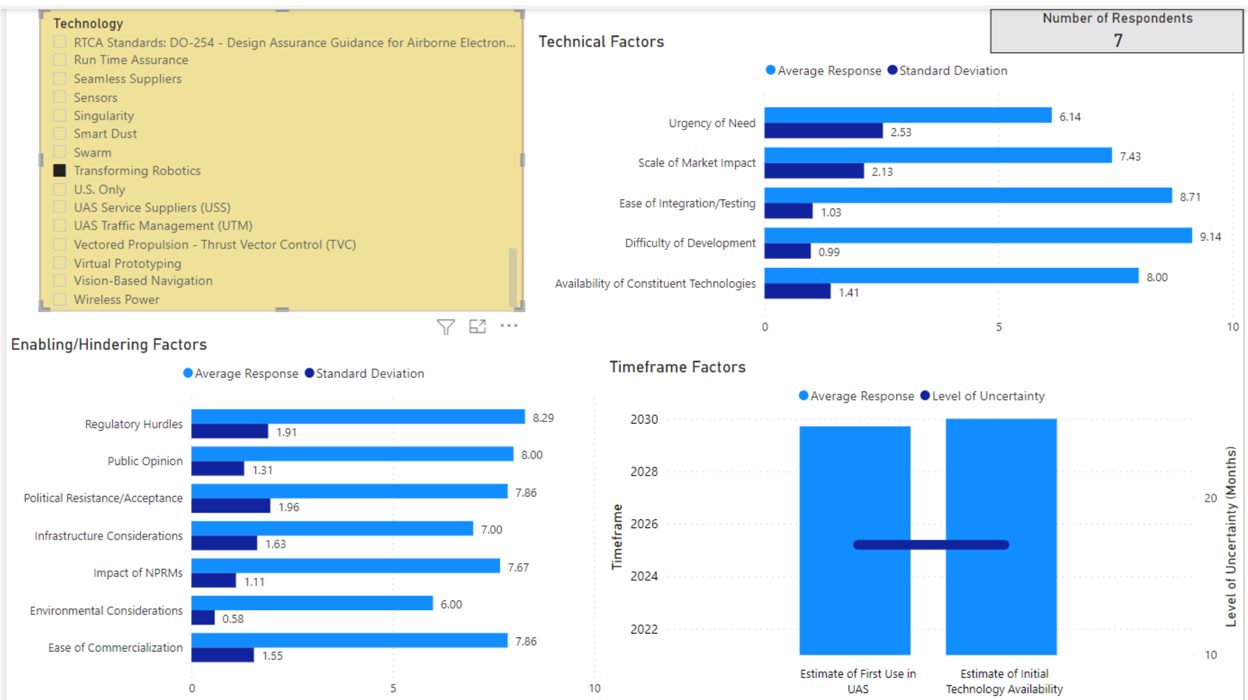

Figure 82. Transforming Robotics Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Difficult to Integrate
- **Difficulty of Development:** Extremely Difficult

- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Somewhat Unacceptable
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2029.71 ± 17/12
    - **Estimate of Initial Technology Availability:** 2030.14 ± 17/12

7.61 U.S. Only

A letter from the White House to the House Committee on Financial Services and the Senate Committee on Banking, Housing, and Urban Affairs, notifies the committee chairs that the Pentagon will start doing more to acquire small drones. The Department of Defense will take actions to develop and purchase equipment and materials needed for creating, maintaining, protecting, and expanding production capability for small unmanned aerial systems. The Pentagon and Congress have expressed concerns about the data security of drones that receive software updates from and can transmit cloud data to servers in China (Atherton & Mehta, 2019).

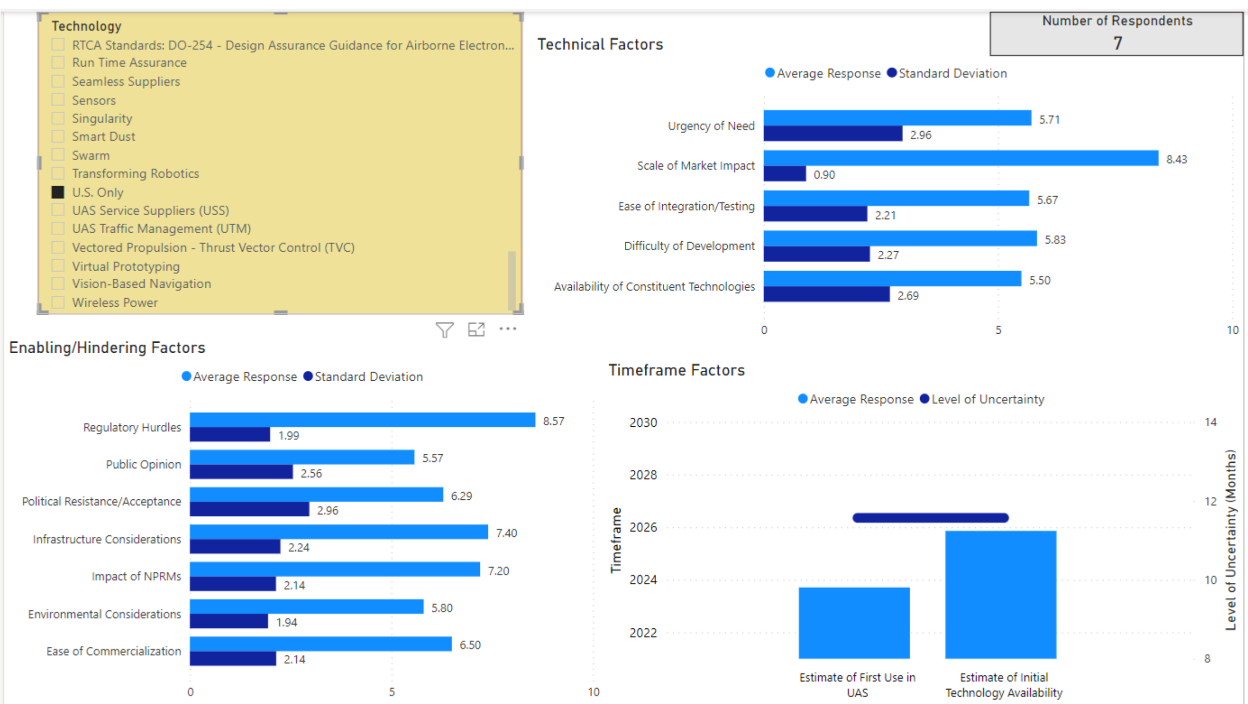

Figure 83. U.S. Only Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent

- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Serious Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

7.62 UAS Service Suppliers (USS)

UAS Service Suppliers, such as SkyGrid, help enable the safe, secure, and efficient use of our airspace. They act as a communication bridge between authorities and drone operators, and often provide tools to monitor the airspace, execute safe missions, and store operational data.

UAS service supplier network: Multiple UAS service suppliers can operate in the same geographical area and create a network to share information and ensure situational awareness. Shared information includes flight plans, flight status, and aircraft location (Akbar, 2020).

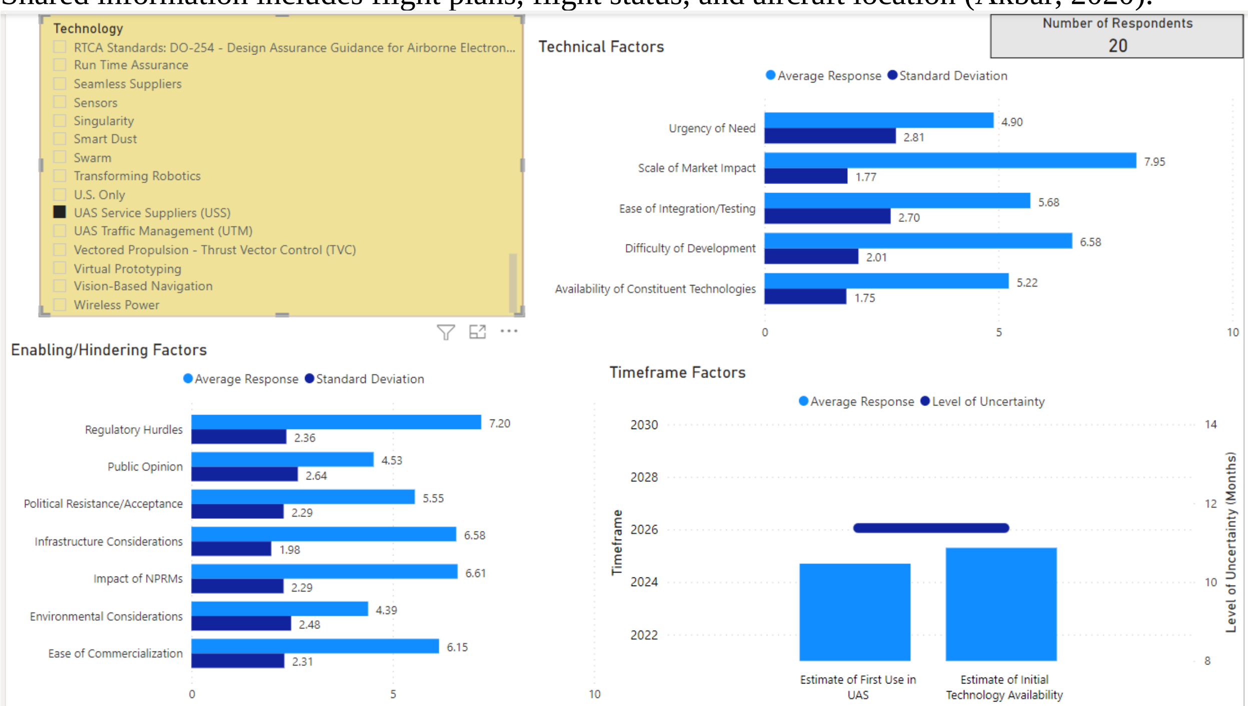

Figure 84. USS Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate

- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2024.70 ± 11.37/12
  - **Estimate of Initial Technology Availability:** 2025.30 ± 11.37/12

7.63 UAS Traffic Management (UTM)

Unmanned Aircraft System Traffic Management (UTM) is a "traffic management" ecosystem for uncontrolled operations that is separate from, but complementary to, the FAA's Air Traffic Management (ATM) system. UTM development will ultimately identify services, roles and responsibilities, information architecture, data exchange protocols, software functions, infrastructure, and performance requirements for enabling the management of low-altitude uncontrolled drone operations (Federal Aviation Administration, 2021e).

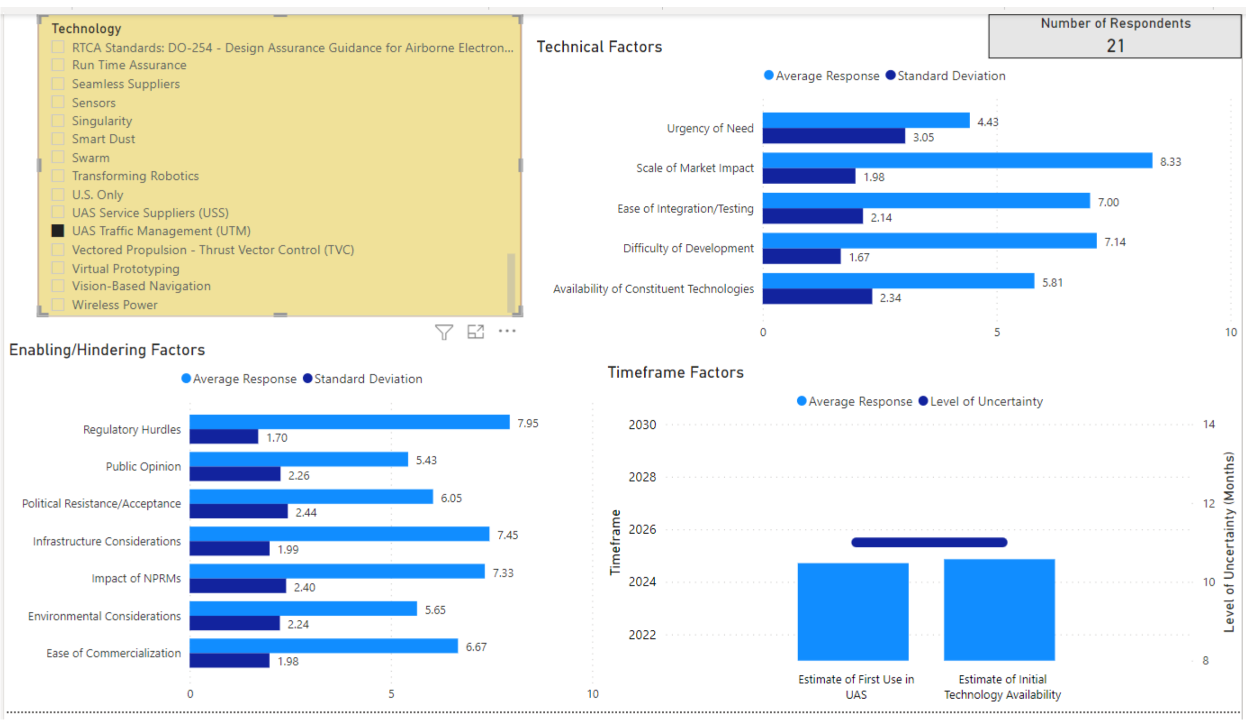

Figure 85. UTM Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent

- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2024.71 ± 11/12
    - **Estimate of Initial Technology Availability:** 2024.86 ± 11/12

7.64 Vectored Propulsion - Thrust Vector Control (TVC)

Thrust vectoring, also known as thrust vector control (TVC), is the ability of an aircraft, rocket, or other vehicle to manipulate the direction of the thrust from its engine(s) or motor(s) to control the attitude or angular velocity of the vehicle. Now being researched, Fluidic Thrust Vectoring (FTV) diverts thrust via secondary fluidic injections. Tests show that air forced into a jet engine exhaust stream can deflect thrust up to 15 degrees. Such nozzles are desirable for their lower mass and cost (up to 50% less), inertia (for faster, stronger control response), complexity (mechanically simpler, fewer, or no moving parts or surfaces, less maintenance), and radar cross section for stealth. This will likely be used in many UAVs, and 6th generation fighter aircraft (Saito & Fujimoto, 2009).

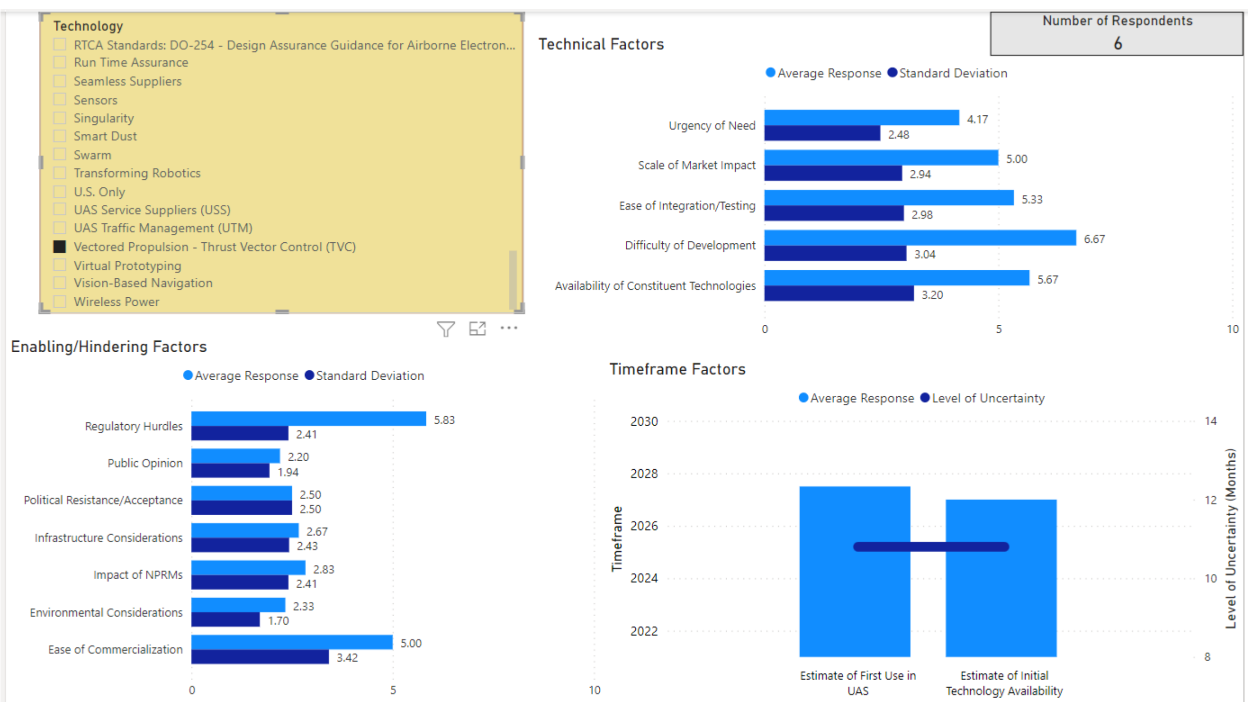

Figure 86. Vectored Propulsion Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2027.50 ± 10.8/12
  - **Estimate of Initial Technology Availability:** 2027.00 ± 10.8/12

7.65 Virtual Prototyping

Virtual prototyping is a method in the process of product development. It involves using CAD, computer-automated design (CAutoD), and computer-aided engineering (CAE) software to validate a design before committing to making a physical prototype. This is done by creating (usually 3D) computer generated geometrical shapes (parts) and either combining them into an "assembly" and testing different mechanical motions, fit and function. The assembly or individual parts could be opened in CAE software to simulate the behavior of the product in the real world (LaCourse, 2003).

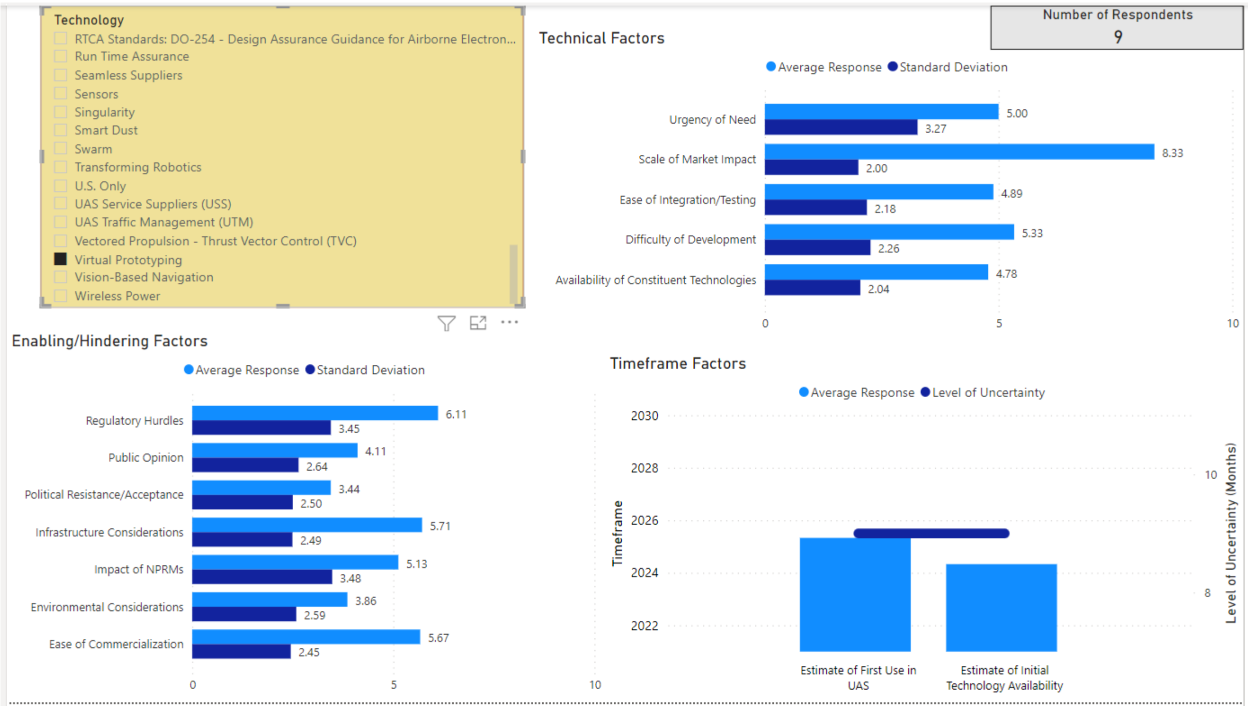

Figure 87. Virtual Prototyping Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2025.33 ± 9/12
    - **Estimate of Initial Technology Availability:** 2024.33 ± 9/12

7.66 Vision-Based Navigation

With the rapid development of computer vision, vision-based methods, which utilize cheaper and more flexible visual sensors, have shown great advantages in the field of UAV navigation. The vision-based navigation proves to be a primary and promising research direction of autonomous navigation with the rapid development of computer vision. First, the visual sensors can provide abundant online information of the surroundings; second, visual sensors are highly appropriate for perception of dynamic environment because of their remarkable anti-interference ability; third, most of visual sensors are passive sensors, which also prevent the sensing system from being detected (Lu et al., 2018).

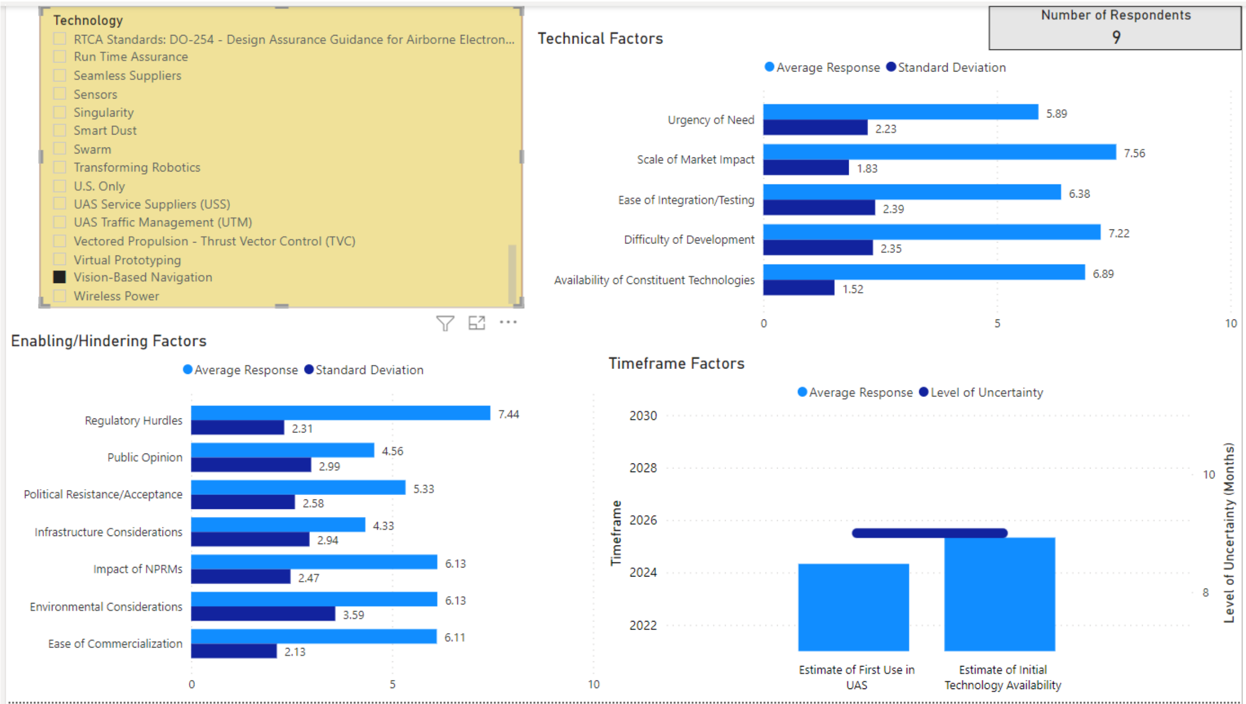

Figure 88. Vision-Based Navigation Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Slight Difficulty
- **Availability of Constituent Technologies:** Slightly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Substantially Concerned About Environmental Issues
- **Ease of Commercialization:** Significant Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2024.33 ± 9/12
  - **Estimate of Initial Technology Availability:** 2025.33 ± 9/12

7.67 Wireless Power

Certain proposed charging stations utilize inductive coupling to power the drone. This technique works by inducing a voltage in a transmitter coil placed on the charging pad, which generates a magnetic field to induce a voltage in a receiver coil on the drone to wirelessly charge it. The closer the drone is to the charging pad, the greater the voltage and charge that can be generated. Researchers found that a distance of 12cm or less is ideal to charge the drone's battery. When the primary coils on the pad and the receiving coils on the drone are separated beyond this distance, the charging will stop. Deliveries from an UAV, or drone, have launched in some cities, and it won't be long before drone drop-offs will be a regular occurrence. However, a number of power supply issues must be addressed first to make sure a UAV will hold charge long enough to fly to and from drop-off locations with additional payload (IEEE Xplore Digital Library, 2019).

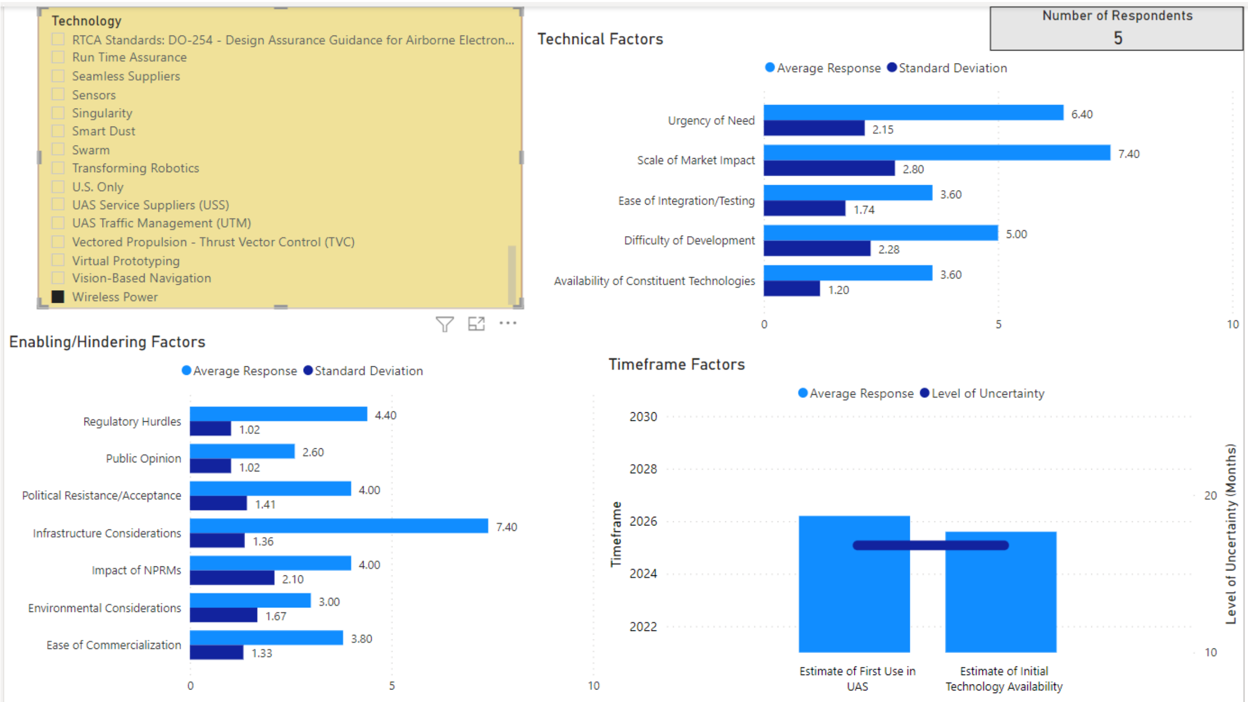

Figure 89. Wireless Power Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns

- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
    - **Estimated First Use in UAS:** 2026.20 ± 16.8/12
    - **Estimate of Initial Technology Availability:** 2025.60 ± 16.8/12

7.68 Findings Relative to Technologies and Concepts Categories

As the technical/conceptual categories were being defined, they were also categorized in nine aggregate categories. UAH grouped these technologies into the nine categories for organizational purposes. These were summarized in Table 1 and repeated here:

Aerodynamics/ Performance	Data/ Comm/ Security	Materials	Operations/ Flight	Power	Regulation	Research/ Design/ Systems	Sensors/ Imagery	Supply Chain/ Manufacturing
Adaptive Aerostructures	6G	Aluminum/Aluminum Alloys	Autopilots/Flight Control Systems (FCS)	Alternative Power	BLOS	ASSURE	3D Scanning	3D Printing/Additive Manufacturing
Autonomy Expert Systems	Cyber Security	Composites	Brain Control	Battery Management	BVLOS	Business Case Tool Sets	Advanced Sensing	Rapid Build
Beyond Aerodynamic Maneuvers (Supermaneuverability)	First Net	Conductive Inks	Gesture Control	Wireless Power	Certification	CONOPS Driven	Augmented Reality	Robotic Builds
Machine Learning	IOT Convergence	Metamaterials	GPS Denied		Integration Pilot Program (IPP)	Integrators	Off-board Sensors	Seamless Suppliers
Morphing Materials	Live Map	Plastics	LAANC		Notice of Proposed	Miniaturization	Radar	U.S. Only
Non Deterministic Approach	LVC	Resins	On-Board Autonomy		Part 135	Model Based Systems Engineering	Sensors	
Vectored Propulsion - Thrust Vector	Mesh Networks		Rapid Deployment		Remote ID	NanoTech	Smart Dust	
	Micro Clouds		Run Time Assurance		RTCA Standards: DO-178B - Software Considerations in Airborne	Singularity		
	Multi-Threading		Swarm		RTCA Standards: DO-254 - Design Assurance Guidance for Airborne	Virtual Prototyping		
			Transforming Robotics					
			UAS Service Suppliers (USS)					
			UAS Traffic Management					
			Vision-Based Navigation					

The following subsections are based on the summarized data within each of these categories.

7.68.1 Aerodynamics/Performance

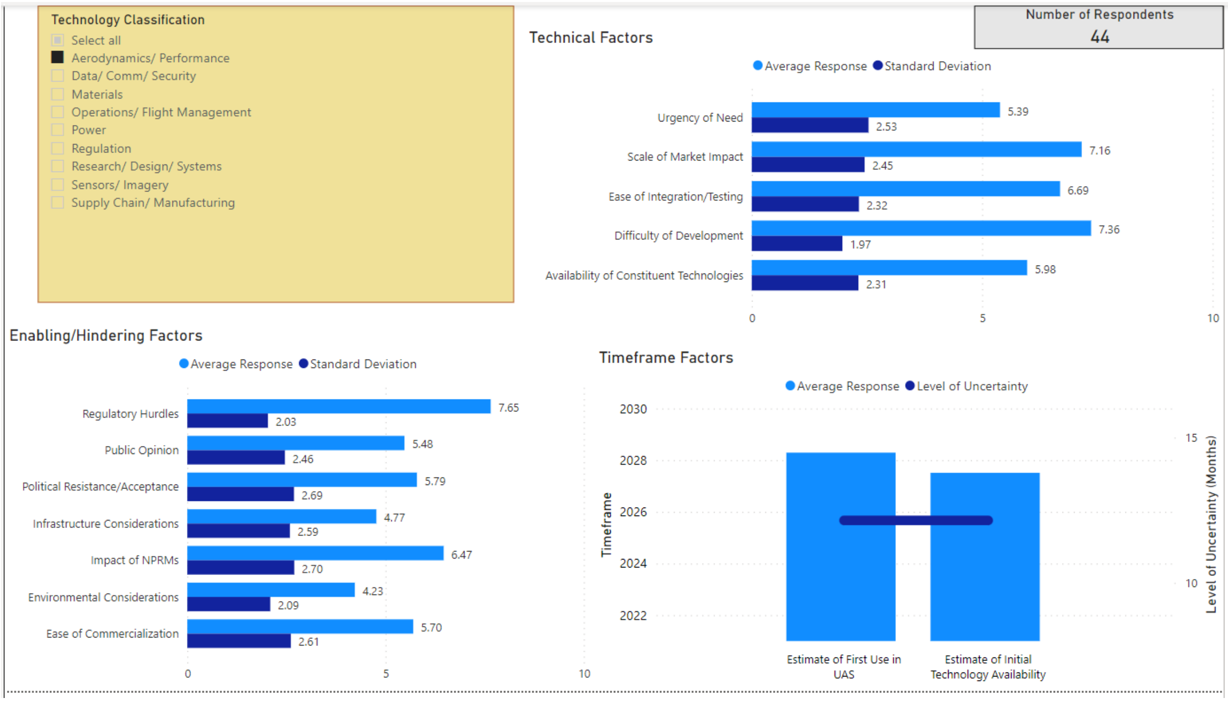

Figure 90. Aerodynamics/Performance Category Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2028.29 ± 12.15/12
  - **Estimate of Initial Technology Availability:** 2027.51 ± 12.15/12

7.68.2 Data/Comm/Security Category Responses.

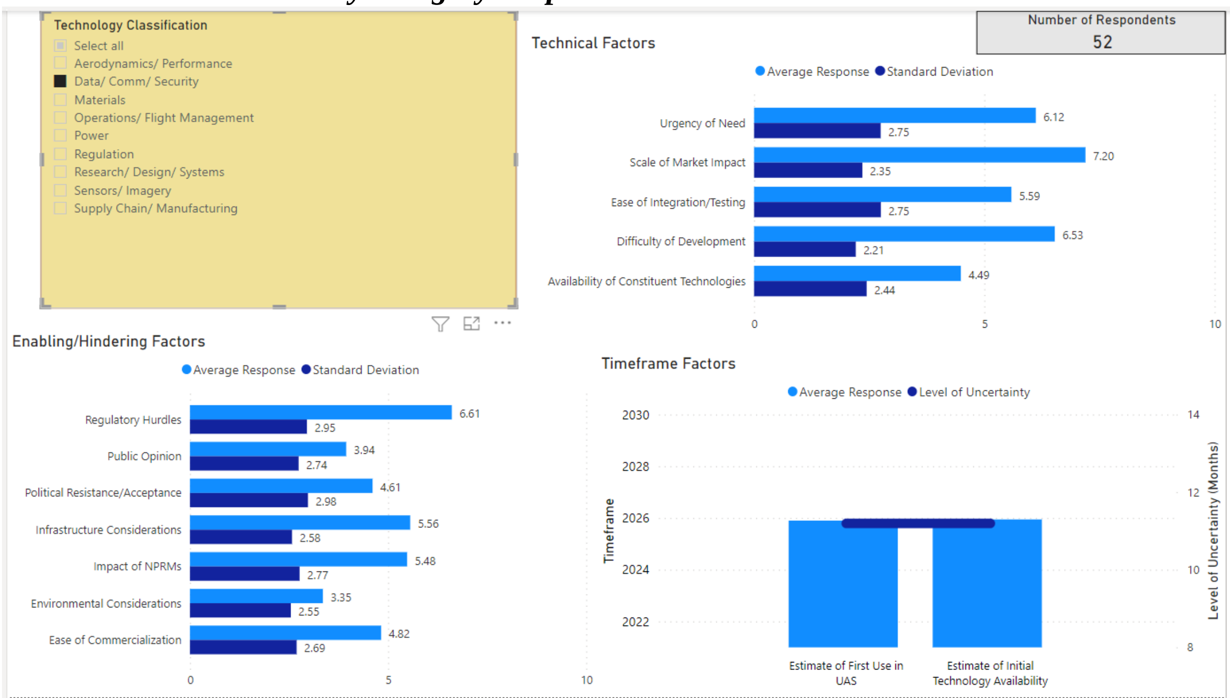

Figure 91. Data/Comm/Security Category Responses.

Technical Factors

- **Urgency of Need:** Slightly Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2025.90 ± 11.19/12
  - **Estimate of Initial Technology Availability:** 2025.94 ± 11.19/12

7.68.3 Materials

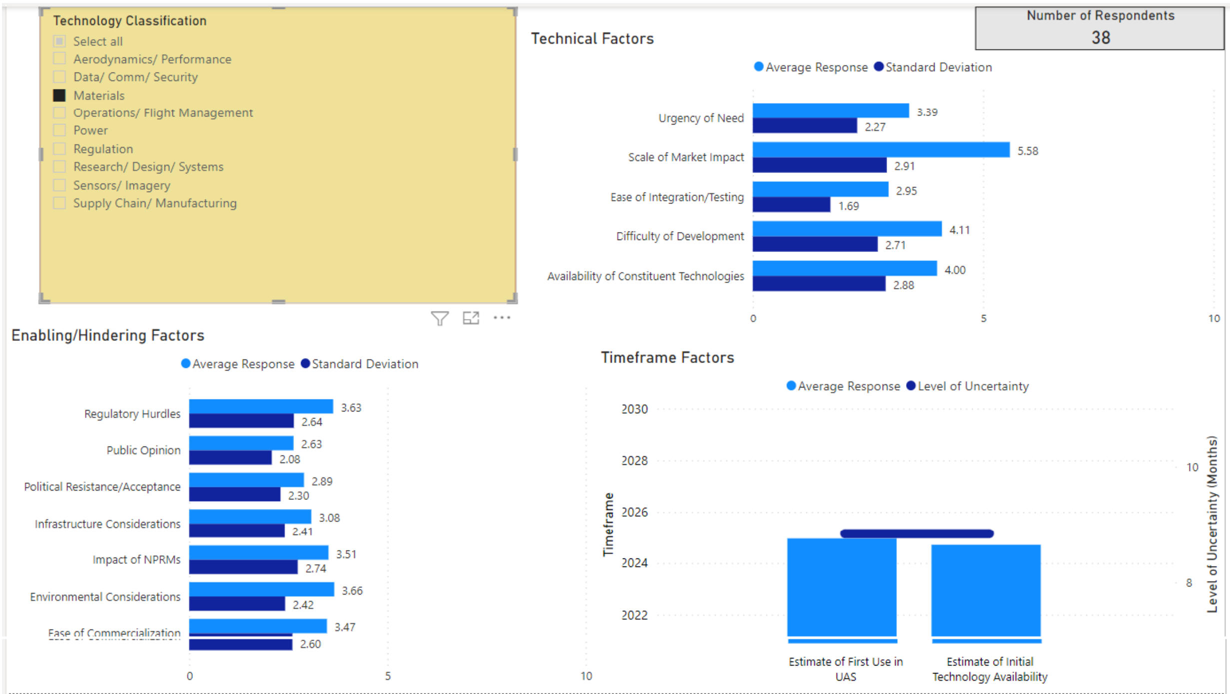

Figure 92. Materials Category Responses.

Technical Factors

- **Urgency of Need:** Quite Urgent
- **Scale of Market Impact:** Moderate Impact
- **Ease of Integration/Testing:** Moderately to Easy Integration
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Mostly Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Minor Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Low to Moderate Infrastructure Concerns
- **Impact of NPRMs:** Low NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Low-Moderate Commercialization Challenges

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2024.95 ± 8.84/12
  - **Estimate of Initial Technology Availability:** 2024.71 ± 8.84/12

7.68.4 Operations/ Flight Management

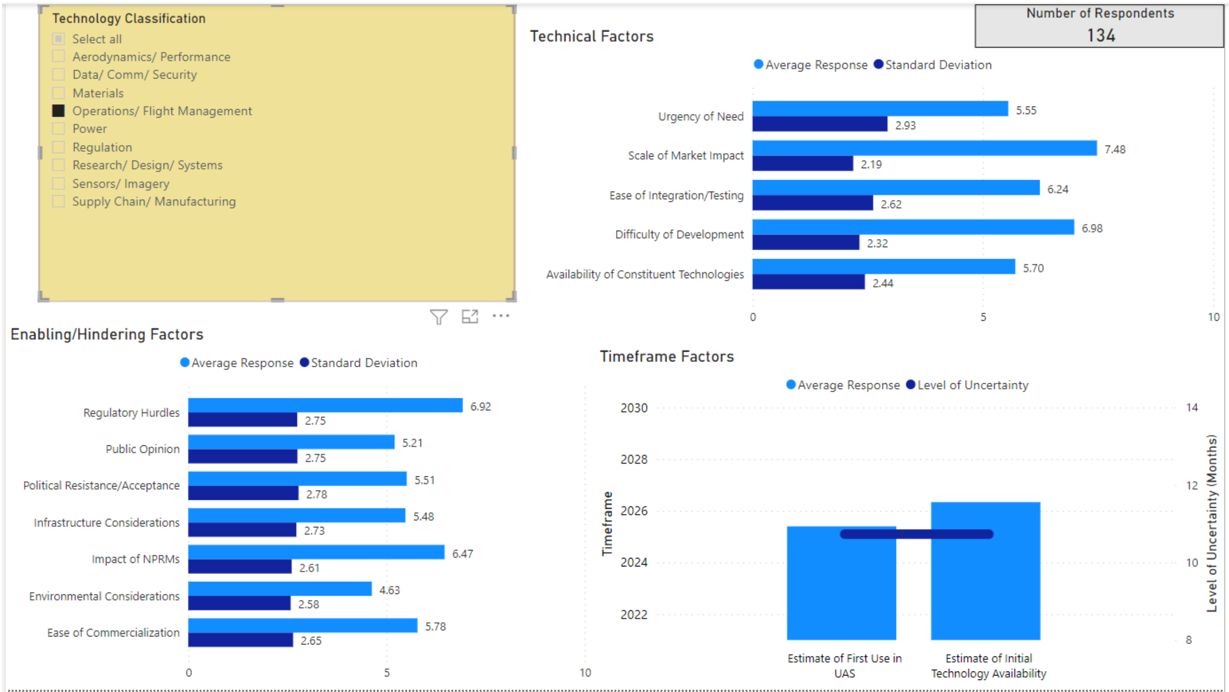

Figure 93. Operations/Flight Management Category Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Somewhat Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2025.40 ± 10.73/12
  - **Estimate of Initial Technology Availability:** 2026.34 ± 10.73/12

7.68.5 Power

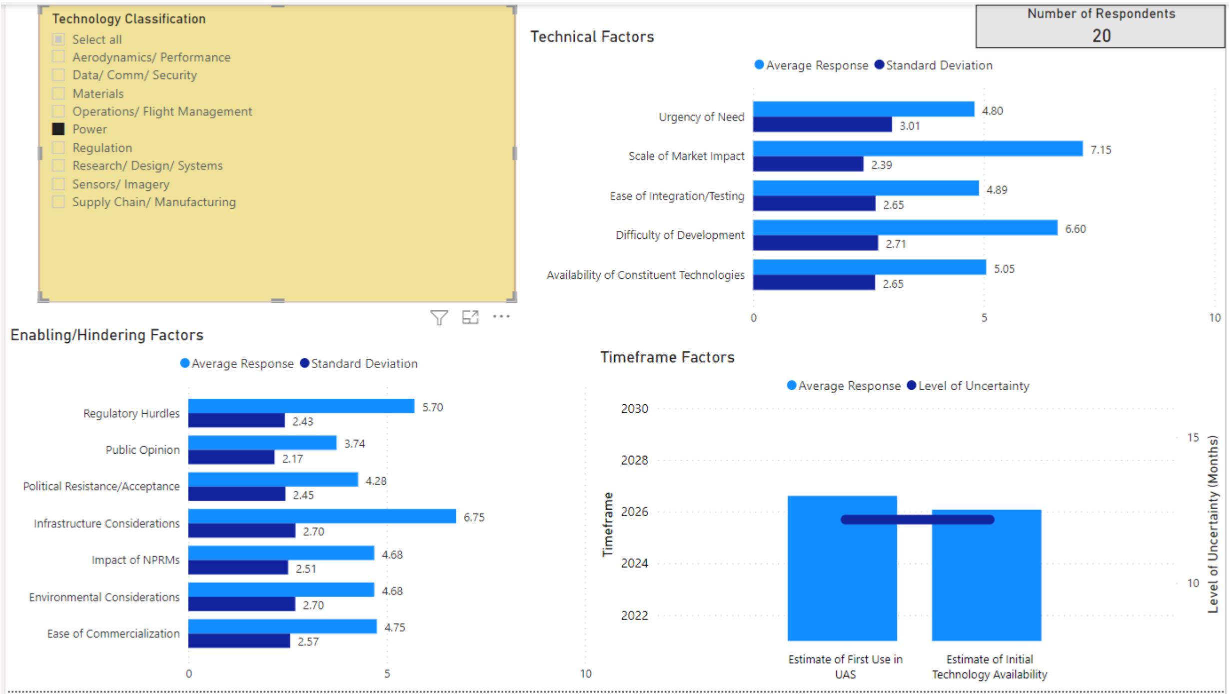

Figure 94. Power Category Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate to High Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2026.61 ± 12.17/12
  - **Estimate of Initial Technology Availability:** 2026.08 ± 12.17/12

7.68.6 Regulation

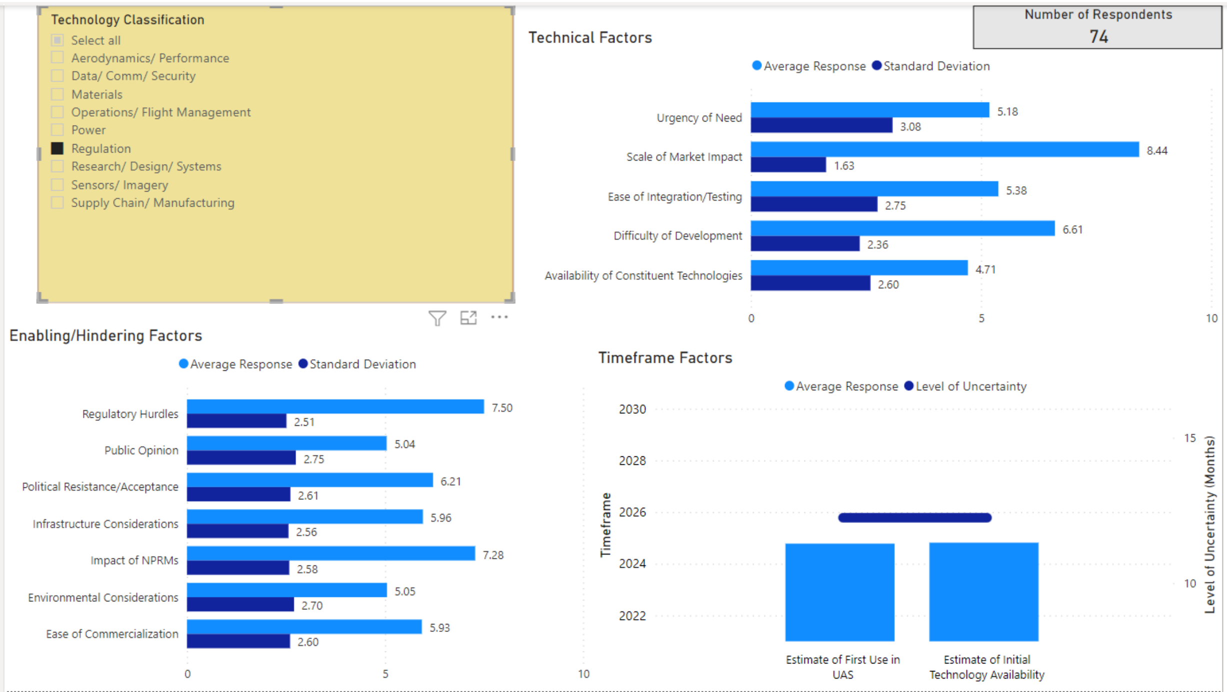

Figure 95. Regulation Category Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Substantial Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Substantial NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2024.78 ± 12.25/12
  - **Estimate of Initial Technology Availability:** 2024.82 ± 12.25/12

7.68.7 Research/Design/Systems

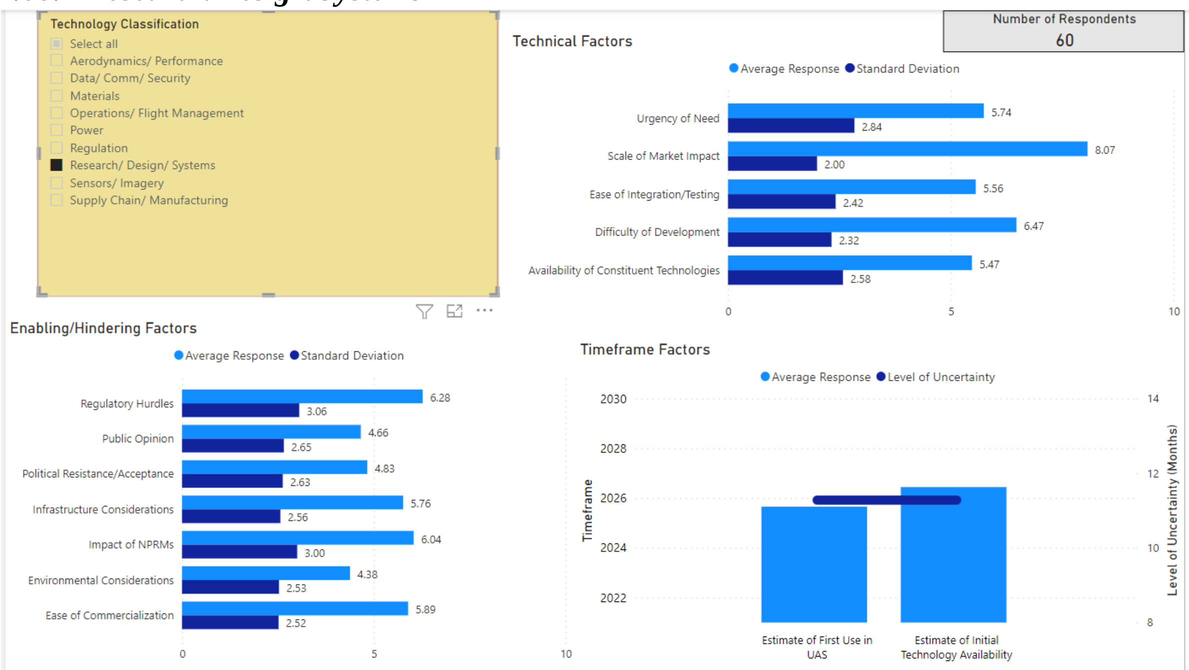

Figure 96. Research/Design/Systems Category Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Substantial Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Substantially Difficult
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Substantial Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2025.66 ± 11.28/12
  - **Estimate of Initial Technology Availability:** 2026.44 ± 11.28/12

7.68.8 Sensors/ Imagery

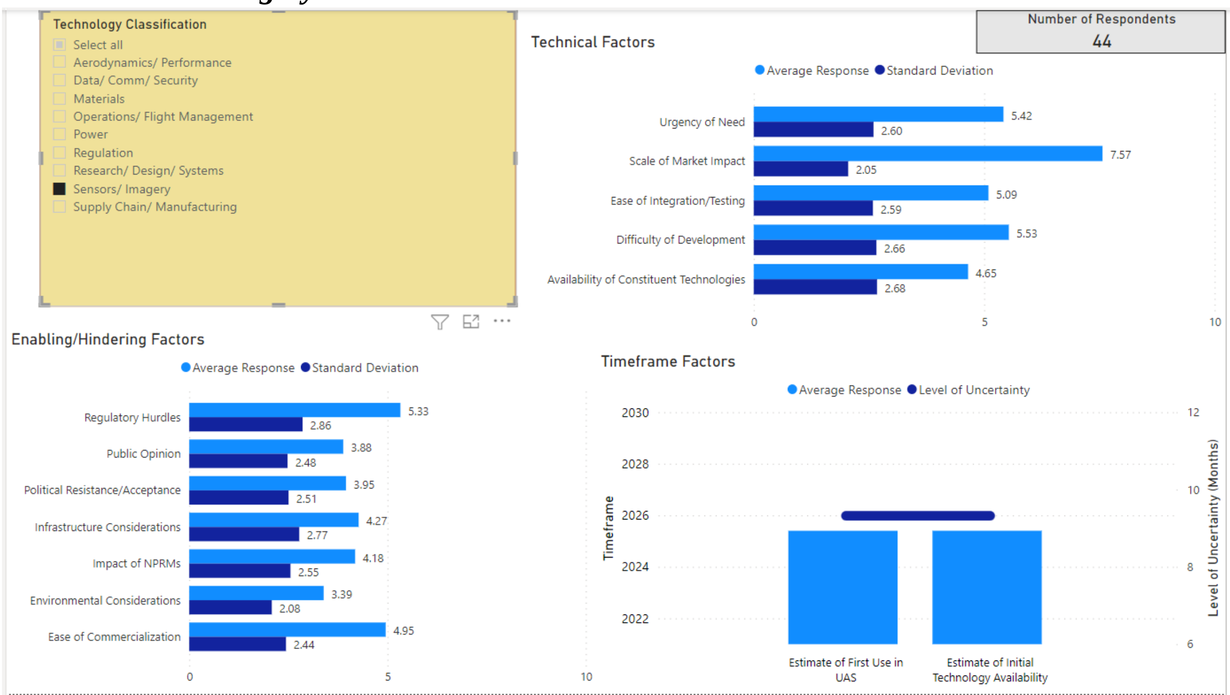

Figure 97. Sensors/Imagery Category Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Somewhat Acceptable
- **Political Resistance/Acceptance:** Few Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Low to Moderate Environmental Concerns
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2025.40 ± 9.32/12
  - **Estimate of Initial Technology Availability:** 2025.40 ± 9.32/12

7.68.9 Supply Chain/ Manufacturing

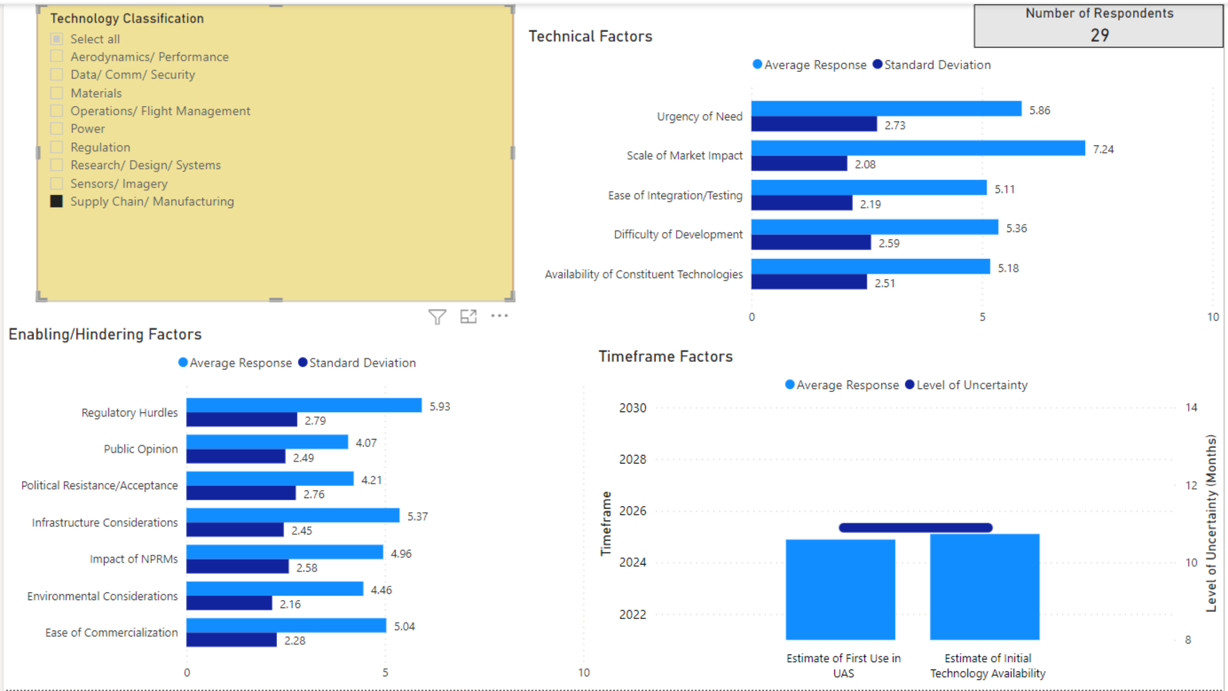

Figure 98. Supply Chain/Manufacturing Category Responses.

Technical Factors

- **Urgency of Need:** Moderately Urgent
- **Scale of Market Impact:** Above Moderate Impact
- **Ease of Integration/Testing:** Moderately Difficult to Integrate
- **Difficulty of Development:** Moderate Difficulty
- **Availability of Constituent Technologies:** Somewhat Available

Enabling/Hindering Factors

- **Regulatory Hurdles:** Moderate Regulatory Hurdles
- **Public Opinion:** Neutral Acceptability
- **Political Resistance/Acceptance:** Moderate Political Challenges
- **Infrastructure Considerations:** Moderate Infrastructure Concerns
- **Impact of NPRMs:** Moderate NPRM Impact
- **Environmental Considerations:** Moderately Concerned Regarding Environmental Issues
- **Ease of Commercialization:** Moderately Difficult to Commercialize

Timeframe Factors

- Average Projected Times (Year ± Uncertainty):
  - **Estimated First Use in UAS:** 2024.88 ± 10.89/12
  - **Estimate of Initial Technology Availability:** 2025.10 ± 10.89/12

8. APPENDIX – B4: SAMPLE SCREENS FROM THE PASAUT APPLICATION

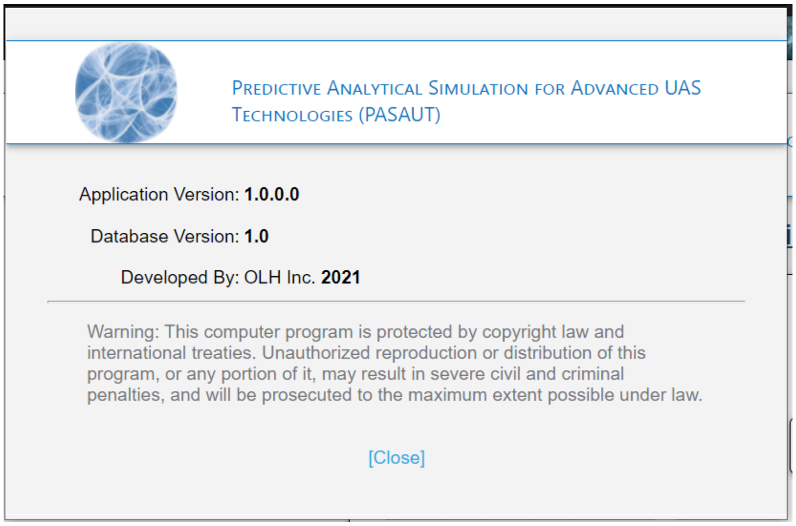

Figure 99. About Screen (Available to All Users).

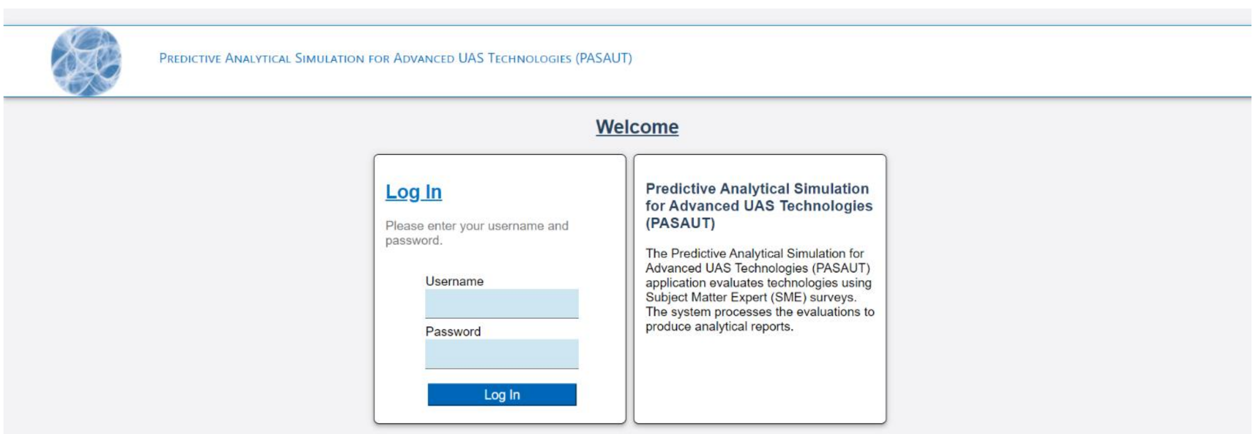

Figure 100. Log In Screen (Available to All Users).

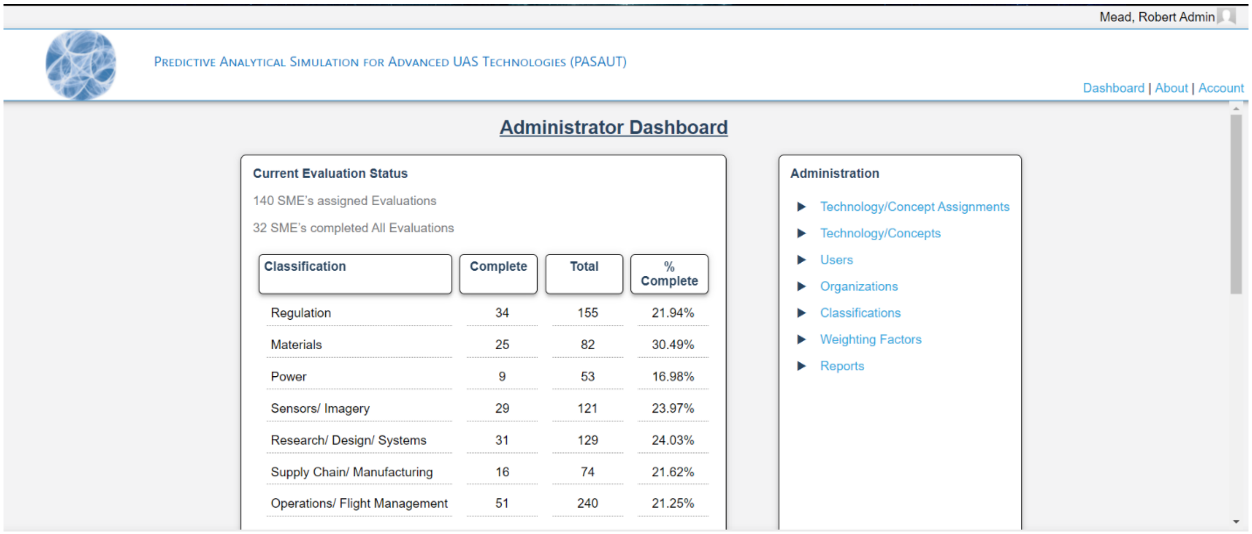

Figure 101. Administrator Dashboard (Administrator Only Screen).

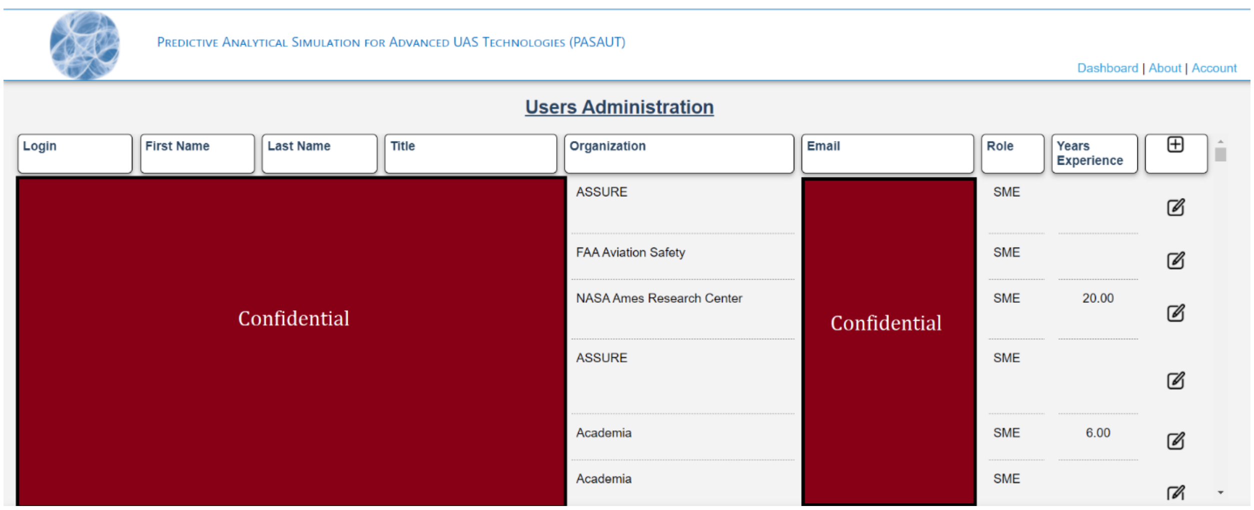

Figure 102. User Administration Screen (Administrator Only Screen).

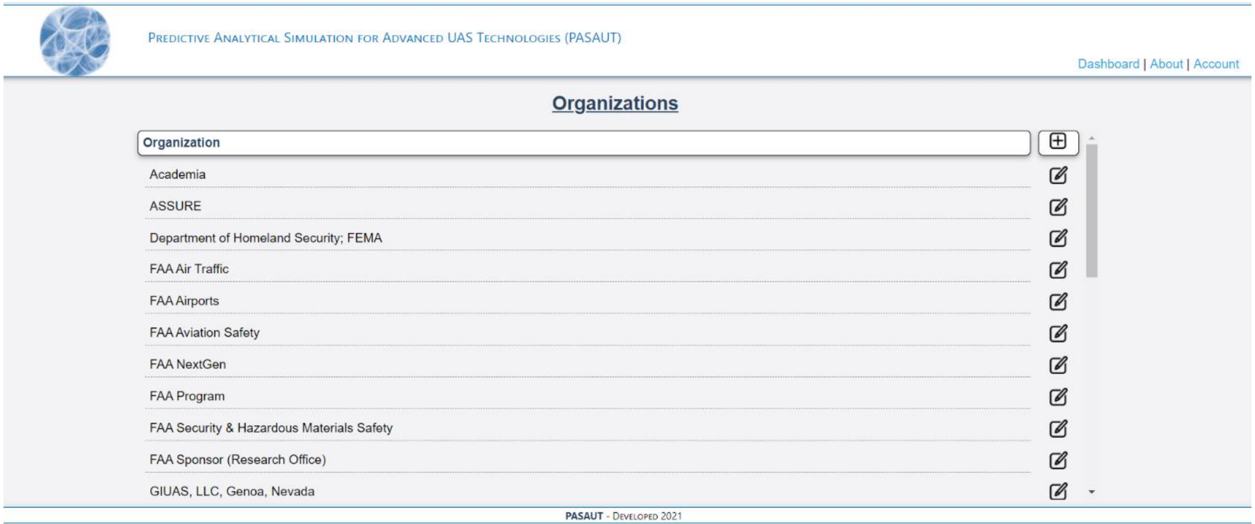

Figure 103. Organizations Screen (Administrator Only Screen).

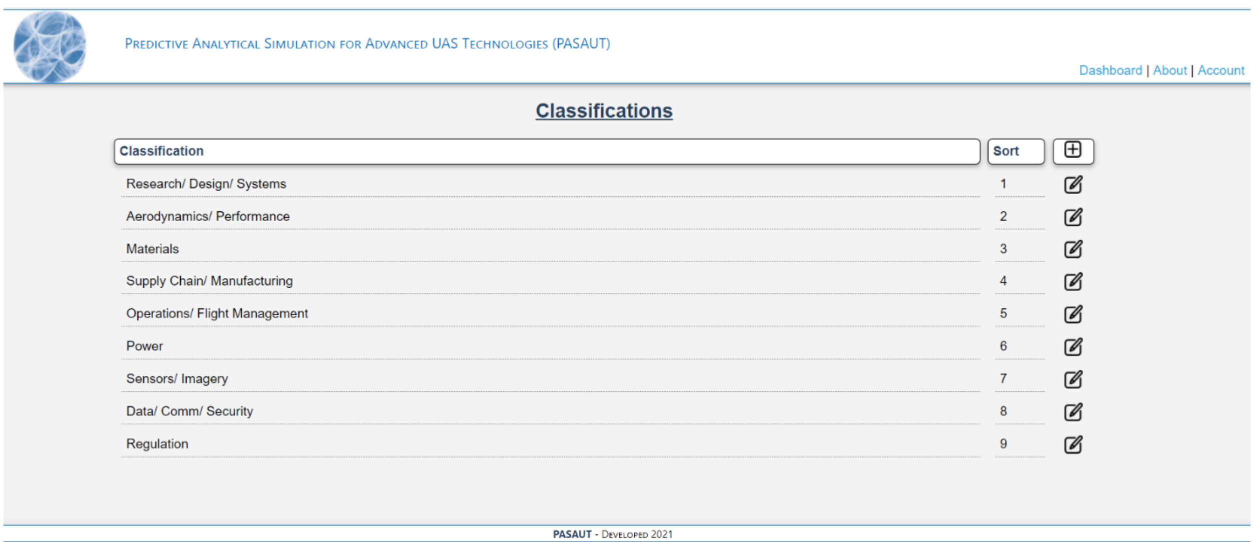

Figure 104. Organizations Screen (Administrator Only Screen).

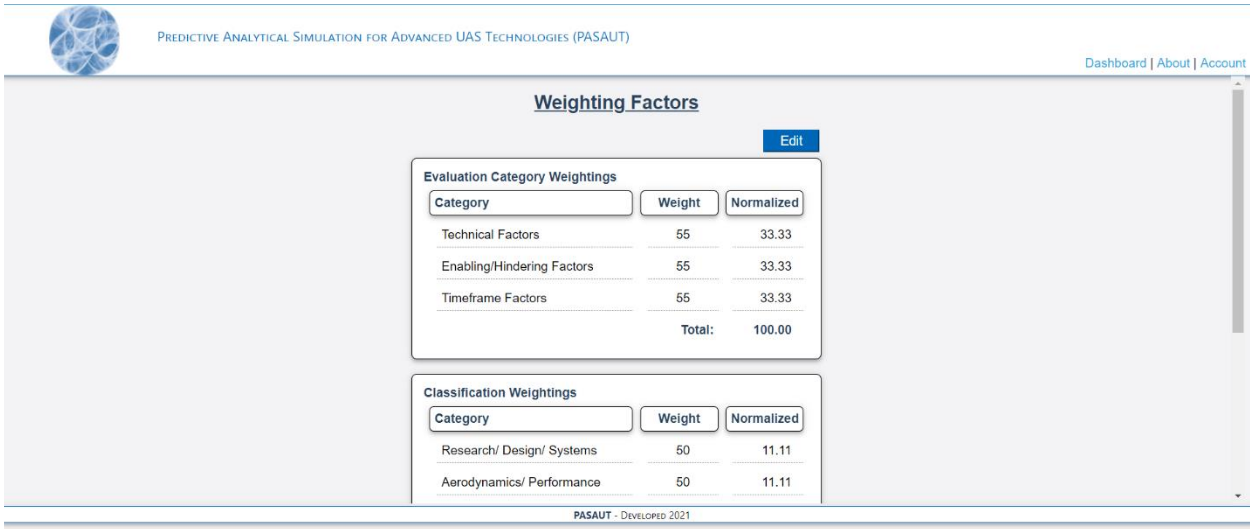

Figure 105. Weighting Factors Screen (Administrator Only Screen).

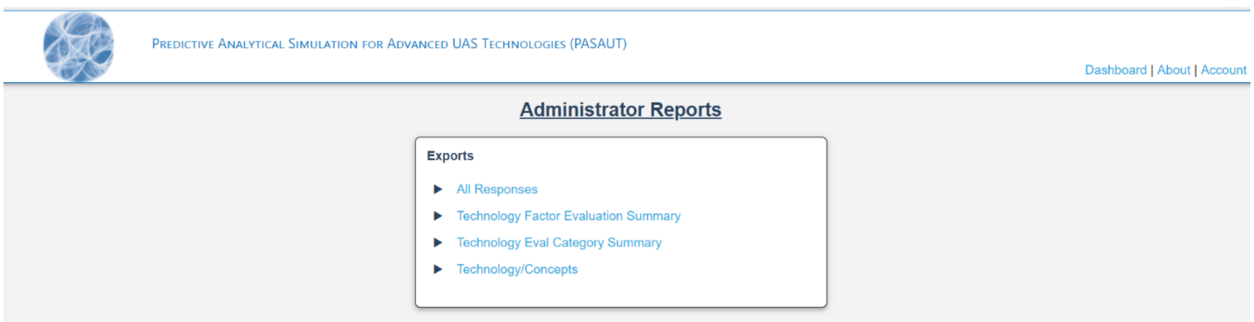

Figure 106. Reports Screen (Administrator Only Screen).

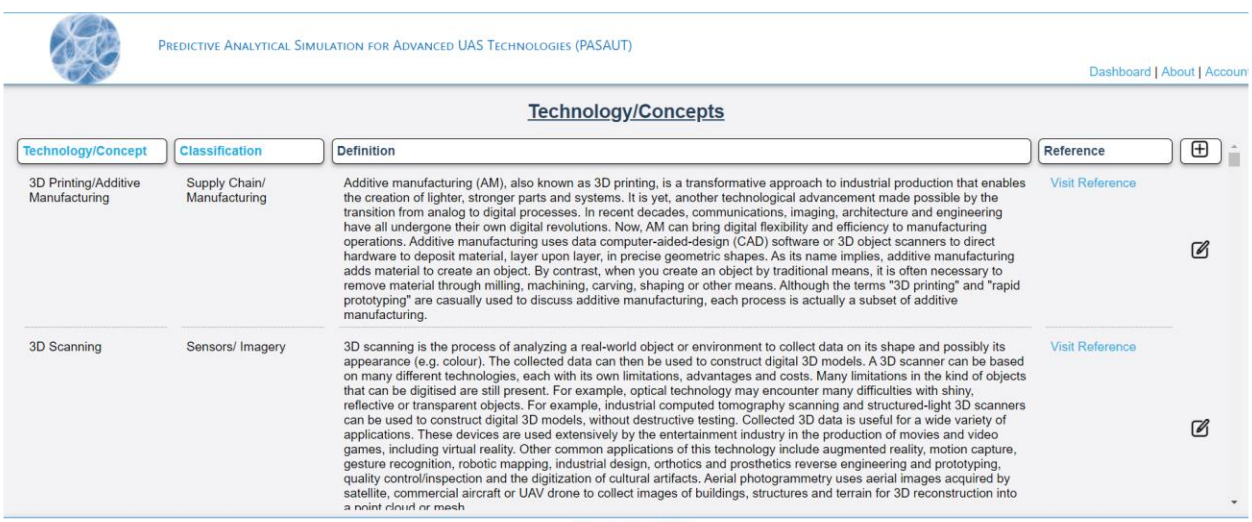

Figure 107. Technology/Concept Screen (Administrator Only Screen).

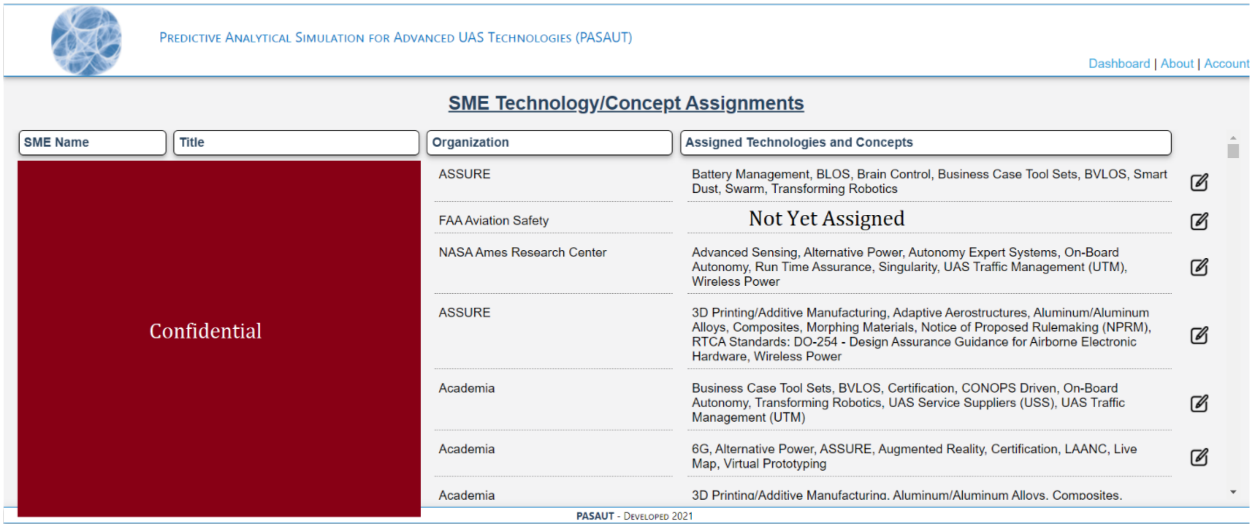

Figure 108. SME Technology/Concept Assignments Screen (Administrator Only Screen).

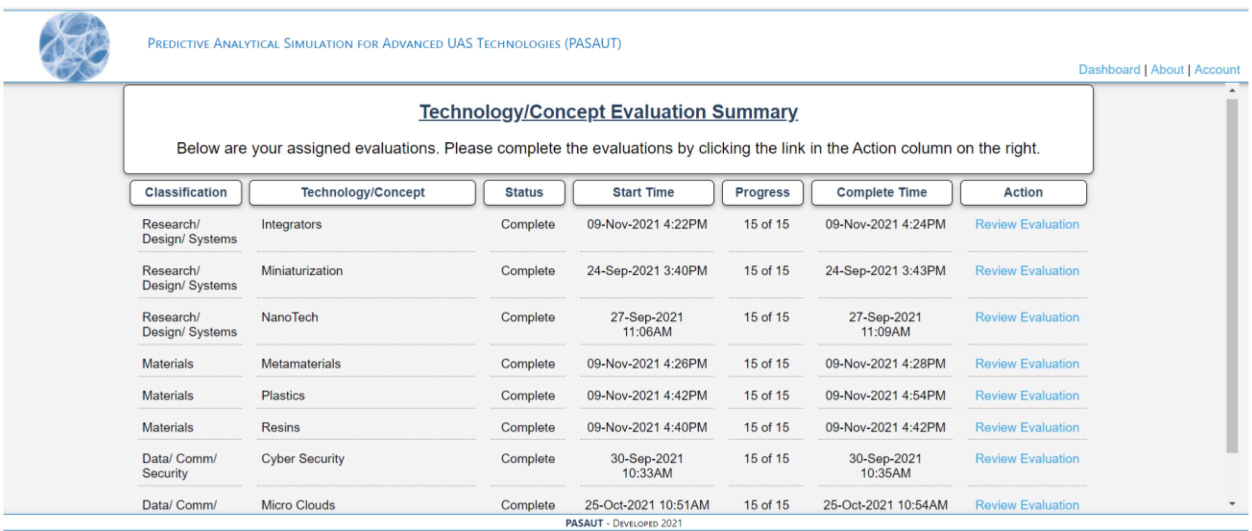

Figure 109. Technology/Concept Evaluation Summary (SME Screen).

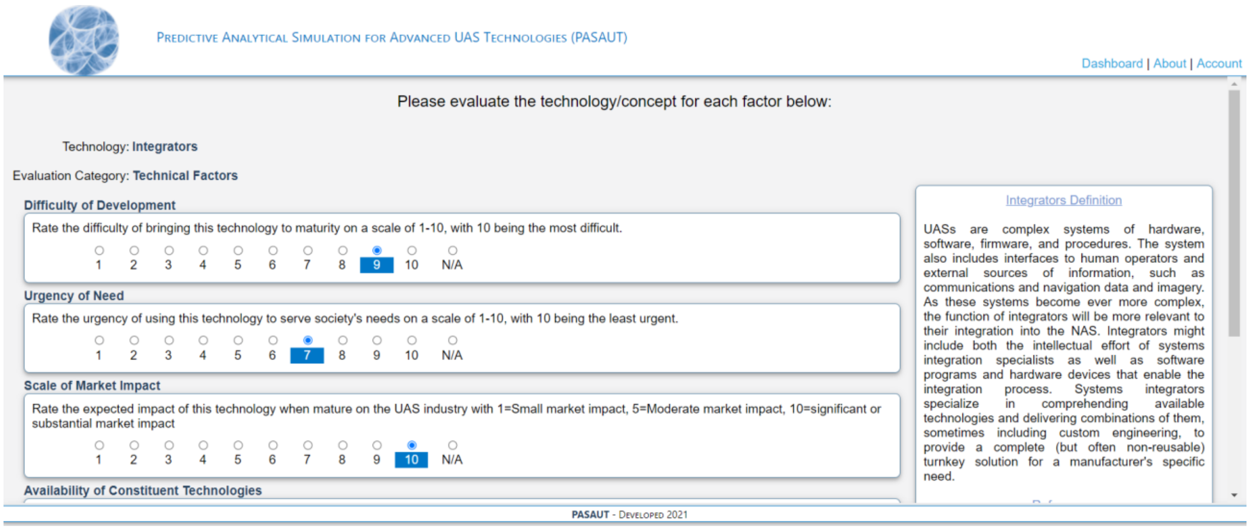

Figure 110. Technology Evaluation Input Screen (SME Screen).

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