JOHNS HOPKINS
WHITING SCHOOL
of ENGINEERING

Self-contained Emergency Communication Unit for Recovery Efforts
(SECURE) Mobile Mesh

Jennifer Glock
Spring 2020

Thank you to my mentor, Steve Biemer, for your support and guidance throughout this course!

SECURE Mobile Mesh
Presentation Outline

- Student Biography
- Intro & Need
- CONOPS
- Functional Concept
- Physical Concept
- Formal Trade Study
- Risk Management
- Test Plan
- System Specifications
- Summary
- Lessons Learned
- Recommendations

Student Biography

- Current Work Life: Systems Engineer at JHU/APL - March 2019
  - Previous Work Life:
    - Research Department @ JHU/APL (3 years)
    - Telecommunications Infrastructure Companies (5 years)
      - Remote areas → Tier 1 Carriers

- Personal Life:
  - Avid volleyball player
  - Travel enthusiast
  - New Auntie to Kirra

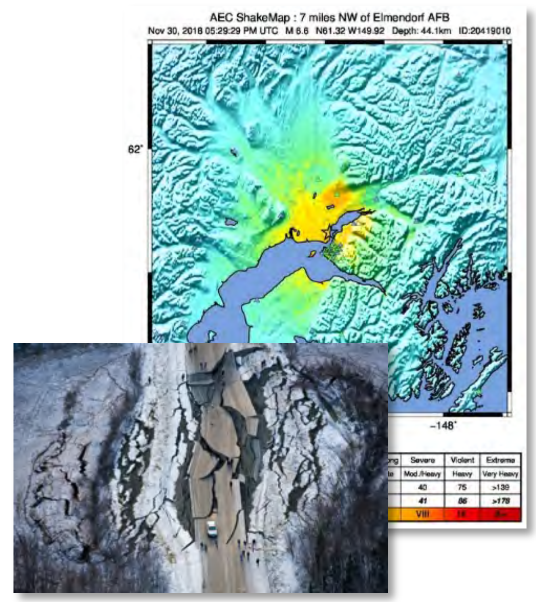
- Education:
  - BS in Business Information Systems, Stevenson University, 2012
  - Pursuing MS in Systems Engineering, Johns Hopkins, (anticipated) 2020

Introduction & Need for the System

Self-contained Emergency Communication Unit for Recovery Efforts (SECURE) Mobile Mesh

- Need for the System: In some regions, Telecommunications Infrastructure is limited
  - If the communication link is broken, users are unable to contact family or emergency personnel
  - Emergency Personnel quickly need real-time situational awareness following a natural disaster
    - Need to know location of inaccessible roads so they can quickly get to residents in need of help/extraction
    - Current technology is limited, expensive or in various forms

- Introduction to SECURE Mobile Mesh:
  - Provides communication network when other avenues are inaccessible
  - Collects reconnaissance data to provide a real-time, aerial picture



7.1 Magnitude Earthquake in Anchorage left residents without food or water supply for days[1]

1. Anchorage Daily News Editorial Board. (2019, December 1). What has the earthquake taught us? Retrieved from Anchorage Daily News: https://www.adn.com/opinions/editorials/2019/12/01/what-has-the-earthquake-taught-us/

Requirements Generation

User Need Generation

- Interviewed SMEs to discuss need for post-disaster analysis, and current methods of gathering reconnaissance data
- Identified external entities that would interface with the system
- Access to external SMEs/stakeholders is limited

System Objectives

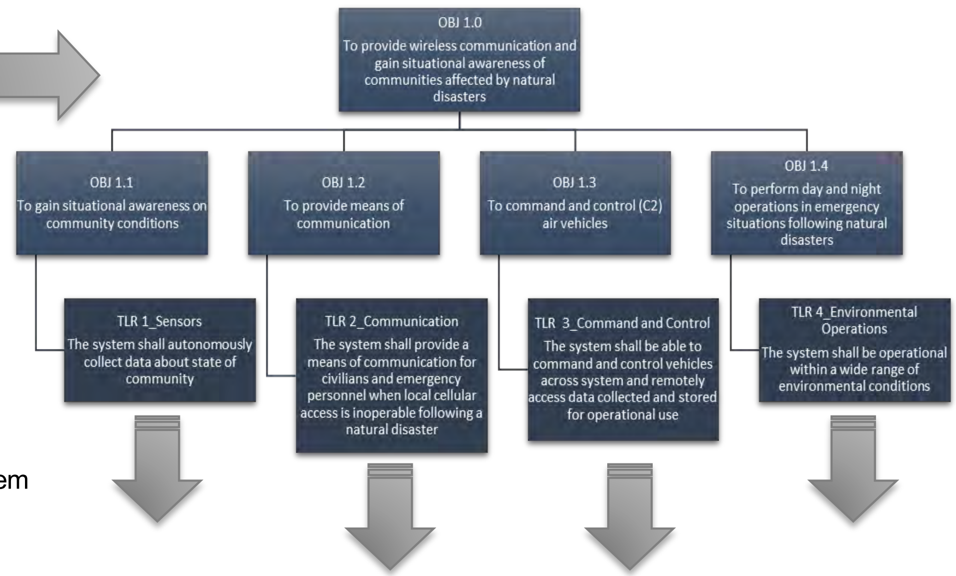
- Derived from SME interviews and additional research of current methods used for disaster recovery

Top Level Requirements

- Derived top-level requirements from system objectives

Generation of System Requirements

- Operational: Capabilities defined by the customer **(56)**
- Functional: Derived from operational requirements, define the actions needed for the system to meet the customer's needs **(67)**
- Performance: Threshold values needed to accomplish the system needs **(15)**
- Constraints: Defines a system's operational boundary **(17)**



Verification Type	Total	% of Total
Qualitative	138	89%
Quantitative	17	11%
Total	155	

Research on Open Source Data Included: geospatial.gov, Google Earth, NOAA Imagery, FEMA, Amazon Public Datasets

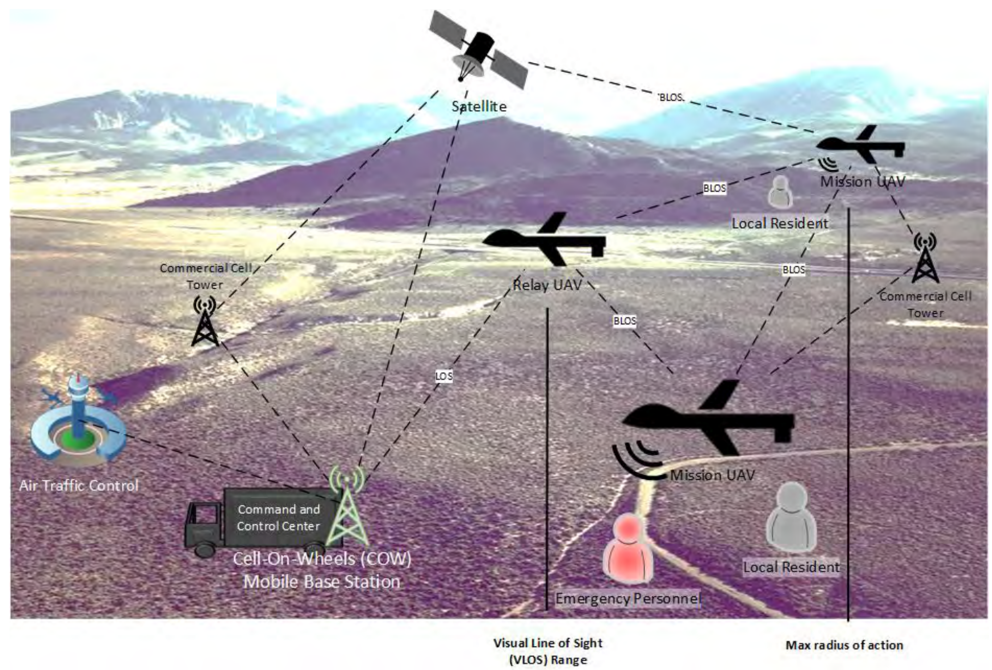
CONOPS - Overview

Concept of Operations converts the User Needs and System Objectives into a high-level operational picture of the integrated system

- CONOPS was used in:
  - Development of functions
  - Constrain the system design
  - Inform risks
  - Create test plan objectives
  - Refine or reveal interface requirements that are needed for successful system operation

- CONOPs was minimally refined for expansion throughout the project, but the original scenarios remained the same

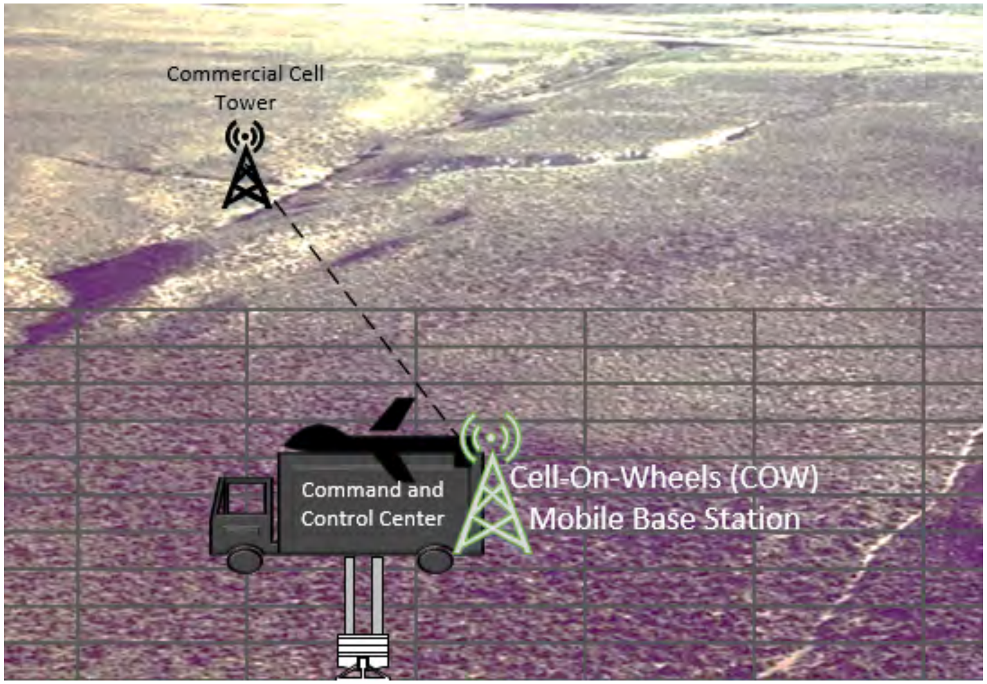
- Initial identification of Internal Systems:
  - Unmanned Aerial Vehicles
  - Cell on Wheels
  - Command and Control (C^2) Center



SECURE Mobile Mesh OV-1

CONOPs – Scenario Review

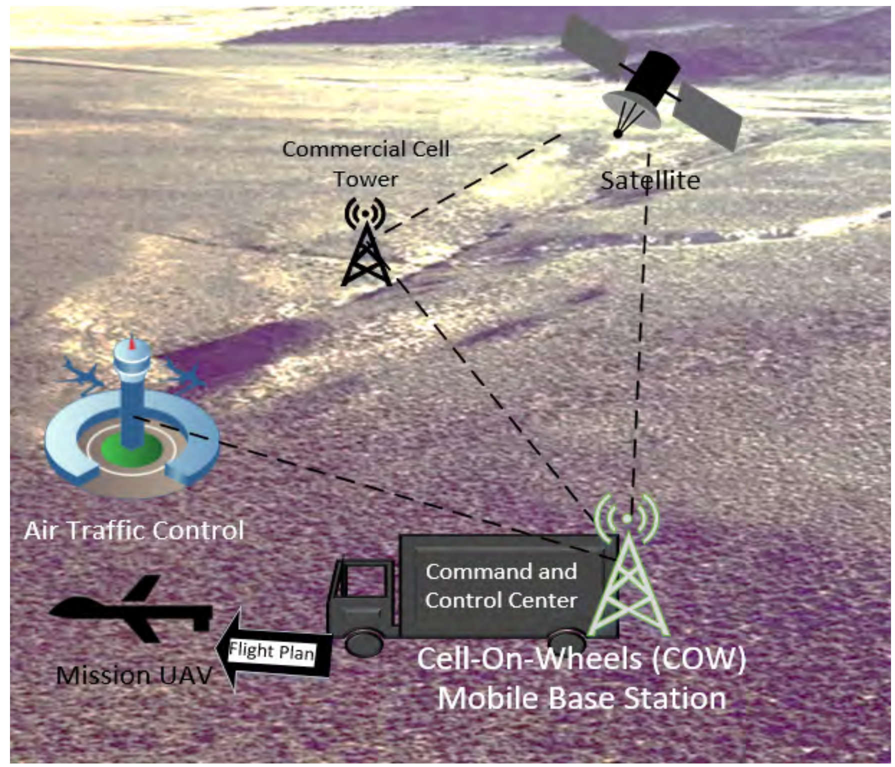
- Scenario 1: Establishing a Baseline – Pre-Launch Set-Up
  - Deploy system, connect to power grid, set-up COW towers



CONOPs – Scenario Review

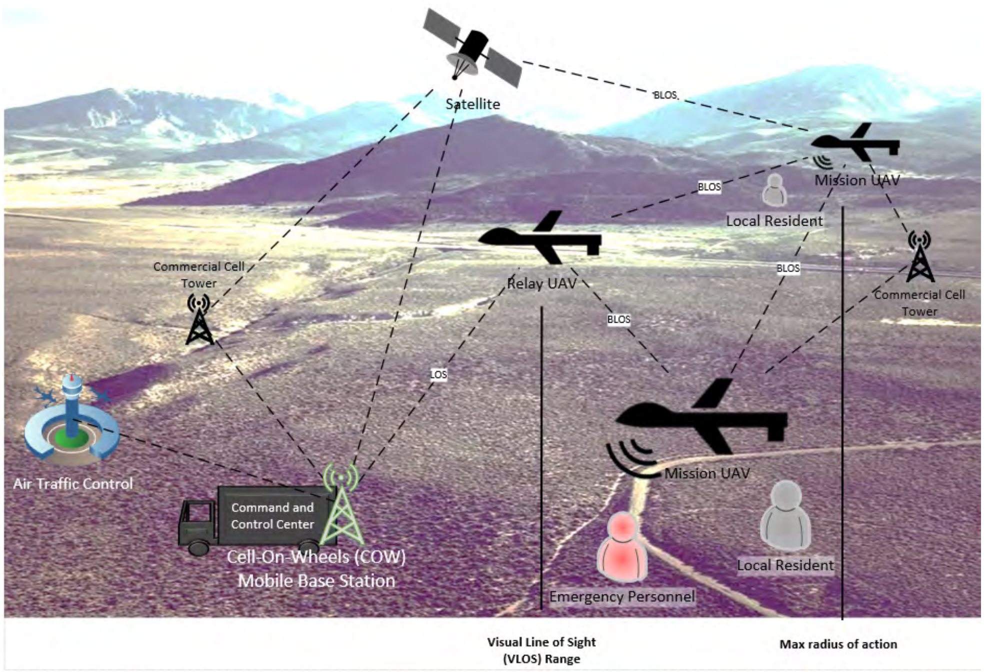
- Scenario 1: Establishing a Baseline – Pre-Launch Set-Up
  - Deploy system, connect to power, set-up COW towers

- Scenario 2: Initial Mission Planning for Post-Disaster Recovery Effort
  - Prepare UAVs, load mission configurations



CONOPs – Scenario Review

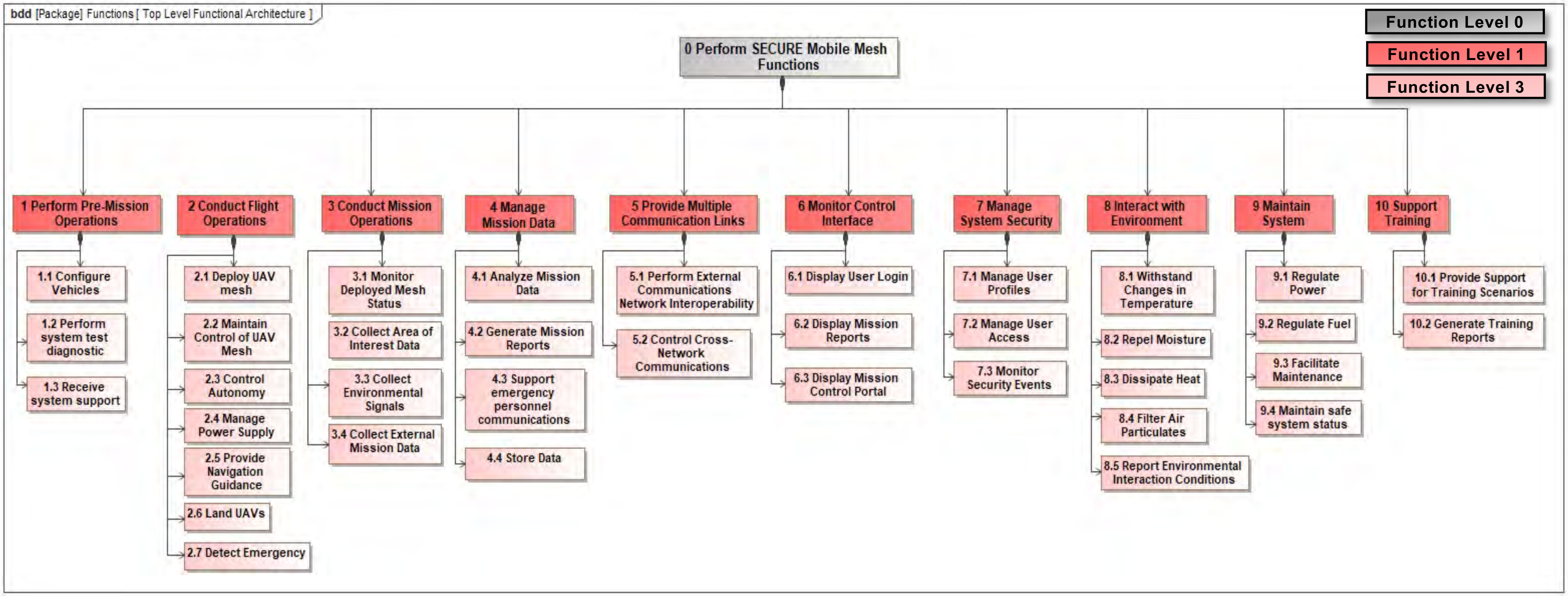
- Scenario 1: Establishing a Baseline – Pre-Launch Set-Up
  - Deploy system, connect to power, set-up COW towers
- Scenario 2: Initial Mission Planning for Post-Disaster Recovery Effort
  - Prepare UAVs, load mission configurations
- Scenario 3: Deploy Communication Mesh
  - Provide aerial mesh communication network
- Scenario 4: Reconnaissance Mission
  - Perform damage assessment, identify residents in need



Functional Architecture – Top-Level Context Diagram

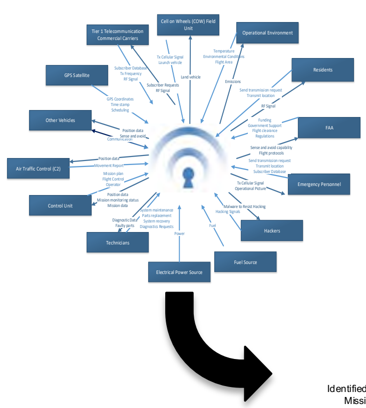
- High-level illustration of the interactions between the SECURE Mobile Mesh and external entities
  - Initially created from CONOPs and requirements

Functional Architecture – Top-Level Hierarchy Tree



Functional Architecture – Functional Flow Diagram

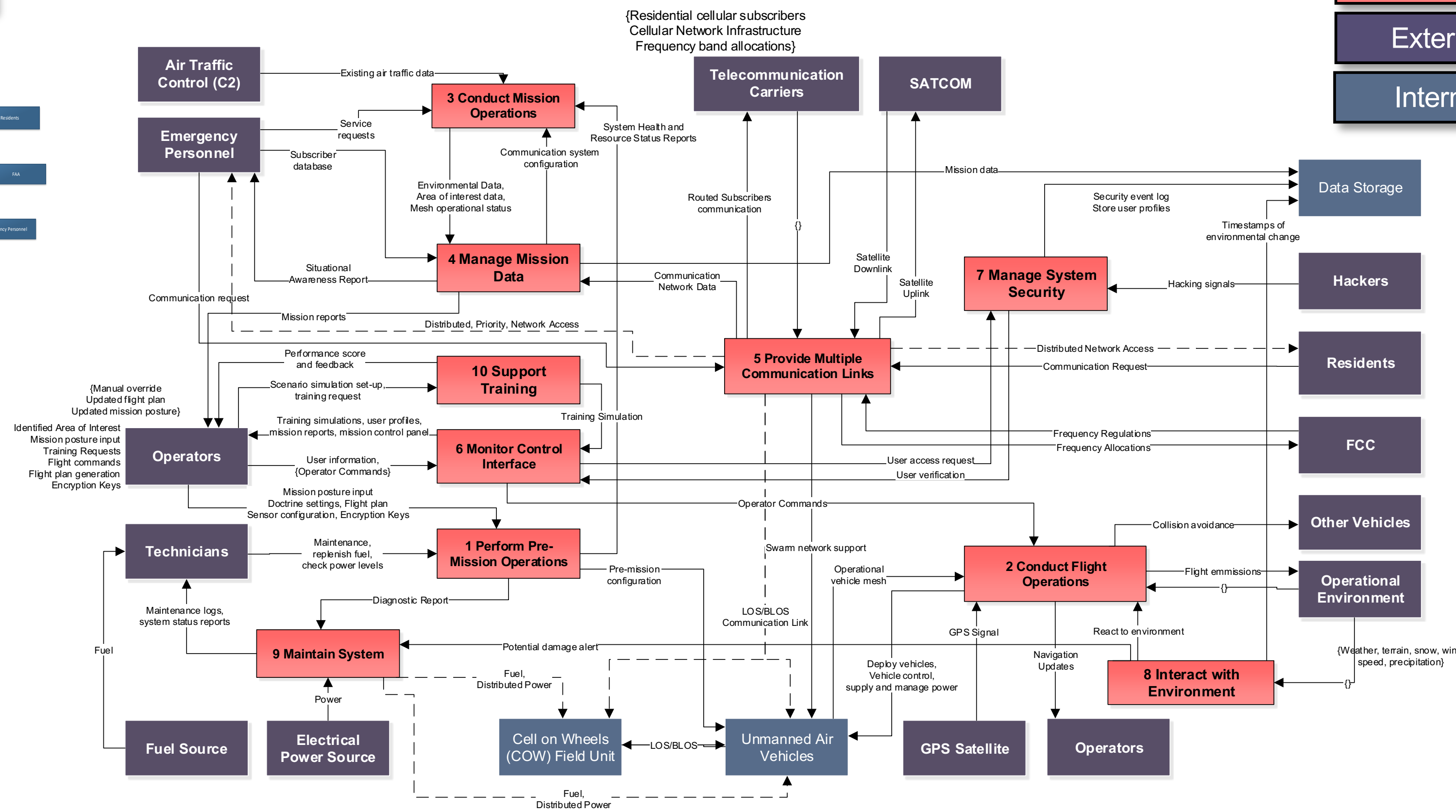
External entities were identified through the context diagram



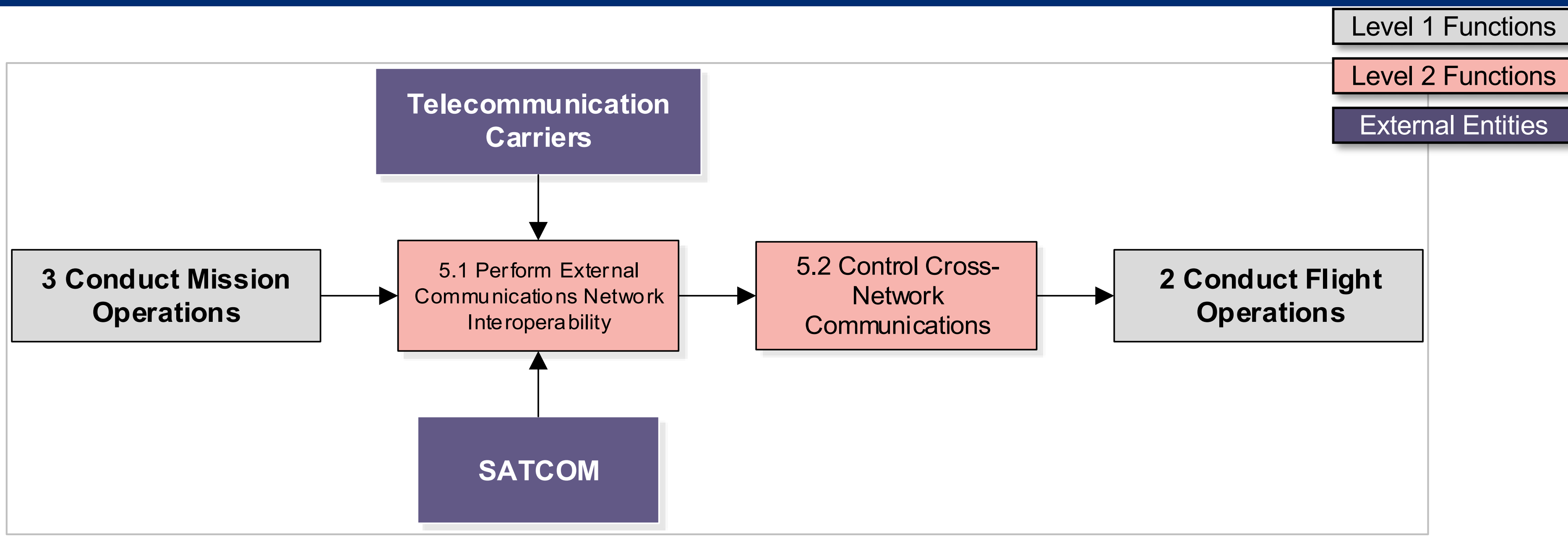
Level 1 Functions

External Entities

Internal Entities



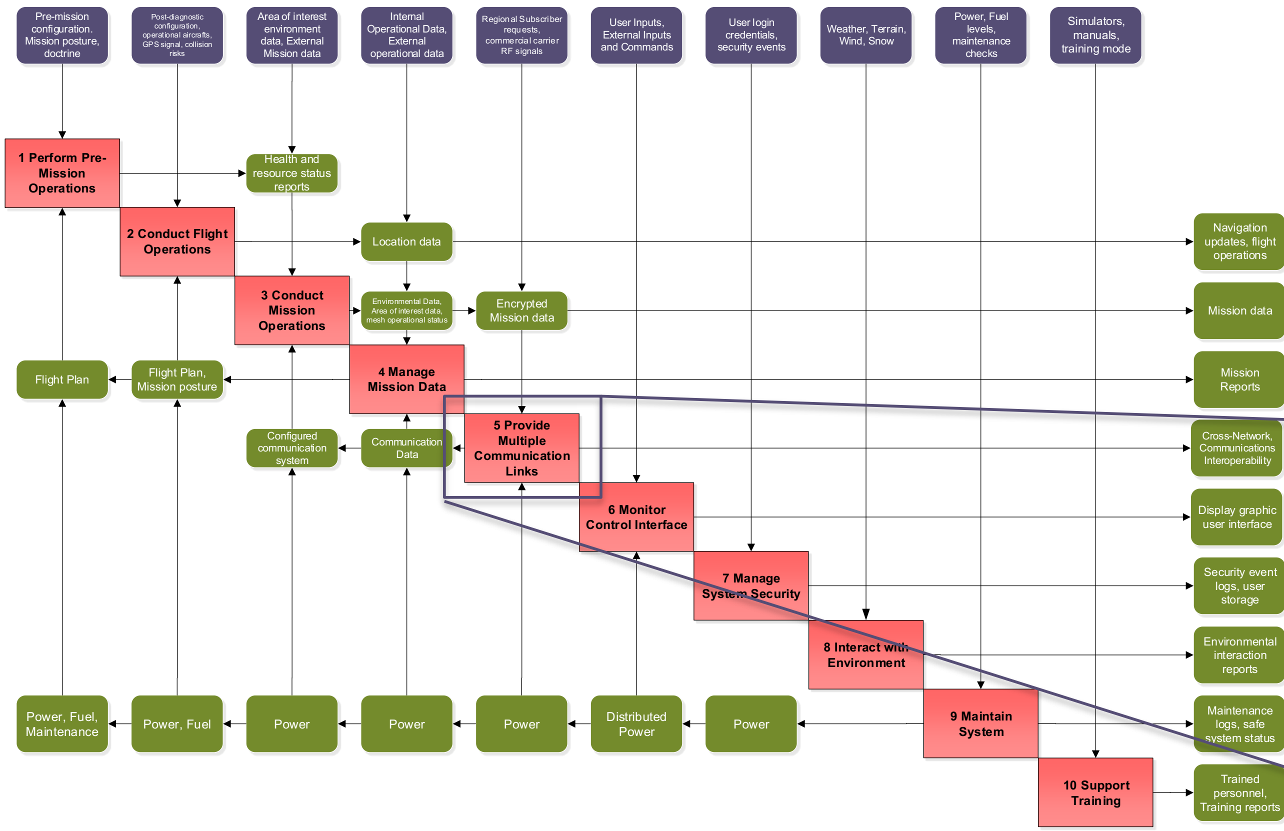
Functional Architecture – Functional Flow Diagram
5.0 Provide Multiple Communications Link



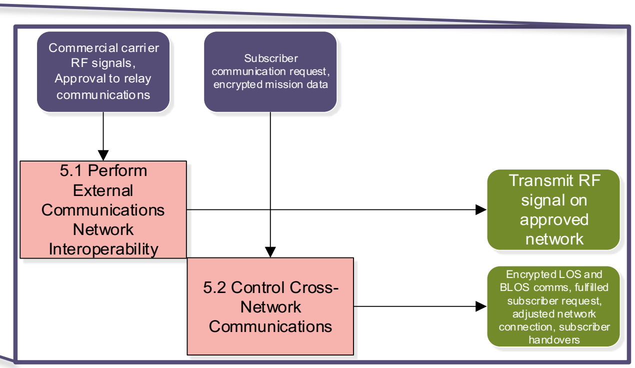
Data from FUNC.3.0 Conduct Mission Operations informs communication functions in FUNC.5

FUNC.5 Communication functions informs flight operations in FUNC.2

Functional Architecture – Top Level N^2 Diagram

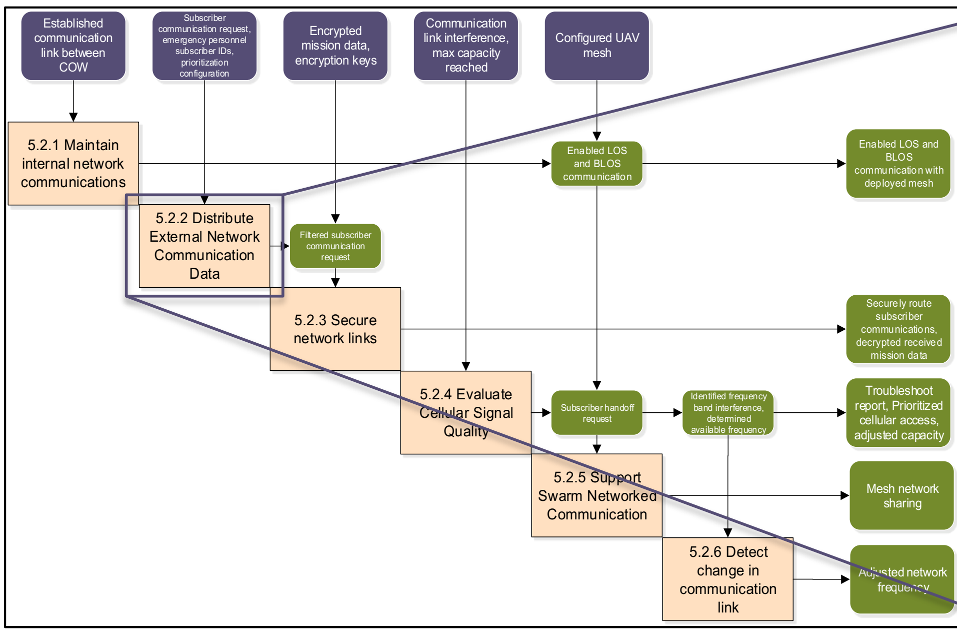


- Ensures all functions have an input and output
- Shows visual interaction between functions and need for further decomposition

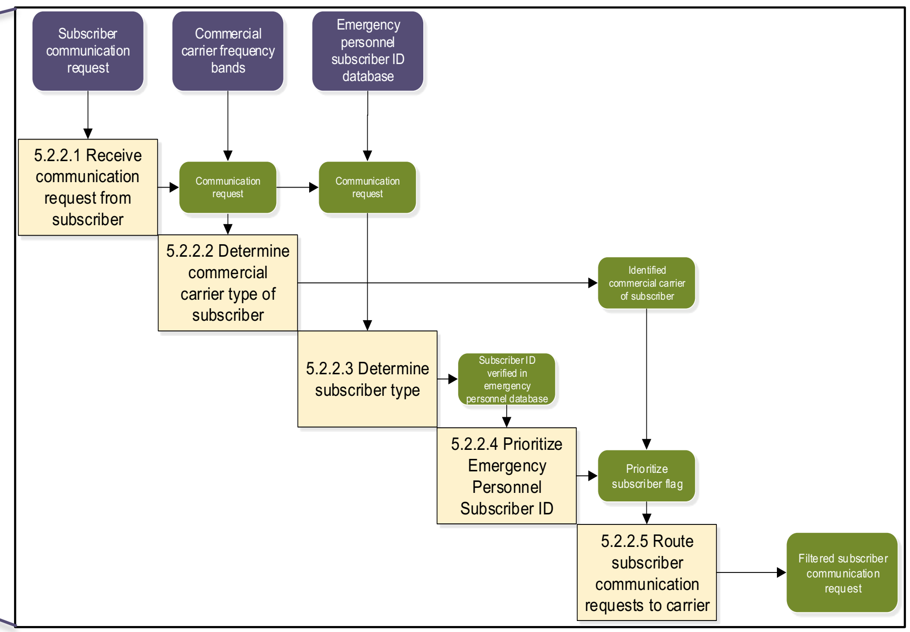


5.0 Provide Multiple Communication Links N^2 Diagram

Functional Architecture - 5.0 Provide Multiple Communication Links Decomposed N^2 Diagram – Level 3 and Level 4



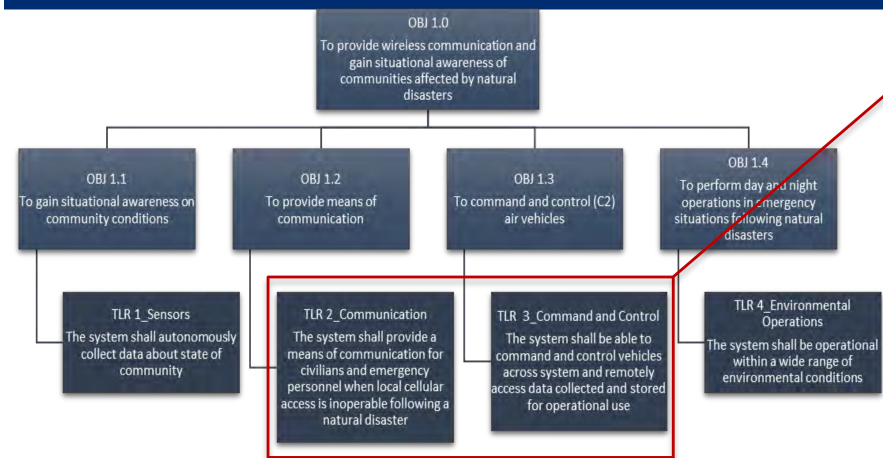
5.2 Cross Control Network Communications N^2 Diagram



5.2.2 Distribute External Network Communication Data N^2 Diagram

Complex functions require further decomposition

Functional Concept – Tracing Functions to Requirements

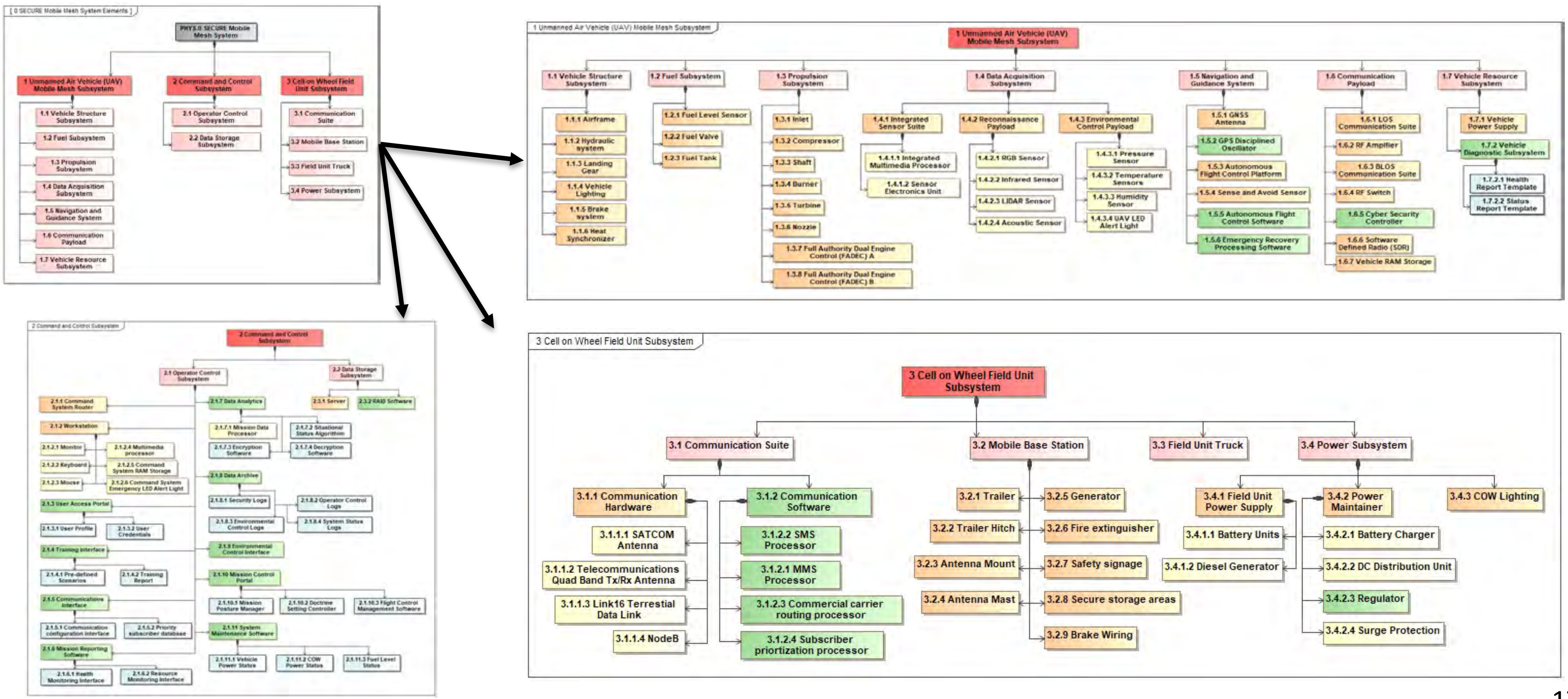


Function ID	Function Name	Requirements ID	Requirements Description
5	**Provide Multiple Communication Links**	REQ.3.5.3.1	The system shall be capable of allowing authorized users to monitor the environmental situation including the status of air vehicles and communication mesh
		TLR.2	The system shall provide a means of communication between civilians and emergency personnel, when local cellular access is inoperable
5.1	Perform External Communications Network Interoperability	REQ.2.3.1	The system shall be capable of transmitting a secure cellular signal
		REQ.3.4.1	The system shall be capable of generating and sending reports on each of the vehicles present in the system
		REQ.3.7.4.2	The system shall be capable of using an algorithm to identify natural disasters in an environment and their outlines such as fires, avalanches, landslides and flooding
5.2	Control Cross-Network Communications	TLR.2	The system shall provide a means of communication between civilians and emergency personnel, when local cellular access is inoperable
5.2.1	Maintain internal network communications	REQ 2.1.3	The system shall provide a means for operator to access reports on resource status and utilization
		REQ 2.1.3.1	The system shall provide a means for operator to remotely request access reports on resource status and utilization
		REQ 2.1.3.2	The system shall be capable of remotely sending reports on resource status and utilization
		REQ 2.1.3.3	The system shall be capable of periodically, remotely sending reports on resource status and utilization
		REQ.2.3	The system shall be capable of deploying a mobile mesh for a duration as defined in the mission posture
		REQ.3.4.1.2	The system shall be capable of generating and sending reports on the mesh of deployed vehicles in the system including overall unit health, effectiveness and navigation plans
5.2.2	Distribute External Network Communication Data	REQ.2.2	The system shall provide a means of communication for residents and emergency personnel (subscribers) accessing communication mesh to reach subscribers on and off the network
5.2.2.1	Receive communication request from subscriber	REQ.2.2	The system shall provide a means of communication for residents and emergency personnel (subscribers) accessing communication mesh to reach subscribers on and off the network
		REQ.2.5.2	The system shall be capable of providing communications between emergency personnel and civilians
5.2.2.2	Determine commercial carrier type of subscriber	REQ.2.2	The system shall provide a means of communication for residents and emergency personnel (subscribers) accessing communication mesh to reach subscribers on and off the network
5.2.2.3	Determine subscriber type	REQ.2.2	The system shall provide a means of communication for residents and emergency personnel (subscribers) accessing communication mesh to reach subscribers on and off the network
5.2.2.4	Prioritize Emergency Personnel Subscriber ID	REQ.2.2	The system shall provide a means of communication for residents and emergency personnel (subscribers) accessing communication mesh to reach subscribers on and off the network
5.2.2.5	Route subscriber communication requests to carrier	REQ.2.2	The system shall provide a means of communication for residents and emergency personnel (subscribers) accessing communication mesh to reach subscribers on and off the network

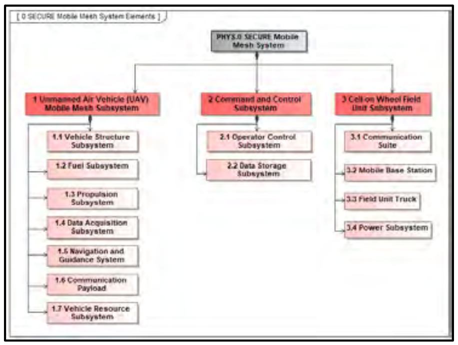
- Functions were traced to requirements to analyze if the functions list is sufficient
- 1-to-Many Relationship between functions and requirements to ensure requirement is satisfied

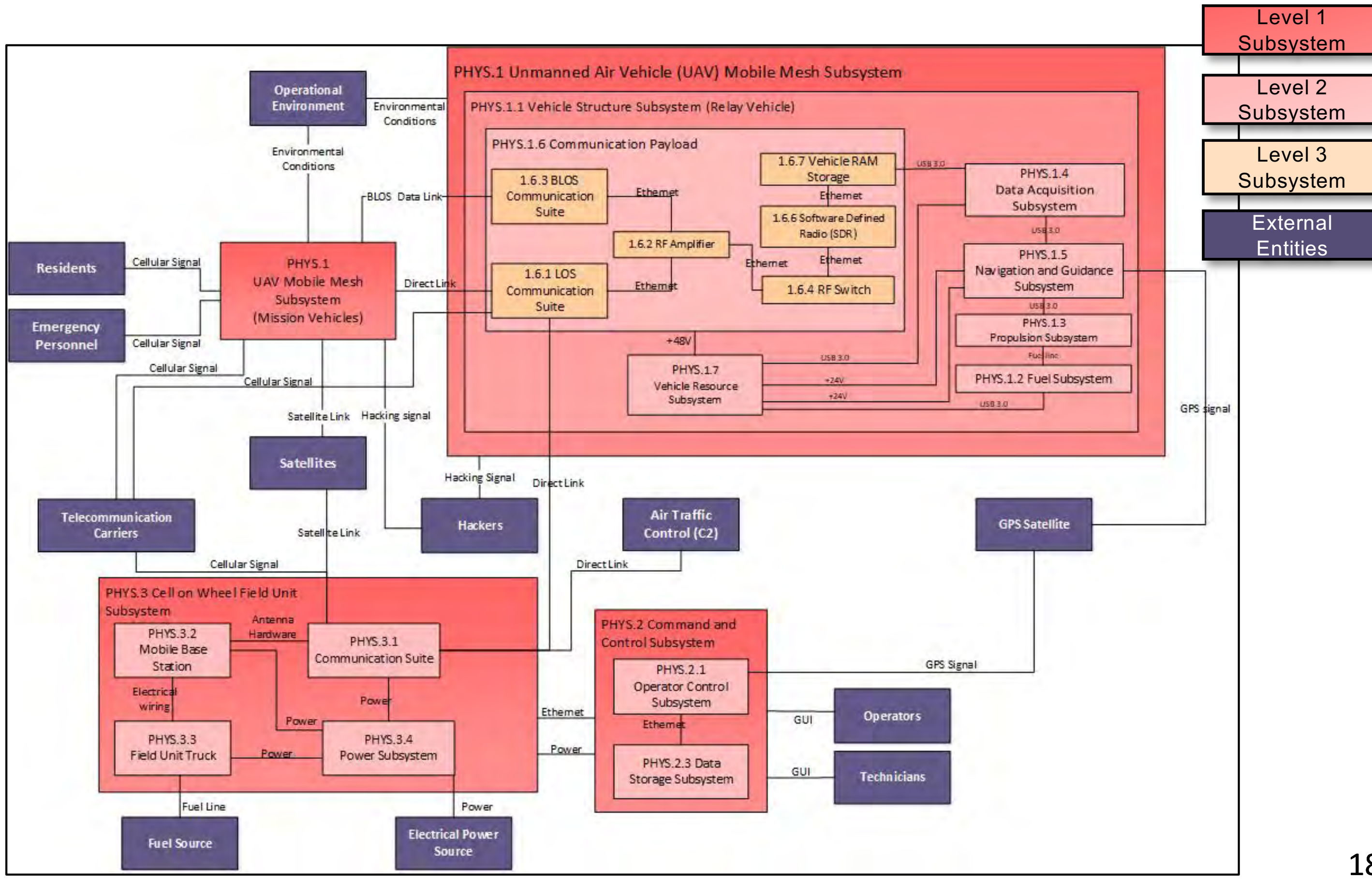
Physical Concept – Physical Hierarchy Trees

Level 1 Subsystem	Level 2 Subsystem
Level 3 Subsystem	Software Component



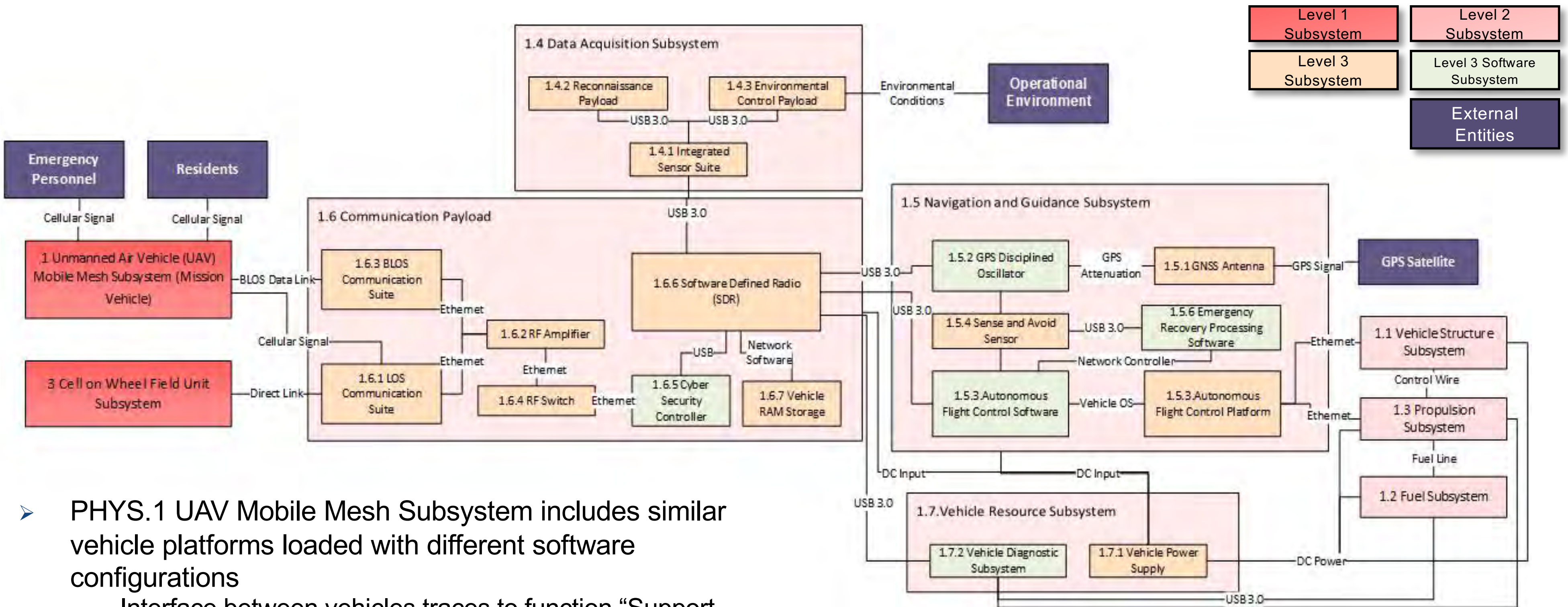
Physical Concept - Top-Level System Physical Diagram





- Top-level subsystems:
  - PHYS.1 UAV Mobile Mesh
  - PHYS.2 Command and Control
  - PHYS.3 COW Field Unit
- Lower levels are shown to provide important contextual interactions about each subsystem

Physical Concept - PHYS.1 UAV Mobile Mesh Subsystem

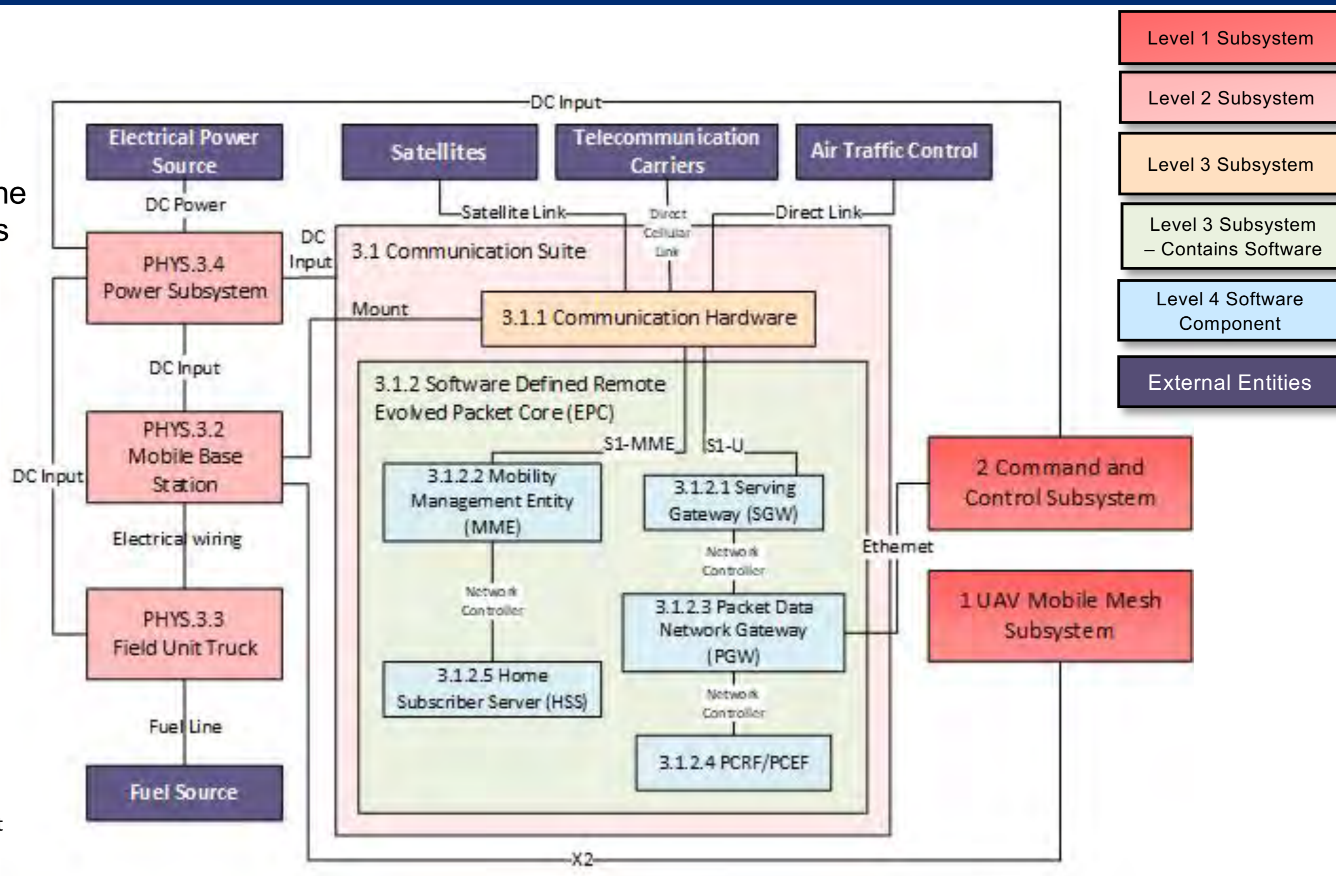


- PHYS.1 UAV Mobile Mesh Subsystem includes similar vehicle platforms loaded with different software configurations
  - Interface between vehicles traces to function “Support Swarm Network Communication”

Physical Concept - PHYS.3 Cell on Wheels (COW) Field Unit

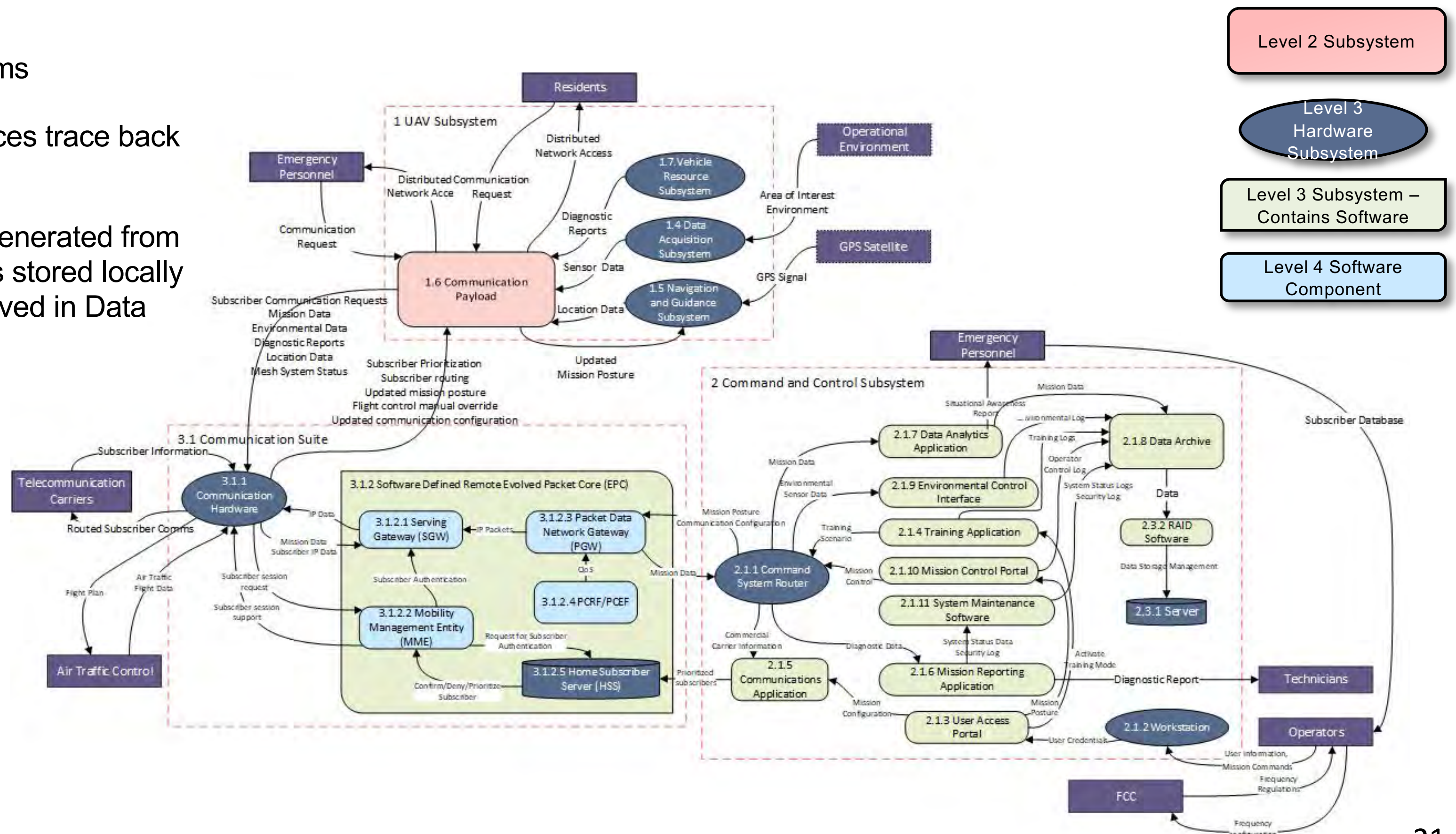
- Software-Intensive System:
  - Some physical components require processing software to trace back to the functions, and satisfy the requirements
- PHYS.3.1 Communication Suite includes Hardware and Software Subsystems:
  - PHYS.3.1.1 Communication Hardware
  - PHYS.3.1.2 Software-Defined Remote Evolved Packet Core (EPC) contains software processing components that were physical hardware in previous generations of telecom

Smart EPC-T300:
Scalable subscriber support, multi-core blades to support multiple carrier types
https://www.neragon.com/products/smart-epc-t300



Physical Concept - Top-Level Data Flow Diagram

- Software-intensive Systems
- Data flowed along interfaces trace back to functional interactions
- Data that is collected or generated from each of the subsystems is stored locally when collected, and archived in Data Storage



Physical Concept - Physical to Functions Traceability

Physical architecture implements functions, satisfying requirements

Physical ID	Function Traceability
PHYS.0 SECURE Mobile Mesh Physical System Elements	FUNC.0 Perform SECURE Mobile Mesh Functions
PHYS.1 Unmanned Air Vehicle (UAV) Mobile Mesh Subsystem	FUNC.1 Perform Pre-Mission Operations, FUNC.2 Conduct Flight Operations, FUNC.3 Conduct Mission Operations
PHYS.1.5 Navigation and Guidance System	FUNC.3.1.2 Collect Control Vehicle Location Data, FUNC.2.2 Maintain Control of UAV Mesh, FUNC.2 Conduct Flight Operations, FUNC.2.5 Provide Navigation Guidance
PHYS.1.5.1 GNSS Antenna	FUNC.2.5.1.1 Receive GPS signal
SOFT.1.5.2 GPS Disciplined Oscillator	FUNC.2.5.1 Acquire position data, FUNC.3.1.2 Collect Control Vehicle Location Data
PHYS.1.5.3 Autonomous Flight Control Platform	FUNC.2.3 Control Autonomy, FUNC.3.1.2 Collect Control Vehicle Location Data
PHYS.1.5.4 Sense and Avoid Sensor	FUNC.2.2.1 Sense and Avoid Obstacles
SOFT.1.5.5 Autonomous Flight Control Software	FUNC.2.3 Control Autonomy, FUNC.2.3.1 Evaluate Collision Risks
SOFT.1.5.6 Emergency Recovery Processing Software	FUNC.2.3.1 Evaluate Collision Risks, FUNC.2.7.2 Initiate Recovery Procedures
PHYS.2 Command and Control Subsystem	FUNC.4 Manage Mission Data, FUNC.5 Provide Multiple Communication Links, FUNC.6 Monitor Control Interface
PHYS.3 Cell on Wheel Field Unit Subsystem	FUNC.5 Provide Multiple Communication Links
PHYS.3.1 Communication Suite	FUNC.5.1 Perform External Communications Network Interoperability, FUNC.5.2 Control Cross-Network Communications
PHYS.3.1.1 Communication Hardware	FUNC.5 Provide Multiple Communication Links
SOFT.3.1.2 Software Defined Remote Evolved Packet Core (EPC)	FUNC.5.2.2 Distribute External Network Communication Data, FUNC.3.4.2 Collect Data from Emergency Services
SOFT.3.1.2.1 Serving Gateway (SGW)	FUNC.5.2.2 Distribute External Network Communication Data
SOFT.3.1.2.2 Mobility Management Entity (MME)	FUNC.5.2.2.2 Determine commercial carrier type of subscriber, FUNC.5.2.2.5 Route subscriber communication requests to carrier
SOFT.3.1.2.3 Packet Data Network Gateway (PGW)	
SOFT.3.1.2.4 Policy and Charging Rules and Enforcement Function (PCRF/PCEF)	FUNC.5.2.3.2 Encrypt communications link, FUNC.5.2.6 Detect change in communication link
PHYS.3.1.2.5 Home Subscriber Server (HSS)	FUNC.4.3 Support emergency personnel communications, FUNC.4.3.2 Maintain emergency personnel subscriber database, FUNC.5.2.2.3 Determine subscriber type

Trade Study – Summary of Trade Studies

- Multiple trade studies performed across subsystems

PHYS.1

Mode S ADS-B Transponder:
Sense and Avoid Sensor

TASE™ 500 HD

CM202A

Software Defined Radio (SDR)

UAV Platform

Selected for formal Trade Study

PHYS.2

Rack Mounted Server

PHYS.3

Power Generator

Field Truck

Ford F-150 Truck w/ Bed Cap		Retro-Fitted Doge Ram Pro Master Van	
			
Pro	Con	Pro	Con
All-Terrain	Limited Personnel Space	Customizable Interior	Limited Terrain
Towing Capability	Gas Mileage	Fully Enclosed	Gas Mileage

SEPC-T300

COW Mobile Base Station

Trade Study – Criteria Selection and Initial Analysis

Criteria selected from UAV related operational, functional and performance requirements

Figure 1 DJI M600 Pro

Figure 2 Aeroscout Scout B-330

Figure 3 Helipse HE190E

Figure 4 Helipse HE300

	Multi-rotor	Helicopter Rotor		
Subsystem Alternative	**DJI M600 PRO**	**Scout B-330 Helo**	**HE 300**	**HE 190 E**
Ref	**Figure 1**	**Figure 2**	**Figure 3**	**Figure 4**
Payload Support (lbs)	13lbs	66lbs	44lbs	40lbs
Altitude (m)	4500m	3050m	500m	1000m
Endurance (min)	16min	180min	120min	60min
Speed (mph)	40mph	62mph	55mph	120mph
Max Wind Speed (m/sec)	11m/sec	20m/sec	22m/sec	20m/sec
Cost ($)	$5,700	$18,000	$20,000	$17,000
Marketed Application	Modular design with pre-installed antennas for reduced set-up time, ideal for professional aerial photography and industrial applications	Survey (data acquisition), HD video live stream; suitable to carry or act as motorial energy source for wireless energy transfer, and act as aerial caches; can carry cellular equipment	Border and port surveying, Agriculture spraying	Border, Agriculture, Lidar, Surveying, Maritime

Subjective analysis rankings recommend elimination of Alternative 1 – DJI M600 PRO and recommends choosing Scout B-330

Value Rankings	DJI M600 PRO	Scout B-330	HE 300	HE 190 E	Norminal Range	
Criteria	Value	Value	Value	Value	Low	High
Payload Support (lbs)	0	1	0	0	10	50
Altitude (m)	1	1	0	1	300	700
Endurance (min)	-1	1	0	0	60	120
Speed (mph)	-1	0	0	0	50	1440
Max Wind Speed (m/sec)	0	0	0	0	10	25
Cost ($)	1	-1	-1	0	1	20000
Score	-1	3	**0**	**1**		
Overall Rank (1= best)	4	1	**2**	**3**		

Pair-wise weight matrix creates quantitative analysis by computing a weighted value for each criteria traced to requirements

	Pair-Wise Weights							
	Payload Support (lbs)	**Altitude (m)**	**Endurance (min)**	**Speed (mph)**	**Max Wind Speed (m/sec)**	**Product**	**N-Root**	**Weight**
Payload Support (lbs)	**1.00**	3.000	5.000	7.000	7.000	735.00	3.74	0.48
Altitude (m)	0.333	**1.00**	3.000	5.000	7.000	35.00	2.036	0.26
Endurance (min)	0.200	0.333	**1.00**	9.000	7.000	4.200	1.332	0.17
Speed (mph)	0.143	0.200	0.111	**1.00**	3.000	0.010	0.394	0.05
Max Wind Speed (m/sec)	0.143	0.143	0.143	0.333	**1.00**	0.001	0.250	0.03
						Sum	**7.76**	**1.00**

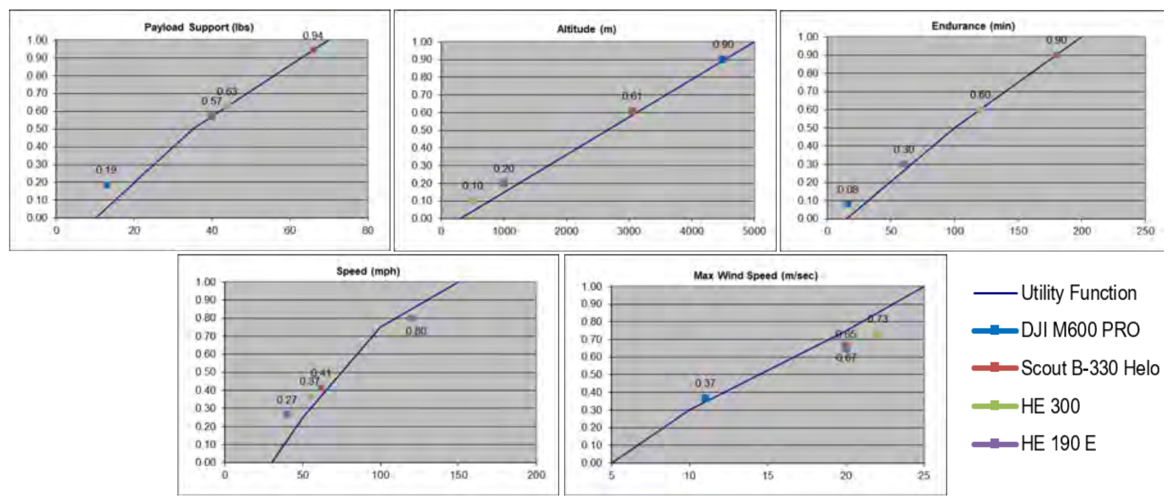
Trade Study – Utility Functions and Analysis

- Utility functions built from:
  - Threshold values in originating requirements
  - Research from industry that led to the creation of new performance requirements

- The given raw "Value" was divided by the max value in the nominal range, and the utility was the resultant value.
  - PayloadCriteria_AltValue1 = 66 | PayloadCriteria_MaxUtilValue = 70
  - PayloadCriteria_AltValue1_Utility = 66/70 = .19

- Utility functions were plotted with the min-max criterion range, and each alternative's utility value was placed on the applicable criteria plot

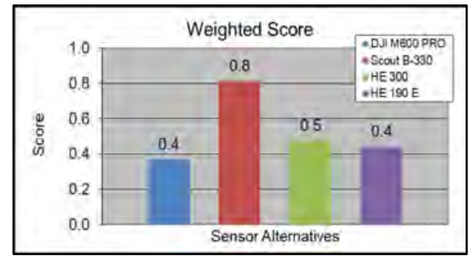
Subsystem Alternative		DJI M600 PRO			Scout B-330 Helo			HE 300			HE 190 E		
Alternative	Utility Function	Value	Normalized Value	Utility	Value	Normalized Value	Utility	Value	Normalized Value	Utility	Value	Normalized Value	Utility
Payload Support (lbs)	[10,70]	13	0.08	0.19	66	0.40	0.94	44	0.27	0.63	40	0.25	0.57
Altitude (m)	[300,1000]	4500	0.47	0.90	3050	0.37	0.61	500	0.05	0.10	1000	0.11	0.20
Endurance (min)	[15,200]	16	0.04	0.08	180	0.48	0.90	120	0.32	0.60	60	0.16	0.30
Speed (mph)	[30,150]	40	0.14	0.27	62	0.22	0.41	55	0.20	0.37	120	0.43	0.80
Max Wind Speed (m/sec)	[10,30]	11	0.15	0.37	20	0.27	0.67	22	0.30	0.73	20	0.27	0.65
Cost ($)	[5k,25k]	5700	0.09	0.77	18000	0.30	0.28	20000	0.33	0.20	17000	0.28	0.32

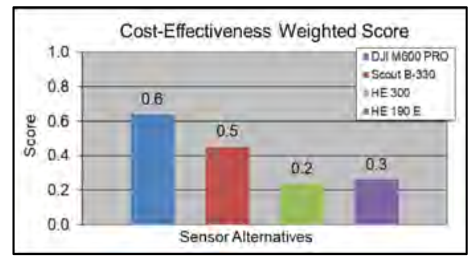


Trade Study – Weighted Results and Sensitivity

- Weighted Results
  - Scout B-330 provides the most utility (high altitude, high support of payload, long endurance)
  - DJI M600 PRO provides the most cost-effective option

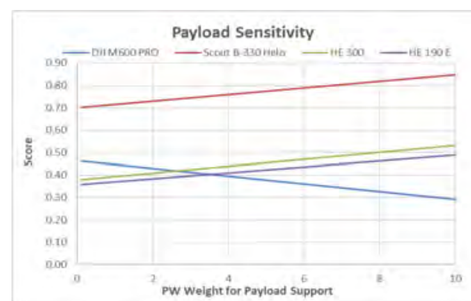
Criteria	Criteria Weight	DJI M600 PRO			Scout B-330			HE 300			HE 190 E		
		Raw Score	Utility Value	Weighted Score	Raw Score	Utility Value	Weighted Score	Raw Score	Utility Value	Weighted Score	Raw Score	Utility Value	Weighted Score
Payload Support (lbs)	0.483	0.080	0.186	0.090	0.400	0.943	0.455	0.270	0.629	0.303	0.250	0.571	0.276
Altitude (m)	0.263	0.470	0.900	0.236	0.370	0.610	0.160	0.050	0.100	0.026	0.110	0.200	0.053
Endurance (min)	0.172	0.040	0.080	0.014	0.480	0.900	0.155	0.320	0.600	0.103	0.160	0.300	0.052
Speed (mph)	0.051	0.140	0.267	0.014	0.220	0.413	0.021	0.200	0.367	0.019	0.430	0.800	0.041
Max Wind Speed (m/sec)	0.032	0.150	0.367	0.012	0.270	0.667	0.021	0.300	0.733	0.024	0.270	0.647	0.021
Operational Utility Function (Weighted Sum)		0.365			0.812			0.475			0.441		
Cost ($)		$5,700			$18,000			$20,000			$17,000		
Cost-Effectiveness Selection Function (Weighted Sum / Cost)		0.64			0.45			0.24			0.26		





- Sensitivity analysis performed to analyze the effect of the highest weighted criteria (payload support) on the results

Payload Support PW-Weight	DJI M600 PRO	Scout B-330 Helo	HE 300	HE 190 E
0.1	0.46	0.70	0.38	0.36
10.00	0.29	0.85	0.53	0.49



Trade Study – Final Selection

- Final Selection: Even when sensitivity analysis was performed, Scout B-330 supports the highest payload, endurance and altitude, all important for adaptability in the mission configuration

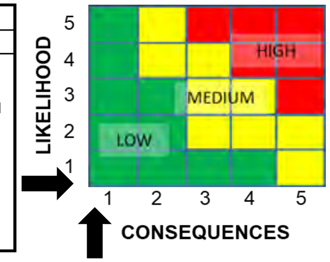
Subsystem Alternative	Scout B-330 Helo
Payload Support (lbs)	66lbs
Altitude (m)	3050m
Endurance (min)	180min
Speed (mph)	62mph
Max Wind Speed (m/sec)	20m/sec
Cost ($)	$18,000
Marketed Application	Survey (data acquisition), HD video live stream; suitable to carry or act as motorial energy source for wireless energy transfer, and act as aerial caches; can carry cellular equipment

Risk Management – Summary of Risks

- Technical risks focused on interfaces between the subsystems
  - Control of the vehicle
  - Unexpected Interference from external entities
- Programmatic risks focused on completing the artifacts
  - Schedule and work-life balance
  - Research required to supplement user need generation

Likelihood

What Is the Likelihood the Risk Will Happen?		
Level		Your Approach and Processes...
1	Not Likely:	...Will effectively avoid or mitigate this risk based on standard practices
2	Low Likelihood:	...Have usually mitigated this type of risk with minimal oversight in similar cases
3	Likely:	...May mitigate this risk, but workarounds will be required
4	Highly Likely:	...Cannot mitigate this risk, but a different approach might
5	Near Certainty:	...Cannot mitigate this type of risk; no known processes or workarounds are available



Consequence

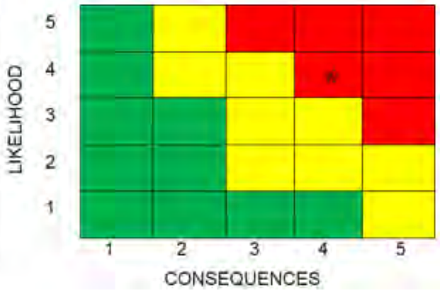
Given the risk is realized, what would be the magnitude of the impact?			
Level	Technical	Schedule	Cost
1	Minimal or no impact	Minimal or no impact	Minimal or no impact
2	Minor perf shortfall, same approach retained	Additional activities required; able to meet key dates	Budget increase or unit production cost increase <10%(1%)
3	Mod perf shortfall, but workarounds available	Minor schedule slip; will miss need date	Budget increase or unit production cost increase >10% (<5%)
4	Unacceptable, but workarounds available	Program critical path affected	Budget increase or unit production cost increase <30%(10%)
5	Unacceptable; no alternatives exist	Cannot achieve key program milestone	Budget increase or production cost increase >30- 70% (10%)

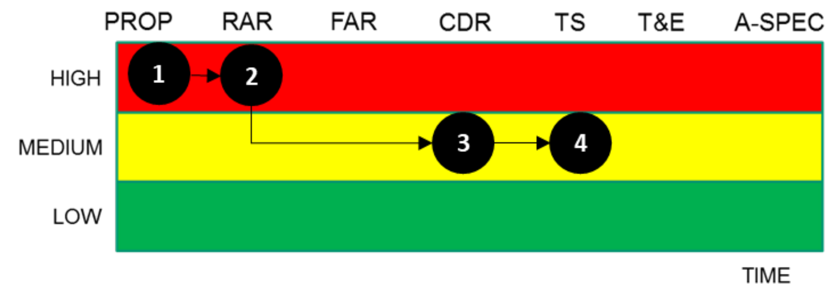
Risk ID	Risk	Origin	Type	Starting Risk Level		Current Risk Level	
				Likelihood	Consequence	Likelihood	Consequence
R.1	Loss of Vehicle Communication	Proposal	Technical	3	4	2	4
R.2	Unlicensed Vehicle Interference	Proposal	Technical	3	4	1	4
R.3	Signal to Noise Ratio	Functional Analysis Report	Technical	4	3	2	3
R.4	Limited Cellular Capacity	Proposal	Technical	4	3	1	3
R.5*	Schedule Project Completion	Requirements Analysis Report	Programmatic	5	4	2	3
R.6*	Access to Stakeholder Information and User Needs	Requirements Analysis Report	Programmatic	4	4	1	4

Risk Management – Risk.1 Loss of Vehicle Communication

Risk.1 Loss of Vehicle Communication

Risk Title	Loss of Vehicle Communication	
Description:	Unintended departure of an aircraft from monitored or controlled flight. Occurs when an aircraft enters a flight pattern that is outside its planned flight path and develops into a stall or spin. (Federal Aviation Administration, 2019)	
Initial Assessment:	Likelihood:	3
	Consequences:	4
	Description of Consequences if Realized:	Loss of equipment, data loss

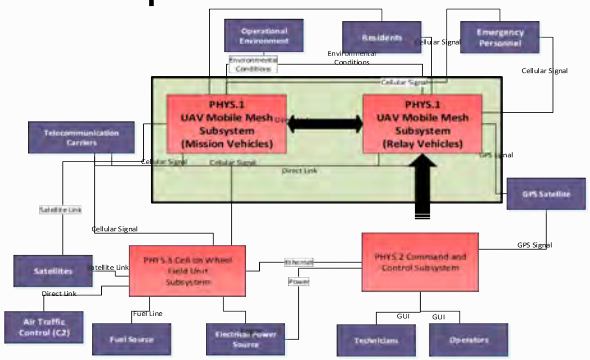




Mitigation Plan					
ID	Associated Report	Mitigation Action	L	C	Impact Description & Rationale
1	Proposal	Initial Risk Identification	4	4	Vehicle is monitored by ground control unit through direct link to the mobile mesh, when communication link is broken, the vehicle cannot be monitored or updated by the operator
2	Requirements Analysis Report	Incorporate requirements to ensure continuous communication link from command and control subsystem to UAV	4	4	Requirements added for the support of C-Band, spectrum designated by the FCC for control and non-payload communications
3	Conceptual Design Report	Include communication hardware in system design that supports the Control and Non-payload communications (CNPC) link (C-band spectrum)	3	4	Vehicles can be monitored and controlled by ground control unit through a direct link
4	Trade Study	Automated homing and landing	2	4	Chosen UAV subsystem includes a safe, autonomous homing and landing sequence in case of link loss

Test Plan – Verify Requirements from Trade Study Criteria

➢ Scope

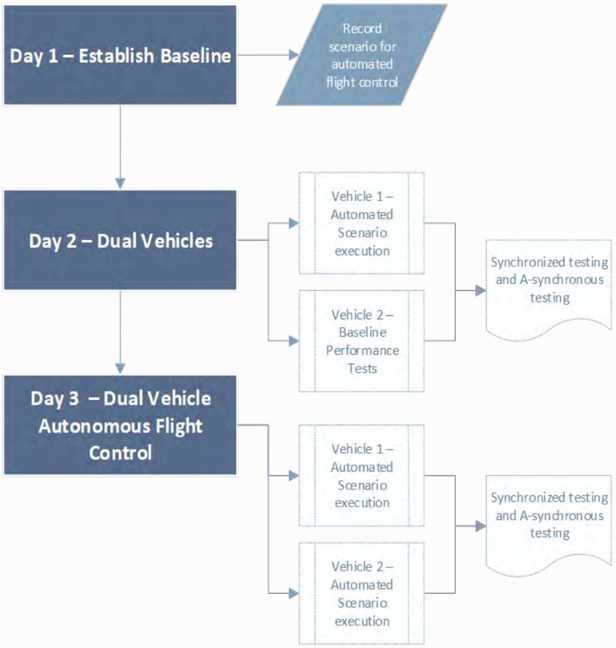


OBJ ID	Objective Title	Description
OBJ.1	Verify requirements	Requirements traceability is shown in section 1.3. Requirements are verified if the test results conclude, with statistical significance, that the capability of the vehicle meet the functional and performance requirements related to the UAV Mobile Mesh Subsystem.
OBJ.2	Reduce Risk	Reduction of Risk is primarily related to the mitigation actions in R.1.4 "Automated Homing and Landing". By demonstrating the technology readiness of the automated homing and safe landing capability, the loss of equipment consequence is reduced to medium (3). Additional demonstrated capabilities contribute to mitigation actions to address and move towards reducing risk. This includes capabilities such as the Collision Avoidance capabilities related to R.2 "Unlicensed Vehicle Interference".
OBJ.3	Train and ready operators for pre-, during and post-flight operations	The FAA has many protocols in place to ensure the safety of the operators, as well as the personnel in the area of the UAV deployment. Prior to test day, the operator must have obtained a Remote Pilot Certificate, in compliance with Part 107, 14 CFR in order to operate the UAV. Successful execution of this objective will ensure the readiness of the operator, and the will give the operator the ability to safely familiarize themselves with the operations of the vehicle, pre, during and post-flight.

➢ Test Environment

➢ Test Articles

➢ Execution



System Specification – A-Spec Requirements

- Requirements created/converted from functions, trade studies, conceptual design report and the final A-Spec review

- Requirements Growth and Conversion
  - 25% Growth
  - Converted 39 to Binary
  - Converted 152 to Quantitative

Deliverable	Total	Quantitative	%	Binary	Qualitative
Requirements Analysis Report	155	17	11%	0	138
Functional Analysis Report	160	20	13%	2	138
Conceptual Design Report	184	40	22%	4	138
Trade Study	188	44	23%	5	138
Test Plan	190	46	24%	6	136
System Specifications	208	169	81%	39	0

System Specifications – Key Performance Parameters

- KPPs are contractual and must be met in order for the system to be accepted by the customer

- KPPs were created through
  - User needs analysis so they can be verified with potential users to verify that their needs are met
  - Tied to top-level functions and were quantified through research during creation of the conceptual design report and trade studies

KPP ID	ID	Name	Description
KPP_1	TLR.0	Main System Requirement	The system shall provide situational awareness services* in a radius of action of 100 (200) air miles
KPP_2	TLR.1	Reconnaissance Data Collection - Sensor TLR	The system shall autonomously collect passive and active reconnaissance data for at least 48 hours.
KPP_3	TLR.2	Telecommunication Services	The system shall provide cellular service interoperability between residents and at least 3 regional Tier 1 Commercial Telecommunication service providers.
KPP_4	REQ.2.1	Operator to Vehicle Communication	The system shall utilize a direct link from the ground control unit to the vehicle mesh for the duration of the mission execution with a maximum of 50ms latency.
KPP_5	REQ.2.1.3.4	Control and non-payload communication Link Support	The system shall be capable of transmitting and receiving data on the C-Band spectrum (5030-5091MHz).
KPP_6	REQ.3.2.1.1	Autonomous Flight Control	The system shall utilize autonomous flight control software with at least 99.995% reliability.
KPP_7	REQ.3.2.1.5	Rapidly Deployable Air Vehicles	The system shall be capable of configuring and deploying operational air vehicles within 24 hours of arriving on-site.

Summary of Final Concept and Final Work

- SECURE Mobile Mesh System Summary:
  - Current design of the system is:
    - TRL 2 (application is limited to analytic studies performed)
      - UAV Mobile Mesh Subsystem may be able to be considered TRL 3 (proof of concept) once testing is completed, depending on how the results from test execution
  - A more detailed systems design needs to be completed and tested before the system can be integrated and implemented
    - Software application development
    - Interface testing and analysis
    - Additional vehicle testing

Lessons Learned

- Pandemics are the worst
  - New motto:
    Expect the Unexpected: Prepare for the Worst, Hope for the Best and Adapt to the In-Between
- It all begins and ends with Requirements!
- Higher need for collaboration = Additional Minds + Creative Approaches
  - I have a new found respect for the systems engineering process as a whole, detail must be taken ensure consistency across the project. This is a lot more work, but can be done when it's just one person, but that limits the scope to the mind of the one systems engineer
  - The more minds that are on the project, the more creative approaches can be taken to accomplish the complex tasks (in a shorter time), but the need for collaboration is increased to produce consistency across the project
- MBSE Tools:
  - Use of tools is important for the creation of artifacts, finding the right tools to communicate correct SysML proved difficult
  - Tools need to be used to correctly to communicate the clearest message…

GOOD SysML > Textual Explanations > Pseudo SysML