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A Systems Approach to Humanitarian Assistance and Disaster Relief: Revolution of Unmanned Systems Technology

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Introduction

Singapore has participated actively in humanitarian assistance and disaster relief (HADR) operations at both the regional and international levels since 1970. In particular, during the aftermath of the Indian Ocean tsunami, the Singapore Armed Forces (SAF) responded with over 1500 personnel, and a couple of airborne and seaborne assets in the SAF largest overseas operation conducted thus far. Given our limited resources and manpower, Singapore's approach to contributing in HADR is focused in our niche areas which our international partners find beneficial. With the proliferation of unmanned technology in both the commercial and military domains, this thesis seeks to study how unmanned technology could be adopted to enhance our overall HADR response using a systems approach.

Aim and Objectives

The aims of this thesis include: (1) explore the complexities and identify issues related to HADR operations; (2) define a problem context for new capability change using unmanned technologies; and (3) analyse the "as-is" system of interest (SOI) to create an idealised "to be" SOI, and provide recommendations on its implementation.

Research Results

Initially, a soft systems approach was adopted to explore the problem space and present the context related to the SAF's HADR capability. This involved developing (1) a Rich Picture and (2) a Pig Diagram to explore the problem situation and identify the relevant stakeholders, followed by (3) a Context Diagram and (4) Root Definitions to establish the context of the SAF's HADR capability, in order to develop an OV-1a for the "as-is" capability (Refer to **Figure 1**).

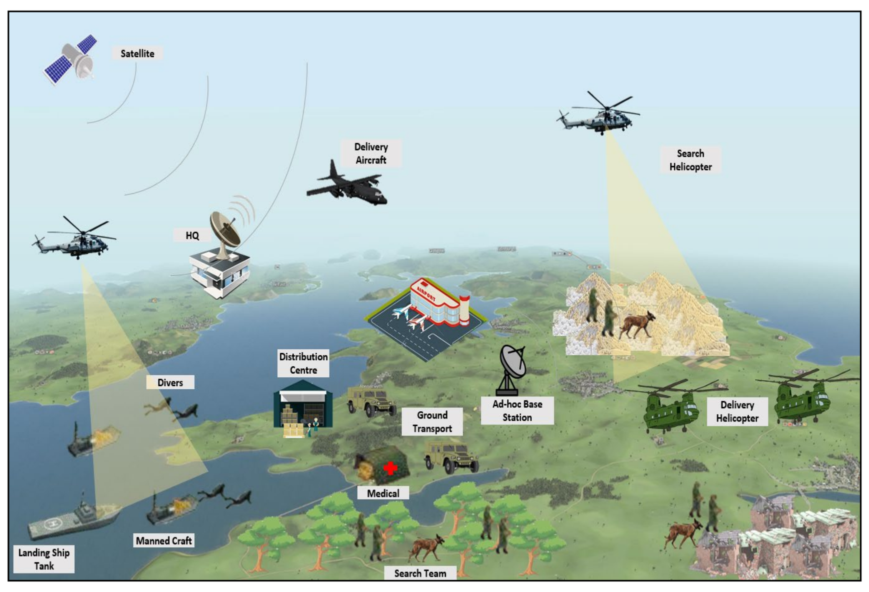

Figure 1: OV-1a for "as-is" Capability

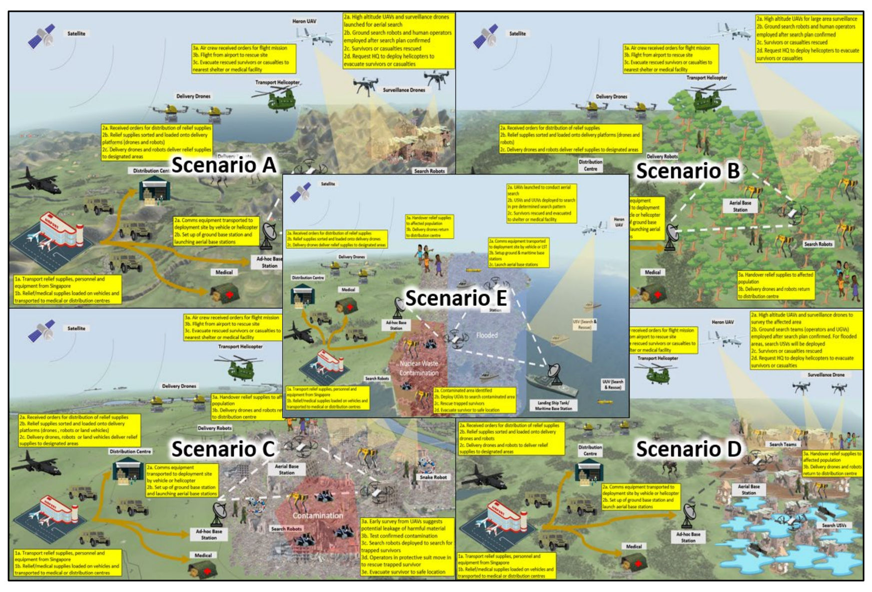

Figure 2: Gap Analysis using Scenario Planning

	Search and Rescue						Deliver Relief Supplies			Communications		
	Evacuation Helicopter	Surveillance UAVs	Search UGVs	Urban Search Robots	Search USVs	Search UUVs	Land Vehicles	Delivery Drones	Delivery UGVs	Aerial Base Stations (UAVs)	Ground Base Stations	Maritime Base Stations
Scenario A (Mountain)	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✗	✗
Scenario B (Forested)	✓	✗	✓	✗	✗	✗	✗	✓	✓	✓	✗	✗
Scenario C (Urban)	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓	✓	✗
Scenario D (Rural)	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓	✗	✗
Scenario E (Coastal)	✓	✓	✗	✗	✓	✓	✗	✓	✗	✓	✗	✓

Figure 3: Relevance of Assets for Different Scenarios

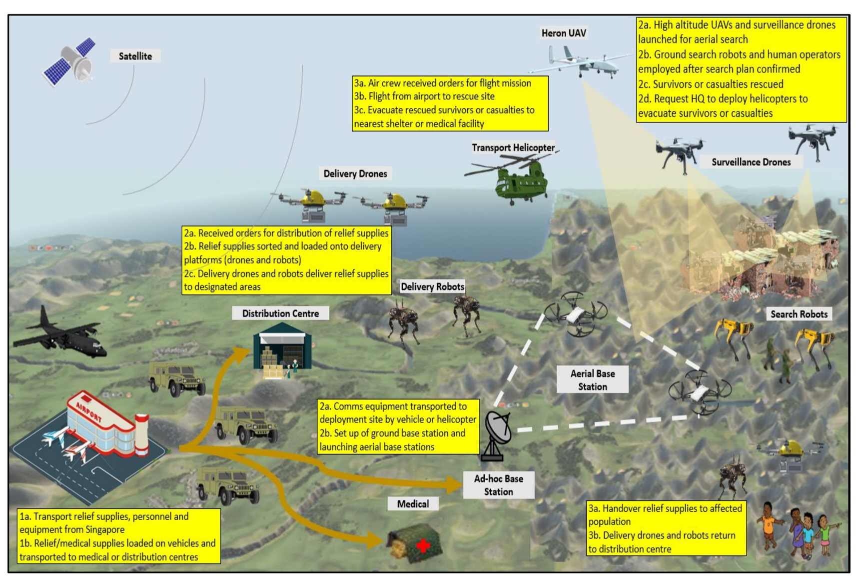

Figure 4: OV-1a for "to-be" Capability

Using the OV-1a for the "as-is" capability as the backdrop, scenario planning was performed to analyse how the capability will be deployed and utilised in different scenarios as shown in **Figure 2**. Based on the challenges identified for the different scenarios, a suite of #unmanned technologies (Refer to **Figure 3**) were identified for (1) search and rescue; (2) delivery of relief supplies; and (3) communications, to derive an OV-1a for the "to-be" HADR capability as illustrated in **Figure 4**.

To provide a deeper analysis, the author selected unmanned systems for delivering relief supplies as the area of focus for further evaluation. To that, (1) Functional Hierarchy Tool; (2) Use Case Diagram; and (3) Event Tree were utilised to elicit the requirements for the potential solutions.

With reference to the requirements, system architecture modelling was applied to guide the development of the structural design for the potential solution options. This involved developing high-level logical architecture models for the (1) delivery UGVs; and (2) delivery UAVs. Subsequently, the logical architecture models will be used to guide and constrain the development of the physical architecture models for potential solution options. In this case, (1) unmanned transport vehicle; and (2) the robotic dog, were identified as potential solution options for the delivery UGVs. For the delivery UAVs, (3) quadcopter; and (4) fixed-wing UAV, were considered potential solution options (Refer to **Figure 5**).

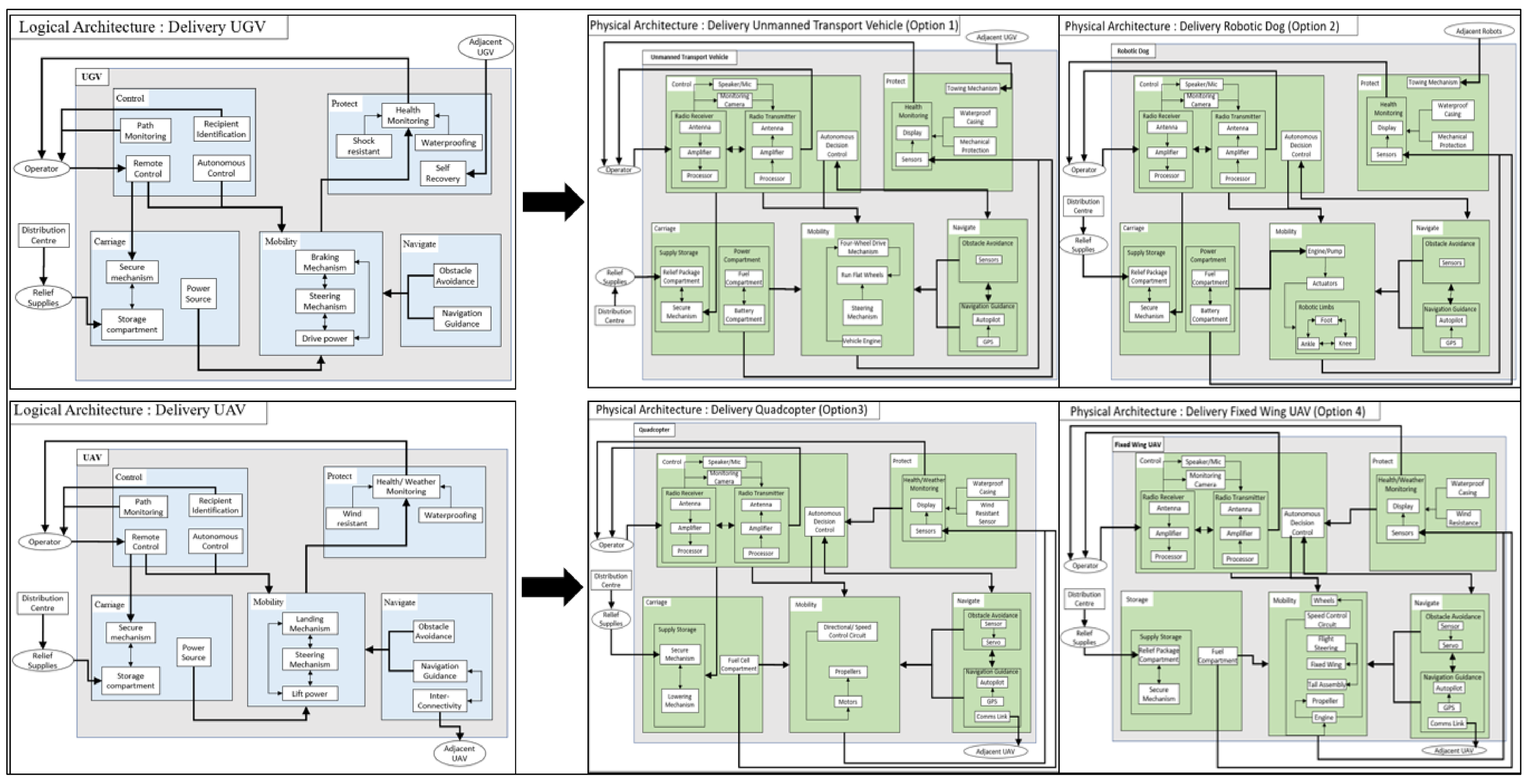

Figure 5: Logical and Physical Architectures for the Potential Solutions

Using SMART MCDA, the four potential solution options were evaluated based on their technical specifications and the delivery quadcopter was identified as the most effective solution option in terms of performance. Sensitivity analysis suggested that the result is reliable and robust to variations to the scores for mobility (40% shift) and weather resistivity (no impact), as well as changes to the prioritisation of the criteria attributes. By plotting the total scores against their estimated costs and drawing the efficient frontier, the (1) delivery quadcopter; and (2) delivery fixed-wing UAV were identified as the two most cost-effective solution options. Eventually, the fixed-wing UAV was eliminated due to its failure to achieve the minimal threshold for mobility, and thus the quadcopter was identified as the most preferred solution option.

Solution Options	Mobility	Range	Speed	Storage	Weather Resistivity
Unmanned Transport Vehicle	3 (Assessed)	5 (100km)	8 (80km/hr)	10 (450kg)	9 (Assessed)
Delivery Robotic Dog	7 (Assessed)	2 (32km)	1 (10km/hr)	4 (182kg)	9 (Assessed)
Delivery Quadcopter	10 (Assessed)	8 (350km)	7 (70km/hr)	6 (250kg)	7 (Assessed)
Fixed-Wing UAV	1 (Assessed)	10 (2500km)	10 (Accessed)	8 (350kg)	7 (Assessed)

Solution Options	Mobility (0.278)	Range (0.236)	Speed (0.194)	Storage (0.167)	Weather Resistibility (0.125)	Total Scores
Unmanned Transport Vehicle	0.834	1.18	1.552	1.67	1.125	6.361 **Rank 3**
Delivery Robotic Dog	1.946	0.472	0.194	0.688	1.125	4.425 **Rank4**
Delivery Quadcopter	2.78	1.888	1.358	1.002	0.875	7.903 **Rank 1**
Delivery Fixed-Wing UAV	0.278	2.36	1.94	1.336	0.875	6.789 **Rank 2**

Figure 6: Multi-Criteria Decision Analysis to evaluate the Solution Options

Recommendations

Moving forward, this thesis could be further expanded to the following:

(1) To extend similar analysis to (1) communications; and (2) search and rescue, to explore and evaluate the potential solution options in these areas.

(2) To include detailed research and analysis on the (1) whole lifecycle costs; and through-life issues that could have downstream implications to the implemented systems.

(3) To provide a more realistic assessment of the complex HADR capability, system dynamic modelling and simulation could be employed to help determine the quantity of the selected unmanned systems and their logistics support required.

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