Modeling Airlift Operations for Humanitarian Aid and Disaster Relief to Support Acquisition Decision-Making

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In a fiscally constrained environment, it is crucial that both equipment manufacturers and defence invest in technology that shows marked operational improvement. A priori identification of cost-benefit at the early acquisition stage is often limited and incomplete, leading to poor value propositions. This conundrum motivates the need to develop a method to evaluate technologies such as levels of autonomy, stealth capability, improved engines, etc. and make tradeoffs against operational measures of performance and effectiveness (MOP/Es) rather than solely against vehicle performance characteristics. The objective of this study is to create an environment in which those trades against MOEs could be performed rapidly to inform technology investment and acquisition decision-making. This environment is built on top of representative models of a discrete event simulation of disaster relief airlift operations to compare technology modifications or vehicle acquisition options rapidly against operational measures of effectiveness.

I. Introduction

Airlift assets are a major component to many natural disaster relief operations, especially for natural disasters affecting widely dispersed and remote areas such as the South Pacific. Relief teams must work against time across vast distances to provide support and infrastructure to the affected population. The Australian Defence Forces (ADF) contribute significantly to international emergency response operations in the South Pacific and Southeast Asia. These humanitarian assistance and disaster relief (HADR) operations require airlift assets to transport relief personnel, to deliver critical supplies, to conduct search and rescue (SAR) operations, and to perform medical team insertion and patient extraction (MEDEVAC). Although ADF HADR operations have been well-established since 2002, the ADF seek to improve operational capability via technologies; either by improvement of existing assets or by potential procurement of advanced vehicles[1]. This study intends to inform any such modification or acquisition with a rapid tradeoff environment capable of comparing multiple airlift systems against HADR operations with means to explore the trade space parametrically.

To demonstrate methodology for development of this trade environment, the Australian Defence Science and Technology Group (DST Group) proposed a scenario involving ADF HADR response to a Category 5 cyclone affecting the islands of Fiji, as defined in the Appendix. This choice of scenario is motivated by the devastation caused by Cyclone Pam on Vanuatu in 2015 and Cyclone Winston on Fiji in 2016. The ADF support to Vanuatu in the aftermath of Cyclone Pam was used as a comparative case. In HADR operations, time is critical and resources are limited. Experience with cyclones Pam and Winston identified five days as the critical window to maximize efforts of the vertical lift assets before naval assets arrive with additional capabilities and support. However, some of the five

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days are consumed by transporting vertical lift assets to the area of operations (AO) due to the distance. Furthermore, most existing rotorcraft require partial disassembly before and reassembly after transport to the AO by fixed-wing cargo aircraft due to size constraints. These same size constraints also limit the number of rotorcraft that can be transported. Maximizing sortie generation of direct-support vertical lift assets in the AO in the five-day window is a primary metric, which was assumed equivalent to maximizing the number of relief-packages delivered. Limiting support personnel, minimizing vehicle downtime, and quickly identifying priority areas for relief are other critical factors affecting the value proposition. Limiting sustainment requirements of vertical lift assets is critical to ensuring cargo aircraft can be leveraged to transport relief supplies for the island rather than for the HADR support elements.

The process-flow required to represent HADR scenarios was represented and executed using a discrete event simulation (DES). The DES allows the performance characteristics of existing assets, technology modifications, and future assets to be compared. A parametric and interactive framework was developed to explore the design space available for operations fully. This paper describes the formulation of the problem, discusses the concept of operations and relief effort constraints, highlights the approach and methodology, and summarizes the outcome of the study. The dashboard and its associated features, as well as conclusions on the process, the capabilities, and the limitations are also presented.

II. Problem Formulation

A. Current Methods and Limitations

Military acquisitions typically follow a rigorous set of procedures and guidelines. It is a complicated procedure; the equipment being procured is technically complex as are the environment of the defence organization and the political pressures. All engineering problems are about managing risk, though it can be difficult to quantify. In military acquisitions, small misjudgments can result in operation failure and can cost millions of dollars.

The complexity and scale of major defence acquisition programs are generally high, resulting in long project durations. Cost overruns, delays, and production complications were often caused by successive changes to requirements and specifications. Modern acquisition processes are meant to mitigate these problems and produce a firm understanding of the scope of the project before commencing manufacturing to control costs[2]. However, added bureaucracy has made acquisitions a slow and inflexible process. Due to the span of time, there is an inherent risk that over this period, requirements will change, or technology will advance, rendering the capability being acquired obsolete before completion of fielding. Typically, aircraft requirements are generated from subject matter expert (SME) input and based upon experience; it is extremely difficult to determine if equipment that meets the needs of current circumstances will fulfill the needs ten years in the future. Furthermore, while aircraft specifications are considered, operational measures of effectiveness often are not; as they are difficult to define, evaluate, and assess. Some technologies may show improvement in aircraft performance but only manifest marginal improvements in operational effectiveness for the investment.

In a fiscally constrained environment, investing only in technologies that show marked improvement is crucial. Both the manufacturers and customer must focus investment and research efforts on these technologies. At present, a priori identification of cost-benefit at the early procurement stage has been limited or not complete, leading to poor value propositions from too many capability acquisition decisions. However, the Australian Capability and Sustainment Group (CASG) is devoting considerable effort to improve the management of Defence acquisition[3].

B. Challenges

In the event of a natural disaster, resources are typically depleted, and people are in urgent need of necessities, such as food, water, rescue, and medical attention. Depending on weather conditions, survival without water could be as little as one hour or as much as five days[4]. This constraint is critical for reaching people to provide drinking water. After delivery of water, or in parallel, food supplies need to be delivered. One major constraint in the mission is the significant deployment distance from the embarkation base in Australia to the point of debarkation in the theatre of operations. The next challenge is becoming fully operational within the shortest possible time using only those resources airlifted in or already available at the point of debarkation. As an example, to fit of blades or rotor heads to helicopters usually requires an overhead crane; if one is not available onsite, a crane or hoist must be brought in. Finally, maintaining continuous, high-tempo operations for even as short a period as 5 days requires a significant logistics footprint to support the required operations and maintenance crews.

C. Deployment Options

The main methods of deployment available for vertical lift vehicles are air transport and sea transport. The concept of operations dictates air transport is imperative to expedite aid to the theater of operations. Air transport can be classified by two means: self-deployment or strategic airlift (STRATAIR) via a cargo aircraft[5]. Self-deployment requires refueling options for vertical airlift vehicles that cannot fly to the destination in one tank of fuel. Refueling can be by accomplished by landing at a waypoint (if one exists) en-route to the destination or by inflight via aerial refuel. Stopover requirements (simple refuel stop versus overnight stop) are dictated by cruise speed, fuel consumption, time required, and crew duty-day limitations. Aerial refuel is often not standard on Australian vertical lift vehicles and would be considered a technology modification. The study assumes that aerial refuel tanker aircraft are available to support self-deployment operations to the theater of operations. Strategic airlift would eliminate refueling requirements by transporting a vertical lift aircraft within a cargo aircraft in a direct flight. Fitting most rotorcraft into a cargo aircraft requires disassembly for stowing and associated re-assembly upon arrival, impacting the mission time. Deployment method ultimately affects the total amount of time available for a mission to be conducted in the target region. Deployment time should be minimized where possible.

D. Delivery Options

Once in the AO, two main methods of package delivery are available for vertical lift vehicles transporting cargo: internal or external loading. Internal loading allows for faster cruise speeds but has the downside of longer loading times as the available crew must configure the payload within the vehicle, most often without the ability to load individual pallets rapidly. Internal loading volume is derived from pallet sizes, however, with delineations: 463L HCU-6/E pallet (standard), 463L HCU-6/E half-pallet, and GMA[6]. The pallet sizes and capacities vary per aircraft. External loading or “sling-loading” limits the aircraft cruise speed, however, this configuration allows for faster loading and payload drop-off. The standard sling-loaded bag is an A22 cargo bag[5]. The payload capacity varies per aircraft for both internal and external loading, and these capabilities and restrictions are important when modelling the delivery capabilities for each.

III. Case Study: Cyclone over Fiji

A. Fiji Geography

Fiji is comprised of two main islands, Viti Levu and Vanua Levu, and 330 other islands, 110 of which are inhabited. The total population is 920,938 as of the July 2017 census[7]. The main two islands account for 87% of the total population, with 75% of the total population living on the coastline of Viti Levu[8]. In August 2017, there were 82,316 total visitors to the islands[9], which increases the total number of people in Fiji at any given time. There are two international airports in Fiji; both on the largest island Viti Levu. In this scenario, the easterly Nausori International Airport (SUV) is assumed to remain operating. Despite most flights arriving in Nadi International Airport (NAN) on the west side of the island, Nasusori is more centrally located in Fiji than Nadi. Both airports can allow large cargo aircraft to land, such as the Royal Australian Air Force’s (RAAF) Boeing C-17 Globemaster.

B. Cyclone Pam Historical Reference

To gain a better understanding of how a Category 5 cyclone could affect Fiji, a case study was performed on the ADF support efforts to Vanuatu after Cyclone Pam in 2015. Vanuatu is also an archipelago country in the South Pacific and is geographically co-located with Fiji. Cyclone Pam primarily affected the islands of Tanna and Erromango, home to 30,000 people and a few thousand people, respectively. In addition to food and water shortages, 80 percent of homes in Tanna and its only hospital were severely damaged[10]. There were 11 deaths and many more injured people requiring medical attention. The relief efforts were operational within 36 hours of the cyclone passing. In total, the ADF provided over 500 personnel and 182 tons of relief supplies. They delivered water, sanitation, and hygiene products to the people of Vanuatu, treated 1,341 patients, accomplished 26 aero-medical evacuations, provided other medical assistance, and repaired key infrastructure, such as the hospital, other health facilities, and schools[11]. To enable these operations, the ADF provided C-17 Globemaster and C-130J Hercules cargo aircraft to mobilize personnel and aid from Australia. In Vanuatu, a KA-350 King Air and three UH-60 Blackhawks were used for SAR and delivery of supplies. Additionally, AP-3C Orion aircraft were used to augment the search efforts. The ADF leveraged amphibious ships to transport supplies and to act as a maritime base of operations[12]. Although a similar composition of assets could be used when modelling the scenario situation in Fiji, this study focused on the intra-archipelago vertical lift of aid supplies only; previously accomplished by the three UH-60 Blackhawk helicopters.

C. Scenario Requirements and Constraints

The mission of interest for this scenario is the delivery of logistics packages, each of size 0.5 m x 0.5 m x 1.0 m (1.6 ft. x 1.6 ft. x 3.2 ft.) and of mass 30 kg (66 lbs). For this mission, the number of packages should be maximized within the first five days post-cyclone. The requirements and objectives for this mission are detailed in Table 1.

Table 1. Requirements and objectives for the HADR logistics mission.

Mission 1: Airlift (Logistics)	
Requirements	Objectives
Deliver logistics packages of 0.5m x 0.5m x 1.0m that weigh up to 30kg each	Maximize area covered Maximize density of deliveries within first 5 days

In the Fiji scenario, it is assumed that support will deploy from the RAAF base in Amberley, near the city of Brisbane, AUS. Although it is the nearest base to Fiji, RAAF Amberley is still 2960 km (1600 nm) from Nausori International Airport (NFNA), as shown in Figure 1. The relief operations are limited to the use of only two C-17 aircraft. For reference, each C-17 can fit a single Blackhawk helicopter with its supporting crew and equipment in the cargo bay. Consumables (fuel, oil, etc.) for all aircraft will also need to be transported to Fiji, therefore, these consumables will be delivered subsequent sorties by the two C-17s and, hence, all vertical lift assets and their supporting crew and equipment must be transported in the first two sorties only. RAAF has existing vertical takeoff and landing (VTOL) aircraft, but not all have the range capable of reaching the outlying islands of Fiji, assuming a base at NFNA. These aircraft characteristics were considered in the model and future airlift vehicle options were also determined in the analysis. As an additional requirement, new airlift options must reach a technology readiness level (TRL) of 9 by the year 2030. The vertical lift systems are required to operate in radius greater than 93 km (50 nm) from SUV and up to 4,500 m (15,000 ft) in altitude. The VTOL aircraft must have a clearance radius between 4.6 and 46 m (15 and 150 ft.), be capable of operating in degraded visual environments (DVE), and fly in wind gusts up to 51 m/s (100 knots). Additionally, the base operations are assumed to have no communication with outlying islands, so a distribution methodology must be implemented.

Figure 1. Distance between RAAF Amberley and Fiji – close-up: distance between Fiji and the surrounding islands.

D. Relief Timeline

In a disaster relief operation, time is the most critical constraint. It is helpful to break down the phases of the entire operation to understand what specific missions will be accomplished when. Phase 0 is “Receipt of Mission” with tasks of prioritizing goals, determining constraints, determining resources required, determining resources available, and identifying units for deployment. Phase I is “Pre-deployment/Staging Operations” with tasks of mobilizing, preparing personnel and equipment for transportation, and loading strategic airlift. It is assumed that the cyclone is meteorologically forecasted and HADR assets are pre-identified and staged at RAAF Amberley; therefore, Phases 0 and 1 are not included in the overall time of operations and do not consume any hours of the five-day operation window. Phase II is “Deployment” at which the five-day window begins. Relief assets either self-deploy or are transported via C-17 to the AO. The transit time to AO is calculated and subtracted from the total time available for operation. Transportation time of vertical lift aircraft via strategic airlift (STRATAIR) is calculated using transit time of the STRATAIR. Transportation via self-deployment requires transit time, refuels, and stopovers if needed. Phase III is “Reception, Staging, Onward movement, and Integration (RSOI).” In this phase, support personnel and equipment arrive in theater and transition to operational relief forces. For either method of deployment, it is assumed that staging of administrative support (operations tents, etc.) are completed in parallel and not accounted for in the model. For vertical lift aircraft transported via STRATAIR, additional time is calculated for aircraft reassembly time and post-reassembly test flights. Phase IV is “Conduct Operations.” In this phase, the logistics missions are conducted. Phase V is “Redeploy” and begins when HADR operations are complete and is not included in the five-day timeline.

Operational Measures of Performance (MOPs) for the five-day operation are the time available for mission, down-time of vehicles, number of sorties generated in theater, and number of hours flown by vehicles. The Operational MOEs for the five-day operation are the number of packages delivered and the number of Tikinas (analogous to counties) visited. These MOEs translate directly to percent of people serviced and percent of country serviced, respectively.

IV. Methodology for Generation and Evaluation of Alternatives

A. Distribution Methodology

As previously mentioned, there is no communication between the base at NFNA and the outlying islands. To know where to deliver packages, a prioritization method is required based on pre-existing population data. The Webster/Sainte-Laguë method was chosen as a suitable way of prioritizing locations within Fiji for distribution[13]. This method was applied to the population size numbers of the enumeration areas (analogous to voting districts) of Fiji an indicative of population distribution[14]. The Webster/Sainte-Laguë method has been used in the past for the allocation of parliamentary seats of the U.S. House of Representatives to the various states depending on their population size. In comparison to other methods[15], the Webster/Sainte-Laguë method inherits the smallest discrimination of smaller numbers in favor of larger numbers, which is an unavoidable result of the discrete distribution number following non-discrete proportion and can be observed for the Jefferson/D'Hondt method[16]. Furthermore, the chosen approach does not only yield a proportional total distribution of flights but also delivers a rank-ordered list of allocation steps. The ranked list is unchanging for a given set of numbers (such as census population data), and thereby only needs to be generated once for use in the simulation. The enumeration areas of Fiji are census-designated areas of connected households and are aimed to be roughly equal size. These areas were chosen as distribution points to allow settlements in remote and sparsely populated areas to be delivered to at an equal rate as those in more densely populated areas as not to bias areas with more people and presumably more surviving infrastructure against areas with lesser population and infrastructure. These were chosen instead of the larger area-level Tikinas. The actual delivery flights however, were still simulated as flights to a central point within the respective Tikina, with the assumption that the delivery to Tikina center would then be distributed to the afflicted enumeration area in rank dictated by the Webster/Sainte-Laguë method.

B. Exploration of Alternatives

Table 2 lists the current Australian Army medium- and heavy-lift helicopters. These existing assets are considered as baseline capability for this simulation. Their basic performance statistics, geometric constraints, and operating conditions are detailed in this table. These values are used in the simulation to determine the throughput capabilities of alternative architectures. Figure 2 illustrates the range capabilities of these vehicles in reference to the local geography. From this image, the CH-47 and MRH-90 are the only current assets able to reach the outermost islands from SUV.

Table 2. Australian Army Lift Helicopters[17-22].

Aircraft	O/H	Combat Radius (km)	Crew	Pax	Cruise Speed (km/hr)	Cargo Cap. (kg)	Max Weight (kg)	Empty Weight (kg)
CH-47F	10	370	4	33	260	10,890	20,870	9,740
MRH-90	46	400	4	18	260	4,200	10,600	6,400
S-70A-9	35	280	4	11	280	1,200	10,660	4,820

To determine the possible improvements due to technology integration and/or acquisition of new assets, potential VTOL assets are also considered. Table 3 lists assets that are projected to be available by the 2030 timeline set for this analysis. The capability of alternative architectures that include these future assets will be

Figure 2. Capability ranges for existing aircraft.

compared to the baseline architectures to determine the performance improvements when technologies and/or additional assets are considered.

Table 3*:* Potential Vertical Takeoff and Landing (VTOL) Options[23-29].

Aircraft	O/H	Combat Radius (km)	Crew	Pax	Cruise Speed (km/hr)	Cargo Cap. (kg)	Max Weight (kg)	Empty Weight (kg)
V-22	-	815	2	24	480	9,070	27,440	15,030
V-280	-	460-740	4	14	520	5,500	25,850	15,000
S-97	-	300	4	6	400	900	5,170	4,050
Boeing CUAS	-	40	1*	0	110	225	565	340

* indicates remote operator

C. Implementation of Technology Improvements

Technology improvements were divided into four different types: general airframe technologies, reduced/zero maintenance technologies, engine core technologies, and operations technologies. To reduce dimensionality, all possible technologies in these categories were treated as bulk improvements affecting different aircraft parameters. The full breakdown is provided in Table 4.

Table 4. Breakdown of engine modification technologies and their physical analogs.

Parameter Group	Technology Group	Aircraft Parameters
Vehicle Parameters	General Airframe Technologies	Maximum Take-off Weight
		Empty Weight
		Maximum Fuel Available
		Cruise Speed
	Reduced/Zero Maintenance Technologies	Mean Time Between Failure
		Mean Scheduled Downtime
	Engine Core Technologies	Cruise Specific Fuel Consumption
		Combat Radius
Operating Parameters	Deployment Technologies	Aerial Refuel
	Autonomy Technologies	Autonomous Operations
		Semi-Autonomous Operations
		Teleoperations

General airframe technologies reflect all technologies used to reduce drag, reduce rotor tip losses, reduce the weight of the aircraft, or the like. This may include technologies such as swept rotor tips or composite landing gear. Reduced/Zero Maintenance technologies reflect technologies currently under development which may be applied to multiple systems in the aircraft, most notably within the powertrain and engines, dramatically reducing the amount of maintenance required both in terms of scheduled downtime as well as mean time between failure. Engine core technologies improve engine core cycle performance, particularly in the specific fuel consumption. Possible technologies include compressor blisks and thermal barrier coated turbine blades.

The vehicle parameters Table 4 represent changes to collections of subsystems which, when implemented, are complex and will require additional analysis. However, this research was not intended to design these subsystems, but instead provide targets for subsystem designers to meet. It was required that all alternatives examined be TRL 9 by 2030. As a result, these parameters in Table 4 were varied as a percent change from baseline values for each aircraft considered. Empty weight, maximum take-off weight, and cruise specific fuel consumption were varied up to ±15% (+/–) from baseline, and all other parameters were varied up to ±25% from baseline.

Operational parameters are affected by a suite of technologies modifying the concept of operations more than the vehicle itself. These technologies are deployment technologies and autonomy technologies. Aerial refuel as a deployment technology enables an aircraft to transit beyond its rated ferry range to fulfill a long-range mission.

Autonomy technologies enable an aircraft to conduct its mission in concordance with one of three levels of autonomy, described in Table 5 below.

Table 5. Levels of autonomy[30].

Autonomy Level	Description
Fully autonomous	Unmanned system (UMS) accomplishes its assigned mission without human intervention
Semi-autonomous	Human operator and/or the UMS plans and conducts a mission and requires various levels of human-robot interaction (HRI) – UMS is capable of autonomous operation in between the human interactions
Teleoperations	Human operator directly controls the actuators or assigns incremental goals on a continuous basis, from a location off the UMS

Autonomy was tied principally to the number of crews per vehicle. HADR missions are sensitive to the number of personnel on site. As the number of personnel increases, the required infrastructure overhead to support the mission will also increase. Autonomy potentially allows the amount of personnel on site to be reduced while retaining mission effectiveness. While other effects may exist, these were not considered as part of this study due to their reduced impact on the mission. The levels of autonomy were mapped to different numbers of crew per vehicle. Fully autonomous systems were mapped to zero crews per vehicle. Semi-autonomous and teleoperated systems were mapped to 0.5 crews per vehicle. Conventional systems were mapped to one crew or greater per vehicle. It is important to note that the "crews" referenced herein are direct piloting and operating crewmembers.

D. Operational Logic

The operational management of this HADR mission was emulated by first establishing a dispatch center, referred to as simply "dispatch", associated with administrative and logistical elements such as cargo handling and refueling. Available vehicles are placed into a vehicle pool, and all available crews are placed into the crew pool. Dispatch handles all mission requests and dispatches missions to vehicles and to crews by checking for available vehicles and crews in the vehicle and crew pools, then assigning missions to whichever crew and assets are free. Fuel and cargo are distributed as required. The vehicle and crew then fly the mission. While the vehicle and crew are on mission, they are removed from the pool. When the vehicle returns to base, both the vehicle and its attendant crew are released back into the pool. For this scenario, dispatch transmitted a fixed list of mission locations governed by the aforementioned Webster/ Sainte-Laguë method.

E. Discrete Event Simulation

Due to the multidimensional nature of the problem, a simulation is required to ensure that all the vehicle entities and their properties are accounted for adequately. In the given scenario, the vehicle attributes are invariant with time during operation in the simulation, but with multiple asynchronous entities operating simultaneously, these entities require management of their state and designated mission sequence. Furthermore, the vehicles are subject to probabilistic events within the simulation to manifest the realistic probability that unscheduled maintenance or operational issues will arise. These different problem elements directed that a discrete event simulation was the most suitable modelling environment the HADR scenario under consideration[31-33]. This simulation was developed in Python using the SimPy discrete event simulation library[34,35]. A graphical representation of the code structure is given in Figure 3. Figure 3 shows that the discrete event simulation that was developed follows the basic structure described in Operational Logic section. Here, the Mission Parameters were the total available simulation time, number of vehicles, number of crews per vehicle, type of vehicle, and percent variations from the baseline performance parameters for each vehicle in operation. Dispatch was represented as a centralized decision-making class that encompasses

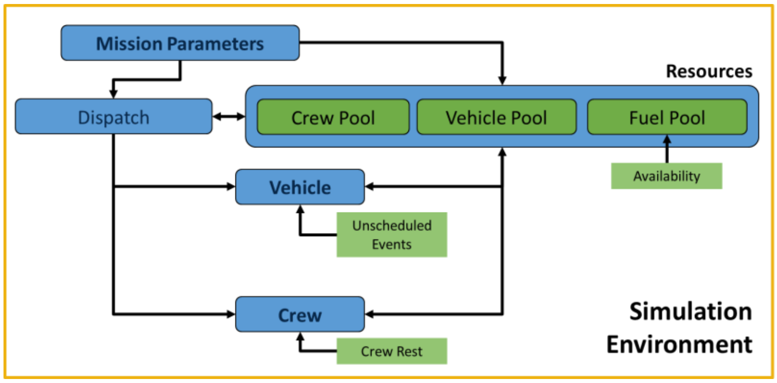


Figure 3. Graphical representation of simulation structure.

mission request generation and mission assignment to vehicles. For the scenario under consideration for this research, mission requests came from a fixed, presorted list that previously described using the Webster/Sainte-Lague method. Each Tikina was represented as a node with latitude and longitude coordinates which tracked the number of times it had been visited.

Pilot availability was modeled by assuming that all crews were constrained to a 12-on-12-off cycle. This cycle constraint means that crews would only be available for half a day and were required to rest for the remaining half. The crew pool was organized to adhere to this constraint. Crews were not represented as individuals, but rather slots within the crew pool. This abstraction remained valid so long as the 12-on-12-off cycle was maintained. In order to coordinate this within the language and logic of the SimPy library, *empty* slots represented available crews, while *filled* slots represented crews that were unavailable.

If fully autonomous vehicles are chosen (0.0 crews required per asset), no pilots exist for each vehicle. However, this is mathematically invalid within the simulation structure; therefore, having full autonomy is analogized to having infinite crews. To model the effect of having full autonomy, the number of crews was set to ten per vehicle, resulting in a crew pool that would be large enough never to be constrained by crew availability.

If semi-autonomous vehicles are selected (0.5 crews required per asset), the number of vehicles available would effectively double due to requiring only 0.5 crews per vehicle meaning that each available standard crew would be able to operate two vehicles simultaneously but would still be restricted by the 12-on-12-off rest requirements. For most other circumstances, it was sufficient to multiply the number of crews per vehicle by the number of vehicles to obtain the crew pool size. A degenerate case was found for when the number of crews per vehicle was equal to one. The solution to this case was to halve the available simulation time for operation while noting the original simulation time for output purposes. This solution arose by observing that if crews are constrained to a 12-on-12-off cycle, then only half the available time will actually be spent flying missions.

Vehicles were represented as a distinct class that contained its vehicle parameters and all methods and functions required to conduct one mission. A given mission was delineated into three distinct segments: probabilistic checks, fueling, and flight. The “probabilistic checks” event modeled all different unscheduled events that could occur to an aircraft before, during, or after a mission. This categorization includes minor events, such as a flat tire discovered during pre-flight inspection, to major events, such as a breakdown of the main rotor powertrain during take-off. A 15% chance of the vehicle suffering a 3-hour delay during a mission and a 15% chance of suffering a 5-hour long delay during a mission were assumed to capture the unpredictable nature of realistic, unscheduled issues. The fueling event modeled the fueling and cargo loading phases of the event, with the assumption that all relevant cargo could be loaded in the time required to refuel the aircraft. The flight event modeled the actual flight of the vehicle, assuming that all cargo was dropped off at the destination and the aircraft returned to base immediately. At each event, the time elapsed to complete the event was tabulated and the fuel state of the vehicle was recorded. For this scenario, the fuel pool was constrained to two fuel pumps, each pumping at 120,600 pounds per hour. This value was obtained by converting the gallons per minute pump rate of typical airport jet refuel trucks into pounds per hour. A conservative value of 300 gallons per minute was used for this scenario, simulating the resource-constrained nature of the problem[36,37].

The SimPy discrete event simulation library makes use of the Python multithreading library. As a result, a key limitation of the discrete event simulation was its inability to handle more than one object class at each hierarchical layer at any one time[38]. The dispatch controller class exists at a higher layer of logic than the Vehicle class, and as a result does not suffer interference. However, attempts to implement more stringent models with interactions between classes resulted in significant errors due to lack of thread locking and thread handling procedures in the simulation design.

F. Surrogate Modelling

The discrete event simulator captures the various asynchronous events well, but for any change in mission or vehicle definitions by the user, a new simulation must be run to assess changes in outputs and mission effectiveness. This need requires considerable computational resources and model integration difficulties that are prone to increase as additional complexity is built into the environment. Moreover, since the simulation itself is probabilistic in nature, a single input to the simulation yields different outputs. The probabilistic uncertainty in the simulation, combined with the prohibitive simulation run times, provided considerable challenges for integration into a decision-support framework. For the simulation behavior to be captured rapidly for changing vehicle properties or deployment information, surrogate models were used.

A design of experiments (DOE) was created to discretize the various operational and performance metrics that define a vehicle in the operational scenario within the simulation environment. Since the project considers various potential asset classes, from as big as a CH-47 or V-22 to as small as the Boeing CUAS, capturing the whole range of design space in a complete DOE would have stressed the quality of the DOE due to extreme interpolation. Therefore, separate DOEs for each asset type were created, and each had performance metric variations of a fixed percentage from the baseline specification. This strategy left gaps in the overall variable ranges but offered better confidence in behavior for the captured ranges.

The variables in the DOE are a mixture of both discrete and continuous types necessitating a combination of a full-factorial for DOE corner points and a fast, flexible space filling design for center points[39]. This method uses a random number of points throughout the design space that are then "clustered" around discrete variable values to create a hybrid space filling design. This method is illustrated in Figure 4, where two continuous variables X3 and X4 are clustered around the discrete variable "No. of vehicles".

The data from the DOE runs was fitted with a neural net surrogate model[40]. This method was used to capture better the nonlinearities inherent in the data resulting from the clustering of data points around the discrete variables. The surrogates have a consistent R^2 (coefficient of determination) greater than 0.99. To assess their quality the model fit error (MFE) and model representation error (MRE) were investigated further, with a mean of the error distribution near 0.5% for all surrogates (see Figure 5). The surrogate models were then directly embedded within the user interface, giving the user parametric control over input parameters and real time visualization of outputs affected.

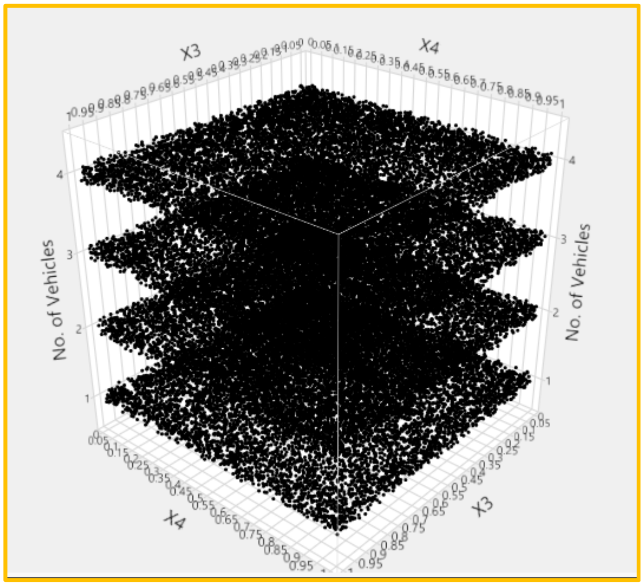


Figure 4. DOE used to capture the design space consisting of both discrete and continuous variables.

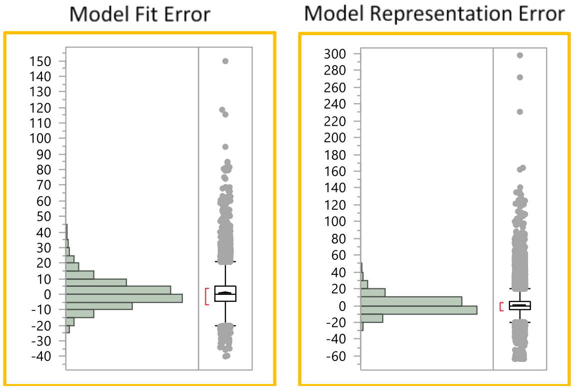
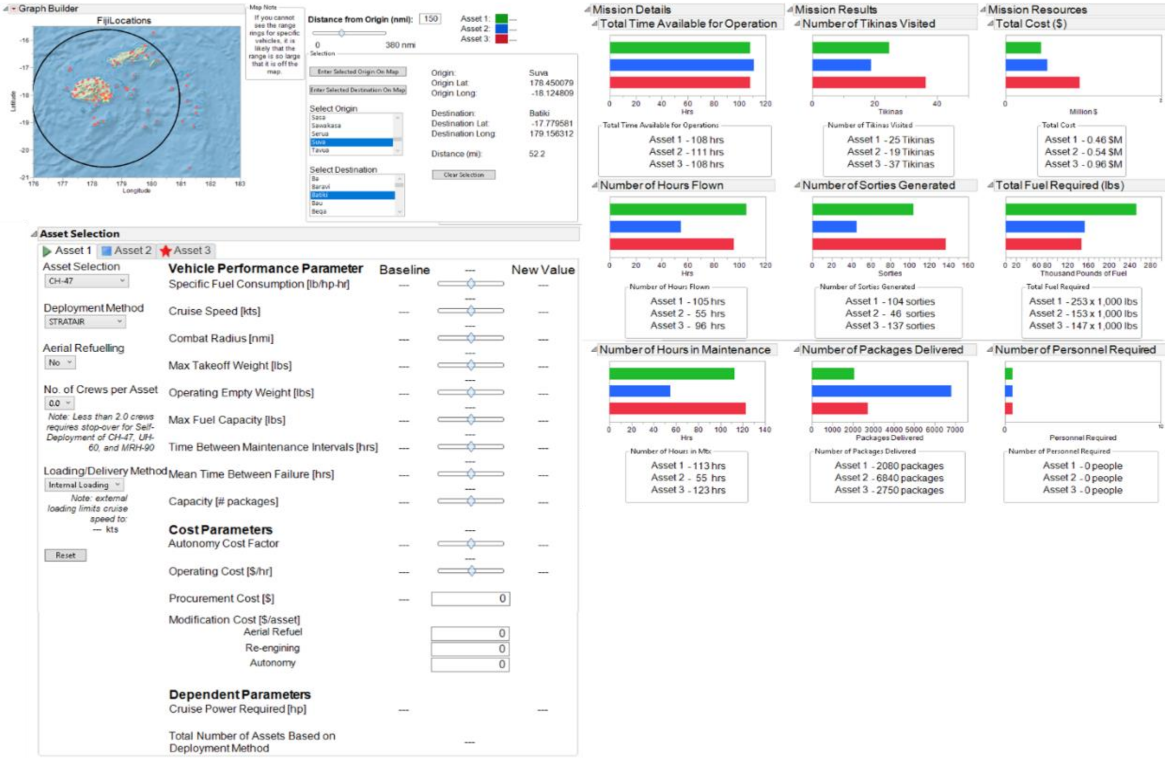


Figure 5. MFE and MRE of one of the general surrogates.

V. User Interface

The last element for the development of this environment for the modelling and simulation of airlift operations for acquisition decision-support is the rapid, parametric user interface. The user interface consists of an interactive page wherein the user can change deployment method details, performance parameters, and cost parameters of selected vehicles and see the rapid response of the measure of effectiveness from surrogate models as described above. This environment has the capability of evaluating three assets at once. The environment is shown in Figure 6. The environment consists of three primary sections: location selection, input variables, and output graphs.



Map Note: If you cannot see the range rings for specific vehicles, it is likely that the range is so large that it is off the map.

Distance from Origin (nmi): 150

Asset 1: ---
Asset 2: ---
Asset 3: ---

Origin: Suva
Origin Lat: 178.450079
Origin Long: -18.124809
Destination: Batiki
Destination Lat: -17.779581
Destination Long: 179.156312
Distance (mi): 52.2

Total Time Available for Operations
Asset 1 - 108 hrs
Asset 2 - 111 hrs
Asset 3 - 108 hrs

Number of Tikinas Visited
Asset 1 - 25 Tikinas
Asset 2 - 19 Tikinas
Asset 3 - 37 Tikinas

Total Cost
Asset 1 - 0.46 $M
Asset 2 - 0.54 $M
Asset 3 - 0.96 $M

Number of Hours Flown
Asset 1 - 105 hrs
Asset 2 - 55 hrs
Asset 3 - 96 hrs

Number of Sorties Generated
Asset 1 - 104 sorties
Asset 2 - 46 sorties
Asset 3 - 137 sorties

Total Fuel Required
Asset 1 - 253 x 1,000 lbs
Asset 2 - 153 x 1,000 lbs
Asset 3 - 147 x 1,000 lbs

Number of Hours in Mtx
Asset 1 - 113 hrs
Asset 2 - 55 hrs
Asset 3 - 123 hrs

Number of Packages Delivered
Asset 1 - 2080 packages
Asset 2 - 6840 packages
Asset 3 - 2750 packages

Number of Personnel Required
Asset 1 - 0 people
Asset 2 - 0 people
Asset 3 - 0 people

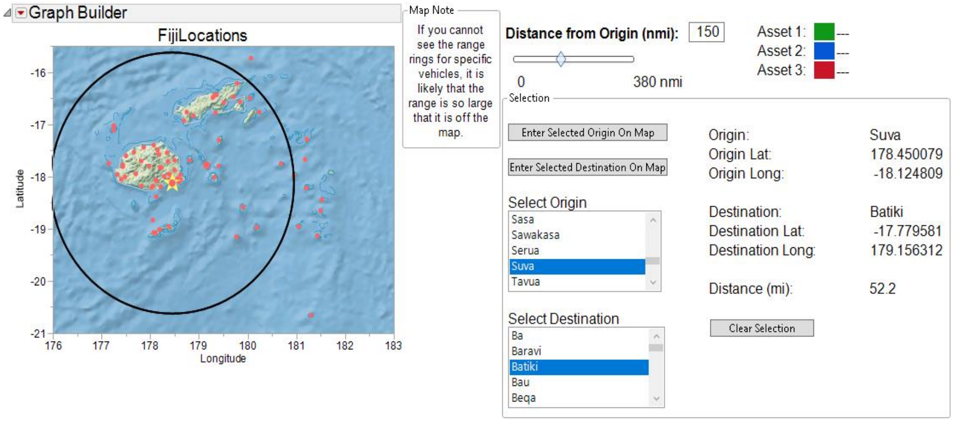
Asset Selection: CH-47
Deployment Method: STRATAIR
Aerial Refuelling: No
No. of Crews per Asset: 0.0
Note: Less than 2.0 crews requires stop-over for Self-Deployment of CH-47, UH-60, and MRH-90
Loading/Delivery Method: Internal Loading
Note: external loading limits cruise speed to: --- kts

Vehicle Performance Parameter	Baseline		New Value
Specific Fuel Consumption [lb/hp-hr]	---	---	---
Cruise Speed [kts]	---	---	---
Combat Radius [nmi]	---	---	---
Max Takeoff Weight [lbs]	---	---	---
Operating Empty Weight [lbs]	---	---	---
Max Fuel Capacity [lbs]	---	---	---
Time Between Maintenance Intervals [hrs]	---	---	---
Mean Time Between Failure [hrs]	---	---	---
Capacity [# packages]	---	---	---
Cost Parameters		---	
Autonomy Cost Factor	---	---	---
Operating Cost [$/hr]	---	---	---
Procurement Cost [$]	---	0	
Modification Cost [$/asset]			
Aerial Refuel		0	
Re-engining		0	
Autonomy		0	
Dependent Parameters			
Cruise Power Required [hp]	---		---
Total Number of Assets Based on Deployment Method		---	

Figure 6. Decision-support environment.

The location selection includes an interactive map of Fiji Tikinas, where the origin and destination can be set to explore theater distances. The user can choose to click on a Tikina district on the map or through the scrolling menus in the selection box that alphabetically list the Tikinas by name. At any point, the origin and destination can be cleared for easier re-selection. Whenever a location is selected, the latitude and longitude coordinates are displayed to the right of the selection. When both the origin and destination are set, the distance between the two places is calculated using the haversine formula and displayed on the dashboard as a black distance ring centered on the selected Tikina origin, with an adjustable distance value. The yellow star on the map does not change, as it is the marker for the capital, Suva (SUV), where the operations are based. The location selection is shown in Figure 7.

The input section begins with the selection of the asset and is followed by selections of deployment method, aerial refuel deployment, crews available for operation per asset, and loading type. Once selected, the baseline values for all the aircraft characteristics are loaded. The selected asset type is color coded and displayed above the location selection box for easy reference next to the output graphs. The characteristics are grouped into Vehicle Performance Parameters,



Map Note: If you cannot see the range rings for specific vehicles, it is likely that the range is so large that it is off the map.

Distance from Origin (nmi): 150

Asset 1: 🟩 ---
Asset 2: 🟦 ---
Asset 3: 🟥 ---

Origin: Suva
Origin Lat: 178.450079
Origin Long: -18.124809

Destination: Batiki
Destination Lat: -17.779581
Destination Long: 179.156312

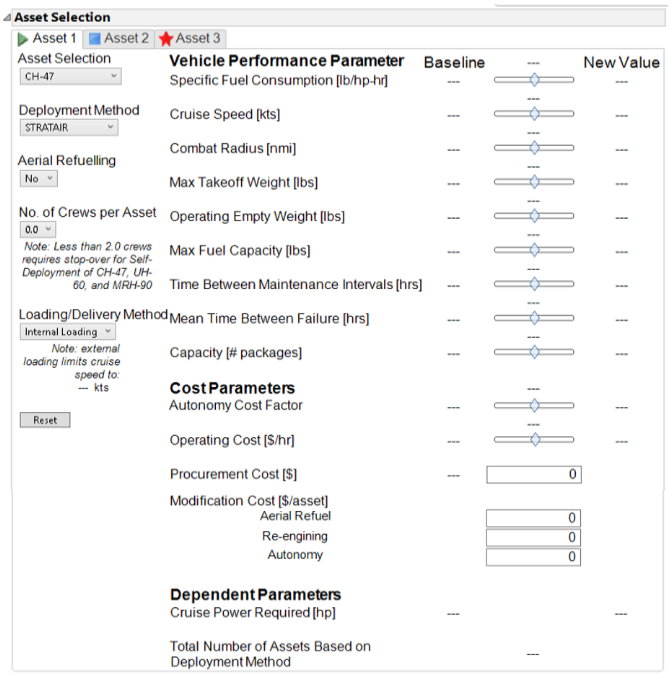
Distance (mi): 52.2

Figure 7. Location selection panel within decision-support environment.

Cost Parameters, and Dependent Parameters. Dependent Parameters are those that cannot be changed by the user but are a function of other variables within the vehicle parameters tab. Table 6 shows the characteristics in the dashboard. Each characteristic can be altered by a percent increase or decrease, representing a technology modification to that property. The percent increase or decrease is shown above the slider bars and the new value of the parameter is displayed and used to calculate the outputs described later. A reset button returns all values to the nominal and the corresponding outputs. The input selection is shown in Figure 8.

Table 6. Dashboard inputs.

Type	Characteristic	Units
Vehicle Performance Parameter	Specific Fuel Consumption	lb/hp-hr
	Cruise Speed	kts
	Combat Radius	nmi
	Max Takeoff Weight	lbs
	Operating Empty Weight	lbs
	Max Fuel Capacity	lbs
	Time Between Maintenance Interval	hrs
	Mean Time Between Failure	hrs
	Capacity	# packages
Cost Parameters	Autonomy Cost Factor	scalar
	Operating Cost	$/hr
	Procurement Cost	$
	Modification Cost – Aerial Refuel	$/asset
	Modification Cost – Re-engining	$/asset
	Modification Cost – Autonomy	$/asset
Dependent Parameters	Cruise Power Required	hp
	Total Number of Assets	# assets



Asset Selection: CH-47

Deployment Method: STRATAIR

Aerial Refuelling: No

No. of Crews per Asset: 0.0

Note: Less than 2.0 crews requires stop-over for Self-Deployment of CH-47, UH-60, and MRH-90

Loading/Delivery Method: Internal Loading

Note: external loading limits cruise speed to: --- kts

Vehicle Performance Parameter	Baseline	---	New Value
Specific Fuel Consumption [lb/hp-hr]	---		---
Cruise Speed [kts]	---	---	---
Combat Radius [nmi]	---	---	---
Max Takeoff Weight [lbs]	---	---	---
Operating Empty Weight [lbs]	---	---	---
Max Fuel Capacity [lbs]	---	---	---
Time Between Maintenance Intervals [hrs]	---	---	---
Mean Time Between Failure [hrs]	---	---	---
Capacity [# packages]	---	---	---
Cost Parameters			
Autonomy Cost Factor	---	---	---
Operating Cost [$/hr]	---	---	---
Procurement Cost [$]	---	0	
Modification Cost [$/asset]			
Aerial Refuel		0	
Re-engining		0	
Autonomy		0	
Dependent Parameters			
Cruise Power Required [hp]	---		---
Total Number of Assets Based on Deployment Method		---	

Figure 8. Input panel within decision-support environment.

The last element of the environment is the output section. Four of the outputs are directly affected by the surrogate models (number of hours flown, number of hours in maintenance, number of Tikinas visited, and number of sorties flown). Of the nine total outputs, four are driven by the surrogate models as mentioned, four are functions of the outputs of the surrogate models (e.g. number of packages delivered is a multiple of capacity in number of packages by number of sorties generated), and the last, time available for operation, is a function of the chosen vehicle and deployment method. The time available for operation is an input into the surrogates along with all the vehicle performance parameters. The results are all plotted in the output section, which is a divided into three different categories: mission details, mission results, and mission resources. These outputs are: time available for operation, flight hours, and maintenance hours for mission details; number of Tikinas visited, sorties generated, and packages delivered for mission results; and total cost, fuel required, and personnel required for mission resources. Note that all graphs will automatically scale to accommodate for larger, unexpected output values. The output section is shown in Figure 9.

Total Time Available for Operations
Asset 1 - 108 hrs
Asset 2 - 111 hrs
Asset 3 - 108 hrs

Number of Tikinas Visited
Asset 1 - 25 Tikinas
Asset 2 - 19 Tikinas
Asset 3 - 37 Tikinas

Total Cost
Asset 1 - 0.46 $M
Asset 2 - 0.54 $M
Asset 3 - 0.96 $M

Number of Hours Flown
Asset 1 - 105 hrs
Asset 2 - 55 hrs
Asset 3 - 96 hrs

Number of Sorties Generated
Asset 1 - 104 sorties
Asset 2 - 46 sorties
Asset 3 - 137 sorties

Total Fuel Required
Asset 1 - 253 x 1,000 lbs
Asset 2 - 153 x 1,000 lbs
Asset 3 - 147 x 1,000 lbs

Number of Hours in Mtx
Asset 1 - 113 hrs
Asset 2 - 55 hrs
Asset 3 - 123 hrs

Number of Packages Delivered
Asset 1 - 2080 packages
Asset 2 - 6840 packages
Asset 3 - 2750 packages

Number of Personnel Required
Asset 1 - 0 people
Asset 2 - 0 people
Asset 3 - 0 people

Figure 9. Output panel within decision-support environment.

VI. Demonstration of Environment Capabilities

The authors considered three different demonstrations to discuss the capabilities of the tool. The first scenario is a baseline vehicle compared to the same vehicle with autonomy upgrades and the same vehicle with a deployment method change. The second scenario is two existing vehicles compared against each other as well as a future vertical lift vehicle – all with matching deployment information. The last scenario is the same three vehicles as scenario two but with potential technology upgrades and different combinations of autonomy and deployment methods. The next three subsections will describe the vehicles in more detail as well as the results that were gleaned from the scenarios

A. Scenario 1

The first scenario compares three S-70A-9 (UH-60) rotorcraft with the deployment and modification details specified in Table 8. From a baseline S-70A-9 (UH-60) vehicle, vehicles 2 and 3 were modified with autonomy and deployment method, respectively. The output parameters of this scenario are shown in Table 7. The modification of the baseline S-70A-9 (UH-60) to operate in full autonomy has equivalent results to the baseline with 2.0 crews per asset. The differences manifest in the number of personnel required for direct operation of the vehicles as well as in the modification cost required to outfit the system with autonomy. The third vehicle, S-70A-9 outfitted for self-deployment, showed marked improvement on the first two vehicles in terms of overall in-theater impact. The obvious reason for this increased impact is that with a self-deployed asset, more assets can be delivered to the theater because the C-17s available for vertical lift system transport are not shipping the vehicle but just the support equipment and crew, despite the longer deployment time. In scenario 1, four S-70A-9s are available via self-deployment vs just two for the strategically airlifted. Although the relationship is not linear such that double the hours flown results in double sorties generated and packages delivered, the results show that for double the assets represented by "Vehicle 3" in scenario 1, the mission results are nearly double for sorties generated and packages delivered.

Table 8. Scenario 1 set-up details.

	Vehicle 1	Vehicle 2	Vehicle 3
Vehicle Type	S-70A-9	S-70A-9	S-70A-9
Deployment Method	Strategic Airlift	Strategic Airlift	Self-Deployment
Aerial Refuel	No	No	Yes
No. of Crews per Asset	2.0	0.0 (Fully Autonomous)	2.0
Package Loading Method	Internal	Internal	Internal
Vehicle Modifications	None	None	None
Added Cost	None	Autonomy Modification	Aerial Refuel Modification

Table 7. Scenario 1 results.

Parameter	Vehicle 1	Vehicle 2	Vehicle 3
Mission Details			
Total Time Available for Operations (hrs)	108	108	108
Number of Hours Flown (hrs)	106	105	214
Number of Hours in Maintenance (hrs)	114	113	227
Mission Results			
Number of Tikinas Visited	25	25	31
Number of Sorties Generated	104	104	199
Number of Packages Delivered	2,080	2,080	3,980
Mission Resources			
Operating Cost ($M)	0.46	0.46	0.94
Total Fuel Required (lbs)	253,000	253,000	513,000
Number of Personnel Required	16	0	32

B. Scenario 2

The second scenario compares three different vehicles with matching deployment method and no modifications. Table 9 shows the details of the scenario. This scenario exemplifies the ability to compare different vehicles' operational effectiveness. Looking at Table 10, the V-280 buys a few extra hours of operating time due to the faster cruise speed achievable of the tilt-rotor configuration and hence decreased deployment time. With the self-deployment option, four S-70A-9s, three CH-47s, and four V-280s are available in-theater. Even though the S-70A-9s and V-280s can fly more hours and generate more sorties than the CH-47s, the CH-47s deliver many more packages due to the significantly larger cargo capacity of these vehicles. The V-280s have the highest operating cost, and the procurement cost of these assets should be considered as well. This scenario shows that more operational impact is achievable by self-deploying the existing CH-47 system rather than the potential procurement of the V-280 fleet.

Table 9. Scenario 2 set-up details.

	Vehicle 1	Vehicle 2	Vehicle 3
Vehicle Type	S-70A-9	CH-47	V-280
Deployment Method	Self-Deployment	Self-Deployment	Self-Deployment
Aerial Refuel	No	No	No
No. of Crews per Asset	2.0	2.0	2.0
Package Loading Method	Internal	Internal	Internal
Vehicle Modifications	None	None	None
Added Cost	None	None	V-280 Procurement

Table 10. Scenario 2 results.

Parameter	Vehicle 1	Vehicle 2	Vehicle 3
Mission Details			
Total Time Available for Operations (hrs)	94	94	108
Number of Hours Flown (hrs)	188	141	192
Number of Hours in Maintenance (hrs)	197	139	245
Mission Results			
Number of Tikinas Visited	30	29	45
Number of Sorties Generated	173	114	267
Number of Packages Delivered	3,460	17,040	5,340
Mission Resources			
Operating Cost ($M)	0.82	1.39	1.92
Total Fuel Required (lbs)	451,000	395,000	295,000
Number of Personnel Required	32	24	32

C. Scenario 3

The last scenario compares three different vehicles with various sets of deployment methods and modifications. Table 11 shows the details of these different assets and combinations. Table 12 displays the results of this scenario. In this table, the “*” indicates the vehicles in Table 11 whereas vehicles 2 and 3 without a superscript are the same vehicles as represented in Table 11 but without the vehicle modifications to show what the modifications do to impact the effects of the vehicles. With the deployment options chosen, there were two S-70A-9s, three CH-47s, and four V-280s in theater, depending on which option was chosen. This selection resulted in a sensible distribution of flight hours per case within the scenario – more hours and sorties generated for more vehicles in theater. As seen in scenario 2, the CH-47 can deliver many more packages than the other vehicles due to its cargo capacity. Comparing vehicles 2 and 3 with their modified states, the reader can observe that the increased cruise speed on the CH-47 can generate more sorties and more packages delivered as a result. Comparatively, the V-280 with a decreased specific fuel consumption does not achieve any difference in operational effectiveness other than a reduced quantity of fuel burned. This scenario shows that even though a decrease in SFC might be an obvious performance improvement, it might not actually manifest in any operational improvement. It is important to note that in addition to the operational costs for these cases, there are procurement and modification costs associated with the chosen selections.

Table 11. Scenario 3 set-up details.

	Vehicle 1	Vehicle 2	Vehicle 3
Vehicle Type	S-70A-9	CH-47	V-280
Deployment Method	Strategic Airlift	Self-Deployment	Self-Deployment
Aerial Refuel	No	Yes	Yes
No. of Crews per Asset	0.0 (Fully Autonomous)	2.0	2.0
Package Loading Method	Internal	Internal	Internal
Vehicle Modifications	None	Cruise Speed Increased by 15%	Specific Fuel Consumption Decreased by 15%
Added Cost	- Autonomy Modification	- Aerial Refuel Modification - Vehicle Modification for Speed Increase	- V-280 Procurement - Aerial Refuel Modification - Vehicle Modification for SFC Decrease

Table 12. Scenario 3 results.

Parameter	Vehicle 1*	Vehicle 2	Vehicle 2*	Vehicle 3	Vehicle 3*
Mission Details					
Total Time Available for Operations (hrs)	108	94	94	108	108
Number of Hours Flown (hrs)	105	141	136	192	192
Number of Hours in Maintenance (hrs)	113	139	143	245	245
Mission Results					
Number of Tikinas Visited	25	29	31	45	45
Number of Sorties Generated	104	114	125	267	267
Number of Packages Delivered	2080	17,040	18,810	5,340	5,340
Mission Resources					
Operating Cost ($M)	0.46	1.39	1.35	1.92	1.92
Total Fuel Required (lbs)	253,000	395,000	392,000	295,000	251,000
Number of Personnel Required	0	24	24	32	32

D. Additional Analysis

While the total time available for operations, number of hours flown, number of Tikinas visited, hours flown, and packages delivered are adequate operational MOP/Es, from an acquisitions sense, these values provide limited insight into cost-benefit for investment without including cost or another normalization factor. By allowing the user to vary operating cost per hour and manually input procurement and modification costs, the raw outputs can be normalized by cost and compared. Using Scenario 3 (Table 11and Table 12), the number of hours flown, packages delivered, and number of sorties generated can be normalized to compare the value proposition of each modification or procurement (means) versus another by simply changing the methods of deployment or delivery (ways) to inform investment decisions. Table 13 demonstrates on of the many comparisons possible.

Table 13. Potential advanced metrics for Scenario 3 vehicles.

Parameter	Vehicle 1	Vehicle 2	Vehicle 2'	Vehicle 3	Vehicle 3'
Advanced Metrics					
Packages per Flight Hour	19.8	120.9	138.3	27.8	27.8
Packages per $T Operating	4.5	12.3	13.9	2.8	2.8
Sorties Generated per $M Operating	226	82	93	139	139

Table 13 shows quite dramatically how well the CH-47 performs compared to the V-280 and S-70A-9, with packages per flight hour metrics four and six times better, respectively, and packages per thousand operating dollars four and three times better, respectively. In the sorties generated per million operating dollars, the V-280 and S-70A-9 both perform better than the CH-47, but the CH-47's large cargo capacity allows it to deliver many packages on limited sorties. These metrics are just examples of how the "cross product" of MOP/Es can be taken to give more insight into the outputs.

VII. Conclusion and Future Work

Current methods of developing future aircraft requirements for modification and acquisition are to survey subject matter experts input and to reference experience and operations. To maximize the value proposition for future acquisition decisions, there is a need to identify the cost-benefit in conceptual design, as the current methods for developing requirements and informing acquisition are inadequate. To do this, the authors analyzed and modelled a concept of operations for a realistic scenario set motivated by Australia's increasing contributions to humanitarian aid and disaster relief in the South Pacific region. The authors identified meeting the need of this effort by creating a simulation environment for evaluating current and future aircraft against measure of effectiveness for the CONOPS of interest. Current and future vehicles and vehicle modifications were identified meeting TRL 9 by 2030. Lastly, a simulation was created for the CONOPS, the design space was sampled, and a rapid, parametric environment was built on representative model functions to evaluate alternatives to support decision-making.

A future work extension includes exporting the results to a multi-attribute decision-making (MADM) analysis tool to support decision-making quantitatively in addition to informing tradeoffs currently. Additionally, the simulation could be augmented to include other HADR missions such as search and rescue and medical team insertion and extraction, details included in the Appendix. The constraints posed on this problem could be converted from static to parametric i.e. changing the number of C-17s available for vertical lift asset transportation or extending the timeframe of operations from five days. Another expansion could be to include simulation of all resources (Navy and Air Force) in addition to the Army's vertical lift assets in-theater. Lastly, the current state of the simulation and associated tradeoff environment assumes homogenous fleet composition, however, that could be extended to support mixed fleet composition – mixing that with the MADM analysis could allow the environment to optimize the fleet composition for operational effectiveness.

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Appendix: Technology Assessment Study – Provincial Air Lift for HADR

Introduction

Humanitarian Assistance and Disaster Relief (HADR) was and remains a significant role for the military. By 2030, greater HADR capabilities will be sought through advances in aerospace technology. The capability that represents the focus of this study is the role of air lift within an area of operations affected by natural disaster. Outlined below are the scenario and missions that should be used as a guide the study. The scenario is for illustrative purposes only and could equally apply to parts of the Australian continent or other countries within the region.

Scenario Description

Event Description: The Australian Defence Force has been involved in several major HADR events from cyclone Pam (2015) in Vanuatu (http://www.abc.net.au/news/2015-03-23/cyclone-pam-before-and-after-pilots-photos/6340434), earthquakes in New Zealand and the tsunami on the Indonesian Island of Aceh.

The scenario for this analysis is a severe cyclone (Category 5) that affects the entire Fiji archipelago, roughly 2800km from the main operating base (MOB) of the Royal Australian Air Force (RAAF) C-17 fleet based at RAAF Amberley. Whilst the cyclone traversed the country in only one day, there are many hundreds of injured and missing persons spread across the two main islands and archipelago. Contact is not possible with many of the outlying islands until some form of visitation or on-site assessment is made.

Figure 1. The Fiji archipelago (Geoatlas.com)

After the immediate task of search and rescue (SAR), medical care is in acute need including first aid. Dehydration is possible within relatively short timeframes due to the absence of remaining structures on small islands. Communications are severely reduced along with existing infrastructure (including fuel supplies) and response options for transportation (local boats, aircraft and helicopters). The Fiji archipelago stretches up to 150nm from the only international airport near the capital, Suva.

Response Description: The Australian Government responds to a call from the Fijian Government for HADR by sending a number of C-17 aircraft loaded with personnel and supplies to land at the international airport, the only airport in the country capable of operating the C-17. Other ADF airlift assets such as C-130J, KC-30A and C-27J are already tasked in support of operations and are therefore unavailable. A maximum of two C-17 sorties can be dedicated to transporting an air lift system. The following attributes required of the air lift system are outlined below. The minimum set of parameters is also indicated.

General system requirements

- Parameter: Operating radius greater than 50nm
- Parameter: Operating altitude up to 15,000ft (on the equator in any season)
- Take off and land vertically

    - Parameter: clearance radius: 15-150ft
- All weather and day/night operation
    - Parameter: wind gusts 0 to 100kts
    - operability in degraded visual environments
- System operators: Manned or un-manned, minimum crew.

The following mission specific requirements (and objectives) are in addition to the general system requirements.

Mission 1: Search and Rescue	
Requirements	Objective
An ability to identify people requiring extraction Extract people (injured or not) from land and sea - Parameter: foliage canopy up to 100 feet high Parameter: Number of people to be rescued 100 to 1000	maximise area searched
Mission 2: Logistics air lift	
Requirements	Objective
Deliver logistics packages of 0.5m x 0.5m x 1.0m that weigh up to 30kg each	maximise area covered and (×) density of deliveries within first 5 days
Mission 3: Medical team insertion/extraction	
Requirements	Objective
Transport at least 1 medical team - A medical team consists of 2 paramedic personnel and 2 logistics packages (0.5m x 0.5m x 1.0m that weigh 30kg each) Ability to evacuate at least one patient per sortie when required	maximise area covered and (×) number of teams transported and (×) number of patients recovered within first 5 days

The weightings applied to each mission's objectives are to be variable.
Further resupply of air lift system consumables (e.g. fuel and oil) should be minimised as this would detract from the maximum lift capacity of the C-17 aerobridge for humanitarian supplies.

Baseline (2017) Option Set
When current operational logistics footprint is considered each C-17 can effectively fit a single S-70A-9 Blackhawk helicopter, mission and support crews and logistics. The capacities and performance of each of these platforms is readily identified from open source literature.