The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/2399-6439.htm

Analysis of vertical lift capabilities of US Navy (USN) in Humanitarian Assistance and Disaster Relief (HADR)

Aruna Apte
Department of Defense Management, Naval Postgraduate School, Monterey, California, USA
Scott Chirgwin
USN, Washington, District of Columbia, USA
Ken Doerr
Department of Defense Management, Naval Postgraduate School, Monterey, California, USA, and
Davis Katakura
USN, Washington, District of Columbia, USA

Received 6 October 2021
Revised 2 February 2022
Accepted 10 February 2022

Abstract

Purpose – Vertical lift (VL) assets are vital and expensive resources in humanitarian missions. What and where supplies are needed evolves in short time following a disaster. The purpose of this paper is to offer analysis to understand the range of capabilities of these assets.

Design/methodology/approach – The authors use scenario analysis to investigate the tradeoff between two key capabilities of VL, agility and speed. The authors do this by generating loads and distances randomly, based on historical data. In post hoc analysis, based on different factors, the authors investigate the impact of configuration of Expeditionary Strike Force (ESG) on providing disaster relief.

Findings – The authors find the most effective deployment of VL in a HADR mission is in supplying essentials to victims in a focused region. Delivering sustainment requirements leads to substantial shortfall for survival needs. If the configuration of the ESGs were changed for HADR, it would better-meet the demand.

Research limitations/implications – Cargo capacity is modeled assuming every aircraft type was equal, in terms of mean and variance of cargo-capacity utilization. Detailed information on cargo-bay configurations was beyond the scope of our model and data. However, this means the benefit of standardizing cargo load-outs and the variability associated with randomized load-outs may be understated in the results.

Practical implications – The analysis presents decision-makers with projections of VL asset performance in the early stages of disaster relief, to assist in planning and contingency planning.

Originality/value – This research deals exclusively with the most critical but expensive capabilities for HADR: VL. The in-depth analysis illustrates the limitations and benefits of this capability.

Keywords HADR, Vertical lift, USN

Paper type Research paper

Introduction

When a major disaster strikes, military and non-military organizations exploit their capabilities and available resources to help. US Navy (USN) is one such organization. USN has been providing Humanitarian Assistance and Disaster Relief (HADR) to nations for a long time.

Journal of Defense Analytics and Logistics
Vol. 6 No. 1, 2022
pp. 73-93
Emerald Publishing Limited
2399-6439
DOI 10.1108/JDAL-10-2021-0012

To achieve efficacy and efficiency, HADR needs to be a function of strategic planning (Yoho and Apte, 2014). However, with the current situation in South China Sea, USN is more inclined to focus on combat readiness than HADR readiness. For this reason, it is even important to execute the humanitarian missions with efficacy and efficiency. This translates to minimizing the cost of humanitarian operations at the same time as delivering as much needed aid as possible.

"The United States is a major contributor to international humanitarian relief efforts. In the past five fiscal years (FY2015–FY2019), the United States provided $44.0 billion in global humanitarian assistance with funding through the US Agency for International Development, the Department of State, the Department of Defense, and the Department of Agriculture" (CRS, 2020).

In certain instances, USN has not necessarily responded strategically to humanitarian disasters (Apte *et al.*, 2013, 2020; Apte and Yoho, 2018). The kneejerk reaction of USN to divert whatever vessel is in the vicinity of the affected area has resulted in high costs and marginal HADR. E.g. when Cyclone Sidr struck Bangladesh in 2007, USN sent a guided missile destroyer (DDG) to the rescue which could approach no closer than 25 miles from the shoreline, which was out of the visible range. The ship was unable to provide tangible relief to the devastated area, an example of a misplaced asset leading to underutilized capability (Apte *et al.*, 2013). Apte and Yoho (2018), after researching capability and cost of the deployed ships found that, "amphibious, PM-2 and Ready Reserve Force (RRF) ships are the most capable ships to support humanitarian operations. On the other hand, Nuclear Carriers, Cruisers and Destroyers and Littoral Combat Ships are less desirable based upon their relative costs and capabilities. Such information is critical for the decision makers to have in setting the maritime strategy for HADR". In their computational experiment they found that when cost was not considered, Nuclear Carriers may deliver adequate HADR. But when cost is considered, the Amphibious ships and Landing Dock ships along with PM-2 and PM-8 delivered more-significant HADR. Apte *et al.* (2020) concluded that, "planners need to consider costs to truly maximize utility, especially in cases where two assets, or a combination of them, have similar utility ratings but significantly different costs. Our findings also demonstrate that asset capabilities, proximity, and the duration of an HADR response matter."

In addition, as the history shows, US forces have been diverted for humanitarian missions far more than combat missions, 366 times for humanitarian assistance as opposed to 22 times for combat from 1979 to 2000 (Figure 1), according to the fact sheets of United States Agency for International Development (USAID) and Center for Naval Analysis. Though the figure shows the diversions from 1900, due to climate change and other issues frequency of diversions for HADR increased the later years. Given this, it is best if USN is better prepared to deploy its most valuable and expensive capability, vertical lift (Apte *et al.*, 2020; Moffat, 2014; Ures, 2011).

In Humanitarian missions, assessment of anticipated performance of the assets deployed to provide relief is necessary. Information on the efficiency and efficacy of assets is useful in pre-disaster planning. Vertical lift assets (helicopters) are a vital and expensive resource for disaster response (Apte *et al.*, 2020; Moffat, 2014; Ures, 2011). Information about what supplies are needed and where they are needed will evolve in the hours and days following a disaster. However, what becomes critical is a clear understanding of the range of capability vertical lift assets can bring to a response mission.

The objective of all the organizations involved in humanitarian assistance for disasters is to mitigate human suffering from death and injuries, missing persons, destruction of infrastructure and property. Providing relief is largely dependent upon the speed and scope of the response. "Famines occur not because there is not enough food in the world but because the food is not where it is needed" (Long and Wood, 1995 p. 213). One can say that human suffering often increases due to disasters because the emergency supplies and services do not reach the affected population in time.

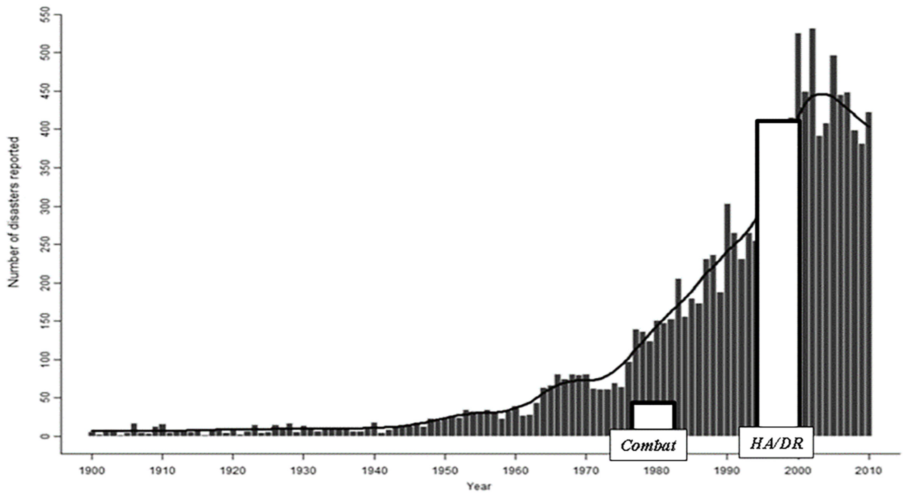


Figure 1.
USN ships diverted for humanitarian operations during natural disasters reported 1900–2010

In a response supply chain (a supply chain established to respond to a disaster), delivery during the last mile is always an issue. Humanitarian agencies face last mile distribution and collaboration problems. How to deliver the right supplies to the right population at the right time? Frequently, the supplies are plentiful, but they cannot be effectively deployed because of logistical problems in the response supply chain and lack of information about demand: what, when, and where? For this last phase of humanitarian aid efficient transportation of the necessary supplies plays a crucial role. However, even with sound planning, the unexpected surges and diversity of demand require supply processes to be agile to ensure that the aid can reduce suffering.

Demand patterns in a commercial supply chain – timeline, requirements, quantity, and location – may be known with reasonable accuracy. But humanitarian organizations often lack comprehensive demand data of this type. Demand patterns are estimated, normally after the disaster strikes. The only certainty regarding this unpredictable demand is that the need is immediate. Requirements, in terms of product type, are either unknown (such as with a vaccine where the strain is not known with certainty) or are not communicated (as in the Pakistan earthquake where women burned donated tweed jackets for fuel). In addition, based on the severity of the disaster, demand quantity can be estimated, but may not be measured accurately, and demand locations, though known, may not be accessible (Apte, 2009). Mitigating the gap between supply and demand of needed commodities, is an essential strategy that can lead to successful humanitarian relief effort. However, without the knowledge of the demand signals it is hard to do. Since demand is so very difficult to estimate, a better understanding of the capabilities of supply is essential.

We focus on quick response through air transportation, specifically vertical lift. We quantify the tradeoff between modes of employment (area served, cargo carried) in terms the number of victims provided-for and to help decision makers assess the most effective way to deploying vertical lift assets.

In a disaster situation, especially earthquake and flooding, when roads are not traversable, vertical lift missions are critical and common. However, these are some of the most expensive humanitarian operations (Apte *et al.*, 2020; Moffat, 2014; Ures, 2011). Decision makers need an efficient and effective procedure to deploy aircraft with adequate supplies, necessary fuel, suitable craft (helicopter/airplane), and an eye towards the cost of these operations.

Though costly, vertical lift is the fastest way to supply critical (survival) commodities like food and water. But one also needs to pay attention to uncertainty in the "what" and "where" of demand. Vertical lift can also respond quickly to changing needs in the required commodities, or changes in delivery locations. The military refers to this ability to quickly change mission orientation as *agility*. So, vertical lift is both fast and agile. Since it is fast, it can deliver the smaller volume of goods-per-person needed for survival, very quickly. But since it is agile, it can also deliver long range, do search and rescue as well as deliver survival goods, and deliver the larger amounts of goods needed for sustainment. But it cannot do all these other missions, and still deliver survival goods as quickly due to limitations of the specifications of the aircrafts. Some are agile whereas some are fast. So, there is a tradeoff between these two modes of employment, and vertical lift is always expensive. Whether, in any given disaster, this expensive asset is best employed for its agility or its speed, depends upon the unique situations of that disaster. We provide an approach to quantify that tradeoff, in order to better inform that choice.

In general, efficient utilization of assets to best promote mission objectives is a key operational decision for any not-for-profit organization. For organizations involved with Humanitarian Assistance and Disaster Relief (HADR), decision-makers must evaluate the predicted performance of HADR assets devoted to relief missions. The efficiency and efficacy of assets is central to HADR planning. Vertical lift assets are a key resource in terms of both cost and capability, so their employment is especially important to plan. What is needed is a warning system for responders – to know as soon as possible if the deployed assets might be insufficient. Such knowledge enables effective asset deployment to where it is most needed but can also help to determine what additional assets might be needed, as soon as possible.

We study these issues through scenario analyses to determine the number of victims that can be provided for, under different modes of employment for vertical lift assets. We next perform post-hoc analyses using optimization to determine how a major disaster would draw upon USN vertical lift assets, and whether some other configuration of vertical lift assets might serve more victims.

Across scenarios requiring the supply of mixed or standardized commodity types, and more-or-less dispersed delivery zone ranges, we investigate the tradeoff between agility (providing for a wider range of victim needs) and speed (providing for a greater number of victims). Within each scenario, we generate loads and distances using probability distributions. Our results will show that for any given mode of employment, vertical lift assets are quite reliable (low variability in number of victims provided-for). But between modes of employment, significantly different performance is obtained. Our simulation-based approach can assist decision-makers in predicting the performance of vertical-lift assets in each relief effort.

Our post-hoc analyses using optimization model finds solutions for providing adequate supplies, and necessary fuel for the trips using suitable aircraft, while minimizing the cost of these operations for Expeditionary Strike Group (ESG). Based on these results, we assess whether it is feasible for USN to act as sole supplier in a major disaster, or if an alliance-wide response is needed. We also examine whether a reconfigured ESG (using a different mix of aircraft) could bring more capabilities to a disaster at a lower cost.

Information about maximum USN capacity is a vital information in HADR for organizations coordinating aid. Our analysis offers decision-makers with estimates of vertical lift asset performance in various possible deployments in the early stages of disaster relief, to assist in planning and contingency planning.

Literature review

The consensus among humanitarian organizations is that the first 72 h are quite crucial at the onset of a sudden disaster for saving lives (WFP, 2018; WMO, 2013; O'Leary, 2004). For survival in this period sometimes humanitarian operations are outsourced. In some instances, response in first 72 h is hard to come by from the host nation. Gossler *et al.* (2020) provide a holistic perspective on the concept of outsourcing humanitarian logistics. The authors offer a conceptual framework based on five dimensions: subject, object, partner, design, and context. Reis (2018) argues that the logistical constructions of swift reaction forces offer great dual-use potential for military operations other than war such as, civil defense or humanitarian assistance. One of the outsourced providers is North Atlantic Treaty Organization (NATO). The author presents NATO response launched to assist the Pakistani government after a major earthquake in 2005, as a practical example. A Nepal earthquake in 2015 posed many problems to the most experienced experts in response supply chains. "Logistically, this particular disaster—because of the geography and the mountainous terrain and poor roads—is probably the most difficult response I have ever had to implement," said Alex Marianelli, senior logistics officer for Asia at the United Nations World Food Program (Page, 2015).

The challenges in response supply chains such as demand surges, the uncertainty of supplies, and the critical time windows in the face of vulnerable infrastructure (both physical and social), pose serious issues (Apte, 2009). Emergency supplies delivered and services provided depend on demand estimation and not just on the provisions and capacities (Cort *et al.*, 2009). Incorrect demand estimation can force the relief providers to depend on surge capacity, an expensive strategy (United Nations, 2007; Duran *et al.*, 2011; Yoho and Apte, 2014). Forecasting the quantity of demand for any particular commodity is a difficult proposition but estimating where and when is even harder (McCoy, 2008; Apte, 2009; Apte *et al.*, 2013). So, while a great deal of work has been done to model the demand signal (the need for services and materiel), less has been done to model the ability of certain assets to satisfy that demand, as we attempt to do in this paper. In this research, we estimate the capability of the vertical lift assets associated with a typical ESG, across a range employment parameters including two different commodity times (survival essentials, and sustainment needs). We investigate the benefits of focusing vertical lift assets on particular commodity types, or particular response zones, when feasible to respond to a particular disaster.

Barbarosoglu *et al.* (2002) develop mathematical models for situations when roads are not traversable, and helicopter missions are common. As mentioned above, the demand signal from a humanitarian disaster is hard to forecast. Therefore, in a post-hoc analysis we develop a linear program to investigate which aircraft perform the vertical lift associated with HADR best, according to their specifications, and demonstrate that the typical ESG configuration is not optimal for HADR missions.

Ures (2011) describes sudden-onset disasters that are subject to a sudden increase in demand. Disasters that are categorized with slow onset, such as an epidemic or onset of a typhoon, can be eased and prepared for through asset "prepositioning or proactive deployment" (Yoho and Apte, 2014). However, sudden onset disasters, such as earthquakes, do not allow for such preparations unless the decision makers prepare for surge capacity external to the disaster. Moffat (2014) and Ures (2011) conclude that the most important method of transportation to satisfy demand in a sudden onset disaster is utilizing vertical lift. Herbert *et al.* (2012) verify the same overall cost outline in their assessment of the tsunami in Japan. They also confirm that vertical lift assets are the main costs drivers in relief efforts (68% of the total costs), and both Ures (2011) and Herbert *et al.* (2012) identify flight operations as the costliest capability.

Some of the literature finds out which ships in the Navy provide the most potential support to HADR and, perhaps more importantly, which ships do not (Kaczur *et al.*, 2012; Apte *et al.*, 2013, 2020; Moffat, 2014; Apte and Yoho, 2018). Aurelio *et al.* (2012) analyze the USN response to Tōhoku earthquake in 2011. Moffat (2014) offers the decision-making tool for the USN leadership for deploying ships with right capabilities. As HADR has become a core competency during a time of limited budgets, the author states that it is important to consider cost effective methods of performing these humanitarian missions.

In the above-mentioned research papers, the authors determine that ships that have vertical lift assets such as helicopters, are better equipped to operate HADR missions. Most of the research used a "capability scoring system" to grade ship types in terms of capabilities and competencies to support HADR. Apte and Yoho (2018) and Apte *et al.* (2020) confirmed these results, emphasizing that ships with vertical lift capabilities are far more valuable than the ones that do not have that capability, in the performance of HADR missions. Baker *et al.* (2002), Salmeron and Apte (2010), Mogilevsky (2013), Burgos and McLean (2018) and Scott and Watson (2018) utilize optimization modeling to resolve issues in air-transportation of supplies to disaster-stricken areas. Ozdamar (2011) and Xavier *et al.* (2011) develop optimization models for vertical lift schedules to minimize time-in-transit.

The operations research (OR) and management science (MS) methods used in disaster operations management have been reviewed (Altay and Green, 2006). They find that the issues are hard to construct for optimal results because of competing objectives. Galindo and Batta (2013) review this idea further and discover that diverse methods like statistical estimation, simulation, and optimization contain approximately 11% of the studies in the humanitarian logistics. Leiras *et al.* (2014) reviewed huge number of published papers related to humanitarian logistics. The authors suggest that future research meet the need for tactical and operational decisions in this field. Gutjahr and Nolz (2016) find that multicriteria optimization in humanitarian aid include most articles with a cost minimizing objective function combined with one or various other objectives such as response time, travel distance and coverage.

The effectiveness of relief provided depends not only on the actual goods delivered or services rendered but also on the demand estimation (Cort *et al.*, 2009; Çelik *et al.*, 2012). Under- or over-estimate of needs assessment can push the suppliers to depend on surge a very expensive strategy (United Nations, 2007; Duran *et al.*, 2011; Yoho and Apte, 2014; World Meteorological Organization, 2013). Forecasting the demand is a difficult task but estimating where and when is even harder (McCoy, 2008; Apte, 2009; Apte *et al.*, 2013).

In this research, in order to establish the tangible performance of assets that are likely to be available, we conduct scenario analyses to address the performance of HADR logistics, especially how the focused use of vertical lift assets might reduce the gap between supply and demand. For this reason, our analysis consists of scenario-based simulations to determine delivery capacity performance. We look at three dimensions: area-coverage, cargo load-out and response-type. We specifically use the example of USN response to the Tōhoku earthquake and ensuing tsunami in 2011. For the HADR in this disaster USN sent Carrier Strike Group (CSG) and Expeditionary Strike Group (ESG). We analyze this deployment to draw inferences. Our capacity-risk analysis recognizes that in practice, actual demand of an affected population will practically always surpass the supplies, especially in the first 72 h of support operations. The critical question we tackle is how vertical lift assets can best contribute to humanitarian missions, and to what extent, within a timeframe of operations.

So, in summary, our scenario analyses will show how to reliably predict the range of what one supplier of vertical lift capacity "might" be able to do with their assets. Whereas, the optimization model is used in post analysis to examine the capability of incremental vertical lift assets, and the optimal mix of those assets, given that no single "supplier of assets" is likely to be able to meet all demand.

Data and methodology

Our problem posits a natural disaster situation based on a past disaster (Tōhoku) and data associated with it. The data we use has been derived from this situation and relief scenarios but is applicable to a broader range of sudden-onset disasters, met with USN vertical lift assets. Specifically, we first assume a large, sudden-onset disaster such as the one that occurred in Japan in 2011.

We perform the scenario analyses using Monte-Carlo Simulation (MCS) with each sortie (a single trip by a single aircraft) randomized in two ways: the time required, and the amount of cargo loaded. The amount of cargo loaded is modeled as a shifted lognormal distribution of weight-loaded. A subject matter expert (SME) with experience flying vertical lift aircraft in large scale humanitarian disasters estimated the minimum, median and maximum weight loaded on a sortie. From these estimates, a three-point approximation (Pearson-Tukey) method was used to estimate the mean, standard deviation and location of a Lognormal distribution (Chirgwin and Katakura, 2020). The time required had several random elements: the refuel time, the distance to the landing zone, the airspeed to the landing zone, and the airspeed on return. Average flight speeds to the landing zone varied by aircraft type, and were drawn from technical manuals, uniformly allowed to vary from a maximum of the airspeed for the aircraft (fully loaded) to a minimum of 5% below this maximum airspeed, based on SME input. Flight times for the return trip were modeled in the same way, based on maximum airspeed empty. For all aircraft, load and unload time were both assumed to follow a Triangular distribution with a minimum of 29, a mode of 29.5 and a maximum of 30 min, again based on SME input that these processes are scheduled to take 30 min, have no "wait time" for queues when they are sea-based, and must be highly reliable to maintain flight schedules (Chirgwin and Katakura, 2020). Finally, the number of sorties a single aircraft could accomplish in a day was also random, based on the cumulative duration of the sorties flown by that aircraft, and a limit that a sortie could not begin if the pilot had already flown for eight hours.

As per search and rescue, it is related to landing zone range. The three landing zone ranges, perform search and rescue (SAR) at different levels (e.g. a "narrow range" scenario may not involve much SAR whereas a "medium range" may involve more SAR, since the wider the area the more likely it is that some victims have not yet been found). Distance to landing zones, weight-of-cargo required per victim, and cargo load-out varied by scenario, as described in the following paragraphs. The complete input model data are is described in Tables 1 and 2. Note that the V-22 is not typically used for search, and is the only aircraft capable of longer range missions.

Our scenarios were designed to allow decision makers to assess delivery reliability based on a particular mix of vertical lift assets for the parameters of landing zone ranges (narrow area: up to 40 miles distant/medium area: up to 80 miles distant/wide area: up to 120 miles distant), response type (essentials/essentials plus dry goods), and load type (random/standardized). A summary of these twelve ($3 \times 2 \times 2$) scenarios can be found in Table 2.

The three landing zone ranges allow us to emphasize percentage of affected population-helped, on search and rescue (SAR) at different levels (e.g. a smaller than 40 nautical mile coverage scenario may not involve much SAR whereas a wide coverage of up to 120 nautical miles may involve much more SAR, since it is more likely that in such wider area some victims have not yet been found). The two response types involve either just essentials (food and water: the primary need in the first few days) or essentials plus dry goods (food, water, shelter and sanitary items: an evolving need at later times). The two load-out types are standardized or random. The random load-outs provide a wider range of whatever is needed, and may involve greater variability in the amount that can be loaded whereas standardized loads allow for less variable allocation of the weight/space tradeoff in loading a cargo bay. Here, we do not necessarily assume "standard" loads imply "optimal" loads. Rather, standard loads are modeled to have the same mean (in terms of weight) as randomized loads, but standard loads have less variance. The sources of such variance are diverse, and may be due to lack of rigorous planning of loads due to changing cargoes between sorties in the random case. We simply assume a reduction in the range of what would be loaded with the standardized load outs, making them more reliable, but not necessarily more effective on

Distance to Landing Zone for one sortie		
Scenario	Distribution	
Wide	Uniform (10, 120)	
Moderate	Uniform (10, 80)	
Near	Uniform (10, 40)	
Long Range	Uniform (120, 250)	V-22 Only
Load and Unload Times (each) per sortie		
	Distribution	
	Triangular (29, 29.5, 30)	
Aircraft-dependent variables for one sortie		
V-22	Cargo-Loaded, lbs (rnd load-out)	Lognormal (3075, 4806, 946)
	Cargo-Loaded (std load-out)	Lognormal (3998, 4863, 473)
	Avg Flight Speed (NM/H) outbound	Uniform (246, 250)
	Avg Flight Speed return	Uniform (258, 268)
MH-60S	Cargo-Loaded (rnd load-out)	Lognormal (1550, 2423, 477)
	Cargo-Loaded (std load-out)	Lognormal (2015, 2451, 238)
	Avg Flight Speed outbound	Uniform (128, 132)
	Avg Flight Speed return	Uniform (140, 160)
	Avg Flight Speed @ search	constant: 60
UH-1	Cargo-Loaded (rnd load-out)	Lognormal (1430, 2235, 440)
	Cargo-Loaded (std load-out)	Lognormal (1859, 2262 , 220)
	Avg Flight Speed outbound	Uniform (134, 138)
	Avg Flight Speed return	Uniform (154, 166)
	Avg Flight Speed @ search	constant: 60
CH-53	Cargo-Loaded (rnd load-out)	Lognormal (4178, 6531, 1286)
	Cargo-Loaded (std load-out)	Lognormal (5432, 6608 , 643)
	Avg Flight Speed outbound	Uniform (120, 125)
	Avg Flight Speed return	Uniform (132, 152)
	Avg Flight Speed @ search	constant: 60

Table 1.
The input model

		Cargo Load-out			
		Randomized	Randomized	Standardized	Standardized
Landing Zone Range	Wide	W-R-E	W-R-P	W-S-E	W-S-P
	Medium	M-R-E	M-R-P	M-S-E	M-S-P
	Narrow	N-R-E	N-R-P	N-S-E	N-S-P
		Essentials	Plus Dry Goods	Essentials	Plus Dry Goods
		Response Type			

Table 2.
Parameter description

average. We explain it further as a limitation of the paper, when we discuss the value-added of optimizing loads.

Our scenario analyses can provide a real-time assessment of reliability and the projected performance of vertical relief efforts, for a given method (focus) of employment. The analysis can help decision makers make reasonably accurate estimates of vertical lift asset performance in the initial stages of disaster aid to improve coordination with other relief organization. Understanding the estimated execution of vertical lift assets in terms of victims provided-for assists in cutting-through logistical ambiguities and realistically supporting as many victims as possible. One caveat is that available aircraft may serve only a small percentage of the affected population compared to the optimal number of aircraft, if a disaster is very large scale. Knowing this, those coordinating the overall effort can direct these key assets to those most in need, and most unlikely to receive assistance from another source.

We collected the data for this purpose from the Naval Visibility and Management of Operating and Support Costs (VAMOSC), a US Navy information system. We also gathered data from technical manuals to define certain capabilities of the aircraft, e.g. airspeeds, capacity limitations, etc. Based on the characteristics and availability we focused on the following aircraft for this research: CH-53E, MH-60S, MH-60R, V-22 short range, V-22 long range, and UH-1.

Figure 2 illustrates a real-world disaster as a primary basis for our model parameters, and the scenarios in our development of methodology. The mode of operation is that a vertical lift asset takes fuel and supplies when aboard an amphibious assault ship (e.g. LHD) or an aircraft carrier. These ship types act as distribution points or hubs for the purpose of our model. We assume that these staging bases are capable of uninterrupted resupply. After fueling and taking supplies onboard for victims a vertical lift asset then distributes supplies to their assigned landing zone near-to, or possibly in, the affected area. The aircraft then returns to the staging-base and repeats this cycle until pilots reach their flight-hour daily limit.

Scenario analyses

The coverage defined below is based on the landing zone range for the given fuel capacity of the aircraft. The area covered is associated with the landing zone as relief radius of the supported area. We developed the scenario analysis model with three factors: Landing zone ranges (3 levels) × Cargo load-out (2) × Response-type (2) for a 3 × 2 × 2 design (Tables 1 and 2):

L: N-Narrow defines narrow coverage between 10 and 40 nautical miles

M-Medium defines medium coverage between 10 and 80 nautical miles

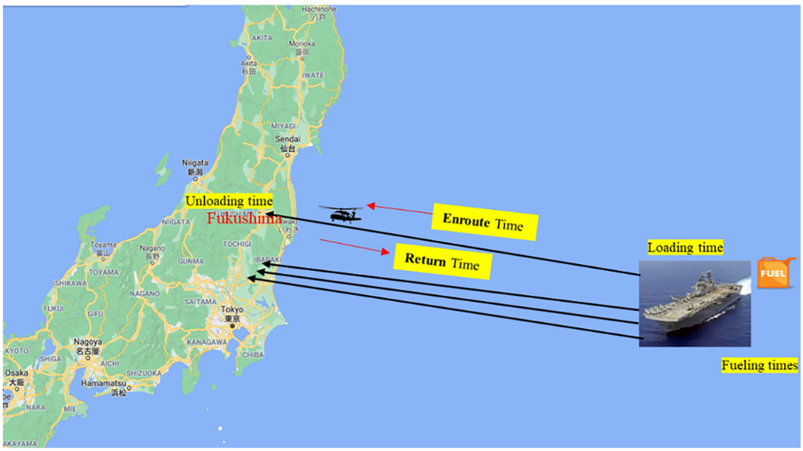
W-Wide defines wide coverage between 10 and 120 nautical miles

C: R-Random defines loading without pre-determined placement of materiel which increases the variability of the amount that can be loaded.

S-Standardized defines loading with mostly pre-determined placement of materiel which decreases the variability in the amount that can be loaded.

R: E-Essentials defines survival supplies (food and water).

P-Plus defines essentials plus dry goods for e.g. hygiene, medical and shelter



Source(s): Adapted from Google Maps

Figure 2.
Hypothetical HADR operation based on Japan Disaster 2011

Three levels of landing zone range (area covered) include narrow, medium, and wide. The narrowest is between 10 and 40 nautical miles, with only 5% of flights (by V-22) to distant locations (up to 250 nautical miles), and no search by returning aircraft. The widest is from 10 to 120 nautical miles, with 25% of flights to distant locations, and 50% of returning aircraft search. The medium coverage is from 10 to 80 nautical miles, with the percentage of distant flights (15%), and return-search (25%) set at the midpoint between the narrow and wide landing zone ranges. The loading is divided in two parts. The first is randomized where material handlers put what is needed into the craft, as best they can. The second cuts the variability of that load-out in half, based on more-standardized loads. Note that these are standard, and not optimal loads. It is important to recognize that loads can never be completely standardized in a sudden-onset response. In such events, cargo areas sometimes have to be used for equipment, or even passengers, because of emergency need. While optimal load plans might be useful on many trips, the incremental benefit of such plans is explored in other research and not in the scope of this analysis. The responses for supplies are of two types. One supplying only food and water per person, and the other supplying dry goods (hygiene, medical and shelter) supplies too. The additional weight in the second type of response means fewer people can be covered. Such design incorporates these factors as increasing/decreasing flexibility in the employment of the vertical lift assets, which will decrease/increase the number of persons covered.

Our data sources included the United States Agency for International Development (USAID, 2005), De Buck *et al.* (2015), the VAMOSC database used internally by the USN, and aircraft technical manuals. Much of this data was tabulated in Chirgwin and Katakura (2020). Data on size of demand is randomly generated but is based upon historical data from the Tsunami which struck Japan in 2011.

Cargo capacity limits, airspeeds with cargo weight, and the relative dependability for search and rescue (SAR) for each aircraft type were drawn from technical manuals. Our selection of aircraft is informed by the aircraft actually used in the Japan 2011 disaster. It includes the V-22, which is a Vertical Takeoff and Landing aircraft and not, strictly speaking, a helicopter. A complete explanation of our rationale in selecting among aircraft can be found in (Chirgwin and Katakura, 2020).

Cost

We used the operating cost of the aircraft (primarily, fuel) alone, and not the cost of transporting aircraft to the disaster site. This makes sense, because only aircraft are currently deployed to the affected area could be called-upon for a relief effort in a timely way. We assumed all other costs (e.g. acquisition and periodic maintenance and uniformed labor) to be sunk costs, not affected by the decision to deploy in humanitarian assistance. Fuel is the main incremental expenditure against USN budgets, from an HADR deployment.

We obtained cost per-flight-hour for each aircraft from the USN VAMOSC database, based on the cost of aircraft deployed in the Pacific Fleet. Details of the cost-per-flight-hour calculations can be found in Chirgwin and Katakura (2020). For example, the most expensive aircraft, the V-22 long, costs 3.78 times as much to operate per hour than the UH-1. Table 3 shows the number of aircraft (a typical ESG Configuration) assumed in our deployment.

Table 3.
Assets ESG

	H-60S	H-60R	V-22 short and long	CH-53E	UH-1
ESG	4	0	15	4	3

Vertical lift capabilities

We estimated three attributes for each aircraft: cargo capacity, flight (relief-range) radius, and capability for SAR. Estimates were synthesized from the Naval Air Technical Data and Engineering Services Command (NATEC) website and the Naval Air Training and Operating Procedures Standardization (NATOPS) manuals. Capabilities were assessed in a manner consistent with Apte and Yoho (2018). Cargo capacities were adjusted to account for fuel requirements.

Vertical lift capacities

Determining free cargo capacity is not straightforward. It depends on restrictions like, maximum aircraft gross weight, trade-offs between fuel and personnel weight, as well as cargo weight. Capacity also varies with temperature, humidity and altitude (Naval Air Systems Command, 2019b). Details of how we estimated capacity for each aircraft can be found in Chirgwin and Katakura (2020). A well-known aviation saying is, “The only time you have too much fuel is when you’re on fire”. So, we assumed aircraft took on maximum fuel on each sortie.

Relief radius

The UH-1, MH60R, and MH60S may be the best aircraft in terms of capability for HADR missions. Other aircraft are not as good for various reasons. The CH-53 with its large size, creates too much propeller downwash and may harm personnel underneath (Naval Air Systems Command, 2019a). The V-22 short and long need a larger landing zone area restricting ground recovery. Evacuation of large numbers of people are more suitable to the CH53 and V-22, due to seating configurations and size. But we are not focused on mass evacuations of large numbers of people. Figure 3 shows the comparison of Cost/Hour, Aircraft Free Space and Relief Radius.

The range of aircraft between refueling stops is a major restriction for supply delivery. Range, or relief radius, varies by aircraft type. Chirgwin and Katakura (2020) used flight profiles for aircraft launched from CSG (aircraft carrier) and ESG (amphibious based platforms LHD) platforms, with common altitude and temperature, to determine fuel burn rates, and thus, relief radius.

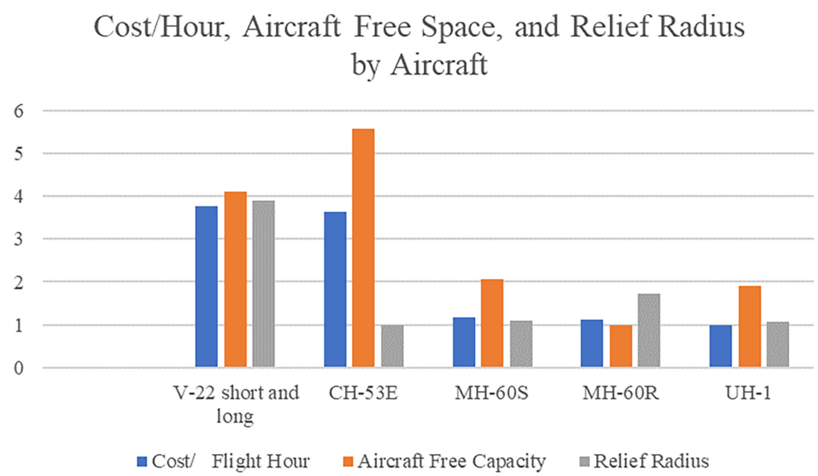


Figure 3.
Cost/hour, aircraft free space, and relief radius by aircraft

Meeting total demand with vertical lift

In VL, the optimal objective function is the minimum cost for delivering of capacity required based on the USN's response to the disaster. It should be noted that since the demand during initial 72 h is too high to meet and humanitarian missions are not the primary goals of the USN, managing efficacy and efficiency are the goals in the HADR missions. Therefore, we focus on reducing the cost while delivering the most supplies. It is a recognized fact that relief delivered depends on the demand estimation (Cort *et al.*, 2009). Under- or over-estimate of needs assessment can force the providers to depend on surge a very expensive strategy (United Nations, 2007; Duran *et al.*, 2011; Yoho and Apte, 2014; World Meteorological Organization, 2013). Forecasting demand in the first 72 h is a challenging task but estimating where and when is even harder in HADR (McCoy, 2008; Apte, 2009; Apte *et al.*, 2013). Therefore, finding the gap between supply and demand is not something that can be easily measured.

We estimate the capacity required is from historical data on the number of persons displaced and needing assistance. We focus on the time when USN and United States Marine Corps (USMC) vertical lift assets reached the disaster area. VL assumes that all the displaced persons are the responsibility of USN and USMC vertical lift assets. We understand that in a realistic scenario, there will be other nations and non-governmental organizations for HADR who would cooperate with each other. Also, we wanted to know the optimal number of aircraft needed. However, we recognize that all these aircraft will not be available for HADR in many instances. They may be otherwise engaged in another part of the world.

All vertical-lift aircraft were transported by US Navy ships to the tsunami relief region by March 19, 2011 (Aurelio *et al.*, 2012). An estimated 255,074 displaced persons were in need of assistance, as described in Figure 4 (United States Agency for International Development [USAID], 2011a-r). VL uses the overall assessment of displaced persons for the computation of the total cargo delivery necessity.

Our results will be stated in terms of victims provided-for. The USAID guidebook suggests that 7.8 lbs. of water and food are essential for survival, for each displaced person every day (USAID, 2005) and 46.5 lbs. per day per person, essentials plus dry goods for shelter, hygiene, etc. are required for sustainment. In reporting our results, we divide the weight of cargo transferred by 7.8 lbs. to determine the number of people that can be supported by supplies of essentials for survival, and we divide the weight of cargo transferred by 46.5 lbs. to determine the number of people that can be supported by supplies of essentials plus dry goods for sustainment.

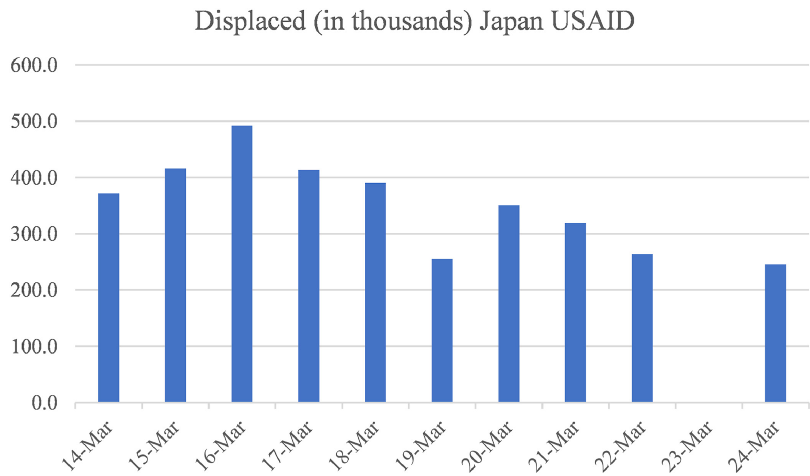


Figure 4.
Displaced (in thousands) Japan USAID

In the survival mode (7.8 lbs. per person), the total daily relief supplies for each day is the product of expected displaced persons and suggested daily cargo per person, which is 1,989,577 lbs. Note that the US Navy has only about 1,000 vertical lift aircraft of the sort examined here, not all of which are mission ready at one time, and some of which are needed to fulfill other missions – not to mention the problem of transporting all these aircraft to a place where they could assist in a single humanitarian mission.

Results

Scenario analyses: the impact of mode of employment on mission objectives

In practice, assistance from the USN is likely to be provided in the configuration given in Table 3, and those responsible for coordinating relief will want to clearly understand the range of capability of this configuration, to better coordinate its use, among all other assets available.

In this paper, we will examine in detail only the Expeditionary Strike Group (ESG) configuration. As we will show, the UH-1 and V-22 Aircraft provide significant capability for HADR that the Carrier Strike Group (CSG) lacks. This has to do with their different missions: the CSG primarily supports fixed-wing aircraft for warfighting missions, while the ESG primarily supports vertical lift aircraft, intended to provide support for operational maneuvers on shore.

Table 4 contains the results of our analyses of the scenarios. The numbers there are the mean and standard deviation of the number of victims provided-for in a day by all vertical lift assets, under the various scenarios, as well as the 5th percentile and 95th percentile of the distribution of the number of victims provided-for in each scenario. Note that these are not confidence intervals of the sample mean but point-estimates from the distribution. So e.g. for a wide-area response, supplying victims for sustainment (essentials plus dry goods), and a randomized load out, we expect to be able to supply fewer than 9,609 victims only 5% of the time, and more than 10,813 victims only 5% of the time. Note further, that the range of victims between the 5% and 95% is relatively small. The vertical lift process is quite reliable, as can be seen by examining the coefficients of variation (standard deviation divided by the mean) of victims served across scenarios, which never exceeds 0.05. That is, for any particular mode of employment, vertical lift is quite reliable.

Table 4 makes plain the tradeoff between modes of employment. A near, focused area of responsibility, with standardized loadouts and only survival supplies provides the most relief (74,337 victims provided-for), while a wide area of responsibility, with randomized loadouts

		Scenario – Range			
		Wide	Moderate	Near	
Load: Randomized	Mean	10,210	11,652	12,312	Response Type: Sustainment
	Stdev	367	308	227	
	5%	9,609	11,147	11,951	
	95%	10,813	12,158	12,694	
Load: Randomized	Mean	65,792	70,859	73,466	Response Type: Survival
	Stdev	1,760	1,635	1,333	
	5%	62,940	68,179	71,350	
	95%	68,738	73,605	75,689	
Load: Standardized	Mean	10,327	11,786	12,456	Response Type: Sustainment
	Stdev	327	246	119	
	5%	9,789	11,374	12,264	
	95%	10,860	12,173	12,654	
Load: Standardized	Mean	66,638	71,711	74,337	Response Type: Survival
	Stdev	1,374	1,147	666	
	5%	64,374	69,802	73,279	
	95%	68,905	73,604	75,448	

Table 4.
Daily victims provided-for across scenarios

and sustainment provides the least (10,210 victims provided-for). Those responsible for coordinating relief in a sudden-onset disaster need to clearly understand such tradeoffs.

In the next paragraphs, we will examine the marginal averages of the main factors of the scenarios (Area, Load Standardization, and Response Type).

Table 5 shows the marginal averages by Landing Zone Area, averaged across the Cargo Load-out and Response Type scenarios. For example, the marginal middle-area response supplies (41,502–38,242)/38,242 = 8.5% more victims than the wide-area response, while the near-area response supplies 12.8% more victims than the wide-area response, on average. The second part of Table 5 shows the percentage change in the range of victims provided-for (a measure of variability) as the area of responsibility shrinks from wide, to middle to near. The average range of victims provided-for is 39.4% smaller for a near-area response compared to a wide area response, showing that a near-area response supplies victims more reliably.

While this variability (risk) reduction between main factors seem substantial in terms of percentage, the variability in sea-based vertical lift for any given mode of employment is quite low, as indicated by the low overall COV. This variance reduction may be more important for land-based vertical lift, which often has more variability because the home base has to serve and fuel a variety of aircraft, including fixed-wing assets, while sea-based vertical lift aircraft are launched from platforms dedicated to their operation and, e.g. rarely have to wait for refueling.

And of course, even small increases in variability matter if you are one of the individuals not provided-for on a given day.

Table 6 shows the marginal averages by Cargo Load-out type, averaged across the Landing Zone Area and Response Type scenarios. Cargo load out makes less of a difference on average than the other factors. The marginal average randomized load-out supplies 98.8% as many victims as the standardized load-out, across configurations. Using optimal (as opposed to merely standardized) loads would make a larger difference, but that is beyond the scope of our analysis.

The variance reductions are much more substantial. Moving to a standardized load reduces the range by 31.1%. Again however, the base level of variability is quite low, so these percentage differences do not translate to large differences in the size of the population at risk of not being served.

Table 7 presents the marginal averages by Response Type, averaged across Cargo Loadouts and Landing Zone area. So, for example, with an ESG, the marginal average

Table 5.
Victims provided-for by Landing Zone Area

	Mean Victims Provided			Range (95–5%)		
	Wide	Middle	Near	Wide	Middle	Near
ESG	38,242	41,502	43,143	3,151	2,760	1,910
		%Change			*%Change*	
ESG		8.5%	12.8%		−12.4%	−39.4%

Table 6.
Victims provided-for by cargo loadout type

	Mean Victims Supplied		Range (95–5%)	
	Randomized	Standardized	Randomized	Standardized
ESG	40,715	41,209	3,087	2,127

Table 7.
Victims provided-for by response type

	Mean Victims Provided		Range (95–5%)	
	Essentials	Essentials Plus	Essentials	Essentials Plus
ESG	70,467	11,457	4,344	870

essentials-plus-dry-goods response supplies only 11,457/70,467 = 16.3% as many victims as the essentials-only response. In general, the reduction reflects the ratio of the weight reduction between Essential (7.8 lbs) and Essential-Plus-Dry-Goods per-person supplies (46.5 lbs.). The range is similarly reduced, representing the largest reduction in victims-at-risk of not being provided-for, across our three factors.

The implication of these results is that the most effective deployment of vertical lift in a HADR mission is in supplying essentials to victims in a focused region. But of course, characteristics of the disaster dictate the employment. If there is no other way to reach distant victims, vertical lift must be used.

And after the first 72 h, as dry goods become more important to sustain victims (depending on weather, etc.) vertical lift may be necessary to transport these items wherever road networks are still destroyed. The results are informative in terms of what vertical lift assets are capable of delivering, and what it may cost, in terms of victims served, to employ them for one type of mission versus another. If vertical lift assets are used to deliver sustainment requirements, the shortfall (for the same population-provided-for in a day) will be substantially greater than if they are used to supply survival needs. The findings relating to the tradeoff between the agility of the response (range of area and diversity of supply type) on the one hand, and supply capacity (victims provided for) on the other hand for this asset class, of course, have implications for other classes of transportation assets as well, as we will discuss in our conclusions.

Having examined the capabilities of currently-configured ESG, we next examine the cost of using Vertical Lift to respond to a humanitarian disaster, how that cost grows as demand increases, and how the cost is affected by the ESG configuration (mix of aircraft).

Post hoc analysis

Optimization model

For post analysis we developed the optimization model VL to minimize the cost of vertical lift operations while meeting the demand.

Indices and index set.

I) Aircraft, $i \in I$, {i = Type of Aircraft; 1: CH-53E; 2: MH-60S; 3: MH-60R; 4: V-22 short range; 5: V-22 long range 6: UH-1}

Input data.

C_i = cost of sortie($US)/sortie for aircraft type i

V_i = number of aircraft that are available for aircraft type i

T_i = sorties that are available for aircraft type i

σ_i = Search and rescue (SAR) capability score for aircraft type i

λ_i = maximum useable free lift capacity (lbs) for aircraft type i

μ_i = aircraft limit capacity (lbs) for aircraft type i

φ_i = maximum aircraft fuel capacity (lbs) for aircraft type i

τ_i = cost ($US)/flight hour for aircraft type i

π_i = hours per sortie (hours/sortie) for aircraft type i

χ_i = maximum sorties per day (sorties/day) for aircraft type i

ρ_i = Range capability score for aircraft type i

D = Total capacity demand, in lbs.

Calculated parameter data.

$$\lambda_i = \mu_i - \varphi_i$$

$$C_i = (\tau_i)(\pi_i)$$

$$T_i = (V_i)(\chi_i)$$

Decision variables.

Xi = Number of aircraft sorties for aircraft type i

Objective (minimize): total cost of vertical lift sortie operations

$$z = \sum_{i \in I} C_i X_i \tag{1}$$

Constraints.

$$\sum_{i \in I} \lambda_i X_i \geq D \tag{2}$$

$$\sum_{i \in I} \sigma_i X_i \leq 0 \tag{3}$$

$$\sum_{i \in I} \rho_i X_i \leq 0 \tag{4}$$

$$X_i \leq T_i,\ i \in I \tag{5}$$

$$X_i \geq 0 \tag{6}$$

Constraint (2) represents the demand in terms of capacity of the aircraft to be satisfied. Constraint (3) account for the Search and Rescue (SAR) capability requirements. We require that at least 25% of the aircraft be SAR-capable. MH60R, MH60S and UH1 are the only assets that are SAR capable. Constraints (3) are therefore derived based on the capability σi, SAR capability score. Based on the subject matter expert's recommendation we require that at least 10% of the optimal mix possess long range capabilities. Constraint (4) accounts for the proportionality of range capability score, ρi for each aircraft. Constraint (5) limits the total number of available aircraft sorties to Ti, based on available aircraft within United States Pacific Fleet (USPACFLT), Vi, and χi. The group that has the aircrafts available for humanitarian aid within the fleet is the ESG. Hence, we looked at the aircrafts available based on the current configuration of ESG. Constraint (6) requires the optimization model to produce a non-negative solution. In VL, we minimize cost of the vertical lift operations in response to the sudden on-set disaster.

$$\begin{gathered} \mathrm{VL}: z^* = \min z \\ \mathrm{s.t.}\{(2) - (6)\} \end{gathered}$$

In case of VL we use 2 million pounds of overall cargo as the lower bound for the capacity demand, D. USN does not have sufficient vertical lift assets that are mission ready all the time. For these reasons, the possibility of supplying sustainment needs entirely with vertical lift assets was removed from further analysis with the optimization model (VL).The optimal solutions for our model minimizing the cost (VL) Are given in Table 8. The decision variables are the total number of sorties and aircraft required. The data for the model is derived from the historical accounts of the USN's tsunami relief for Japan. The results show that the MH-60S and UH-1 aircraft are the most efficient and are selected by the model for minimizing the cost objective while meeting the cargo-loads for demand.

VL model results

Table 8 describes the results from model VL. Here, though the objective is to minimize the cost, we also take into account survival of the affected population. The demand load is 2 million, 75% of the aircraft can do Search and Rescue, and 10% are for long range.

This assortment of aircraft represents our optimal mix based on the cost minimization perspective in VL. The optimal cost of one day of operations is $489,358.03. With this cost the survival needs of 256,650 victims were provided-for with 545 sorties and 175 aircrafts in total. The optimization model VL was meant to determine a minimum cost and most effective mix of vertical lift aircraft (respectively) to satisfy the demand of a sudden-onset disaster the magnitude of that which struck Japan in 2013. Table 3 describes the configuration for ESG and thus as can be seen from these results 19 ESGs with current configuration will be needed to provide the humanitarian support.

Since 19 ESGs is well beyond the capacity of USN, we developed an optimization model to understand the number of ESG's needed to meet the demand with the existing configuration irrespective of the cost. We minimized the number of aircrafts for a humanitarian mission with given load, 75% mission devoted to Search and Rescue, and 10% of the missions requiring long range aircraft. Given the current configuration of ESG (Table 3) we computed number of ESG's needed for the mission. The results were completely out of reach for the same demand. We found that for a load of 2 million number of ESG's needed are 48, for 500,000 number of ESG's needed are 11, and for 100,000 number of ESG's needed is 1. In order to get realistic picture, we created Table 9 describing what percentage of daily peak demand one ESG can meet.

We believe, if the configuration of the ESGs were changed, an ESG configured for HADR (an "EHG") might better-meet the demand. Our reconfiguration is based on the following reasoning: the current configuration has a total of 26 aircrafts. If total aircraft needed for 2 million loads are 297 and we divide these by 26 we see that we only need 12 (11.42) ESGs. Thus, the configuration makes a significant impact if the load is high, or the mission is substantially large.

In Japan, the displaced were almost half a million. Based on our analysis it means that 11 ESG's would have to be deployed, which again, exceeds the capacity of the USN. Therefore, it is understandable that the US Navy brought only a fraction of that capacity to bear in the actual event. Moreover, the primary objective of the ESG's is expeditionary *strike* (defense), so

	CH-53E	MH-60S	MH-60R	V-22 short	V-22 long	UH-1	Total
Number of Sorties	0	237	0	62	55	192	545
# Sorties/Day/Aircraft	2.9	3.16	3.01	4.94	2.06	3.2	
Number of Aircraft	0	75	0	13	27	60	175
Cost/Sortie	$2,110.18	$622.15	$666.67	$1,418.84	$2,754.22	$541.25	$4,89,358.03

Table 8. VL survival

Load	CH-53E	MH-60S	MH-60R	V22-short	V-22 long	UH-1	ESG's
2 million	192	12	0	0	30	63	48
1.5 million	136	56	0	0	30	3	34
1 million	96	28	0	0	15	9	32
0.5 million	44	0	8	7	8	12	11
0.25 million	16	8	0	10	5	3	4
0.1 million	4	0	4	12	3	3	1

Table 9. Load versus ESGs needed

diverting ESG from other areas of the world might be problematic. But realistically, only aircraft already at sea, or stationed nearby could arrive in time, anyway. Indeed, as we have noted, the primary lesson someone familiar with sea-based vertical lift capacity would draw from these recommendations would be that demand from a disaster of that magnitude simply could not be met (in total) from sea-based vertical lift aircraft and needs to be a coordinated multi-national response.

In the Japan 2011 event, the US Navy responded by bringing one CSG and (after a delay to reposition it) one ESG into employment to respond to the disaster. These two configurations represent the two most likely asset configurations that would be used to respond to a major disaster in the near-to-intermediate future, though the CSG is clearly sub-optimal for humanitarian missions, it was on the scene, and its marginal contribution was welcome.

Conclusion

In this research we focused on transfer of supplies, in case of a natural disaster, for survival of the affected population. There is consensus in the humanitarian logistics literature that the most critical capability for the humanitarian operations is the vertical lift required to support survival of the people for the first few days. Aircraft can reach, reach being the key word, a distant devastated area quickly. Hence, we wanted to find out whether and how much this additional reach comes at a tradeoff to efficiency (number of victims provided-for). Capacity comes into play due to the expenses for vertical lift operations, and there is also consensus in the literature that vertical lift is the costliest transport asset deployed for HADR.

We examined the capabilities of the ESG, most commonly deployed asset configurations by the USN, in terms of the number of victims they could provide-for. Scenarios varied in the range the aircraft had to cover, the material they had to carry, and the standardization of cargos. Not surprisingly, vertical lift assets provide-for more victims if given a narrow range, if they carry only essentials, and if they have standardized cargo loads.

What is somewhat surprising is the very large difference between those scenarios, and the very small within-scenario variance. For example, given a narrow zone to cover, and standardized loads of only survival (essential) goods, an ESG can provide for 74,334 victims, with a standard deviation of only 664 victims. On the other hand, if required to cover a wide zone with sustainment material (dry goods) and randomized loads, the same ESG can provide for only 11,038 victims, with a standard deviation of only 294 victims. In other words, vertical lift is not only fast, but also highly reliable. But enormous differences in benefit may be obtained depending on how the assets are used.

In our specific study, we find that 175 aircraft would be needed to fulfill a demand for survival, far exceeding the capacity of a single ESG. Vertical lift assets can serve many needs, but our analysis of the capabilities of ESG clarifies the cost of that flexibility. ESG has considerable flexibility of vertical lift assets. Standardizing cargo loadouts can also reduce the risk of failing to supply victims. However, for a large-scale disaster, a single ESG cannot provide all the needed supplies.

One way to rectify this may be to change the configuration of ESG. An Expeditionary HADR Group "EHG", based on our calculations using Japan as an example, for lower loads MH-60R and V-22 short aircrafts suffice. However, for the larger loads (like 2 million lbs in Japan case), UH-1, V-22 long and MH-60s are needed. CH-53E shows up in all the cases. This suggests that the configuration of EHG must be somewhat flexible. However, the CH-53E, V-22 and UH-1 will always be needed.

Note that, to some extent, the finding of identical benefit from a standardized load, across aircraft configurations, is a limitation of our model. We modeled cargo capacity for each aircraft, however, we assumed every aircraft type was equally easy to load to capacity and had the same distribution of percentage loaded. This is almost certainly not true: some aircraft have more complex cargo areas than others. Data to support modeling these differences between aircraft were not available to us, so this is beyond the scope of our analysis. But the reader is cautioned that, with different configurations of aircraft, the ESG would probably not in practice derive identical benefit from a standardized load.

Our model (VL) was designed to assist with the selection of a mix of key assets (vertical lift) to serve a particular mission (HADR) for a particular organization (USN). We used simulation to conduct numerical analyses across a range of employment choices for vertical lift assets and demonstrated that a narrower focus in employment can dramatically improve mission outcomes as measured by VPF. However, having demonstrated that USN assets alone, like ESG, are unlikely to be sufficient to respond to a large scale sudden-onset disaster, it is even more critical to understand precisely what those assets can (and cannot) do, to assist those coordinating responses from multiple providers.

References

Altay, N. and Greene, W.G. III (2006), "OR/MS research in disaster operations management", *European Journal of Operational Research*, Vol. 175, pp. 475-493.

Apte, A. (2009), "Humanitarian logistics: a new field of research and action", *Foundations and Trends® in Technology, Information and Operations Management*, Vol. 3 No. 1, pp. 1-100, doi: 10.1561/0200000014.

Apte, A. and Yoho, K. (2018), "Resource selection in support of humanitarian operations: a case of the United States Navy", *Journal of Humanitarian Logistics and Supply Chain Management*, Vol. 8 No. 2, pp. 184-198.

Apte, A., Yoho, K., Greenfield, C. and Ingram, C. (2013), "Selecting maritime disaster response capabilities", *Journal of Operations and Supply Chain Management*, Vol. 6 No. 2, pp. 40-58.

Apte, A., Bacolod, M. and Carmichael, R. (2020), "Tradeoffs among attributes of humanitarian operations resources: evidence from United States Navy", *Production and Operations Management*, Vol. 29 No. 4, pp. 1071-1090.

Aurelio, J., Joloya, E. and Kaczur, A. (2012), "An analysis of United States Naval participation in operation Tomodachi Humanitarian and Disaster Relief in the Tsunami-Stricken Japanese Mainland", Master's thesis, *Naval Postgraduate School*, available at: https://calhoun.nps.edu/handle/10945/7366.

Baker, S., Morton, D., Rosenthal, R. and Williams, L. (2002), "Optimizing military airlift", *Operations Research*, Vol. 50 No. 4, pp. 582-602, doi: 10.1287/opre.50.4.582.2864.

Barbarosoglu, G., Ozdamar, L. and Cevik, A. (2002), "An interactive approach for hierarchical analysis of helicopter logistics in disaster relief operations", *European Journal of Operational Research*, Vol. 40, pp. 118-133.

Burgos, A. and McLean, G. (2018), "Optimizing maritime prepositioning force selection of ship class to respond to humanitarian assistance and disaster relief operations in The Pacific Theater", Master's thesis, *Naval Postgraduate School*, available at: https://calhoun.nps.edu/handle/10945/61224.

Çelik, M., Ergun, Ö., Johnson, B., Keskinocak, P., Lorca, Á., Pekgün, P. and Swann, J. (2012), "Humanitarian logistics", in Smith, J.C. (Ed.), *TutORials in Operations Research*, Chapter 2, pp. 18-49.

Chirgwin, S. and Katakura, D. (2020), "An analysis of vertical lift platforms in support of humanitarian assistance and disaster relief operations", Master's thesis, *Naval Postgraduate School*, available at: https://calhoun.nps.edu/handle/10945/66613.

Congressional Research Service (CRS) (2020), "Overview of the global humanitarian and displacement crisis", available at: https://crsreports.congress.gov/product/pdf/IF/IF10568/11 (accessed 17 May 2021).

Cort, J., Jain, N., Kapadia, N., Knepper, M., Knocke, J. and McCutchen, T. (2009), "CARE USA-demand estimation and emergency procurement", *Final Report, ISyE 4106 Senior Design*, Fall 2009, Georgia Institute of Technology, Atlanta, Georgia.

De Buck, E., Borra, V., De Weerdt, E., Vande Veegaete, A. and Vanderkerckhove, P. (2015), "A systematic review of the amount of water per person per day needed to prevent morbidity and mortality in (Post-)Disaster settings", *PLos One*, published online May 11, 2015, available at: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0126395.

Duran, S., Gutierrez, M. and Keskinocak, P. (2011), "Pre-positioning of emergency items for CARE international", *Interfaces*, Vol. 41 No. 3, pp. 223-237.

Galindo, G. and Batta, R. (2013), "Review of recent developments in OR/MS research in disaster operations management", *European Journal of Operational Research*, Vol. 230, pp. 201-211.

Gossler, T., Wakolbinger, T. and Burkart, C. (2020), "Outsourcing in humanitarian logistics – status quo and future directions", *International Journal of Physical Distribution and Logistics Management*, Vol. 50 No. 4, pp. 403-438.

Gutjahr, W.J. and Nolz, P.C. (2016), "Multicriteria optimization in humanitarian aid", *European Journal of Operational Research*, Elsevier, Vol. 252 No. 2, pp. 351-366.

Herbert, D., Prosser, A. and Wharton, R. (2012), "A cost analysis of the Department of the Navy Humanitarian Assistance and Disaster Relief to the 2011 Tōhoku Earthquake and Tsunami", Master's thesis, *Naval Postgraduate School*, available at: https://calhoun.nps.edu/handle/10945/7356.

Kaczur, J., Joloya, E. and Aurelio, V. (2012), "An analysis of United States Naval Participation in operation Tomodachi Humanitarian and Disaster Relief in the Tsunami-Stricken Japanese Mainland", Master's thesis, *Naval Postgraduate School*, available at: https://calhoun.nps.edu/handle/10945/7366.

Leiras, A., de Brito, I. Jr, Peres, Q., Bertazzo, T., Tsugunobu, H. and Yoshizaki, Y. (2014), "Literature review of humanitarian logistics research: trends and challenges", *Journal of Humanitarian Logistics and Supply Chain Management*, Vol. 4 No. 1, pp. 95-130.

Long, D. and Wood, D. (1995), "The logistics of famine relief", *The Journal of Business Logistics*, Vol. 16 No. 1, pp. 213-229.

McCoy, J. (2008), "Humanitarian response: improving logistics to save lives", *American Journal of Disaster Medicine*, Vol. 3 No. 5, pp. 283-293.

Moffat, D. (2014), "Cost analysis of U.S. Navy Humanitarian Assistance and Disaster Relief Missions", Master's thesis, *Naval Postgraduate School*, available at: https://calhoun.nps.edu/handle/10945/44620.

Mogilevsky, P. (2013), "Optimizing transportation of disaster relief material to support U.S. Pacific Command foreign humanitarian assistance operations", Master's thesis, *Naval Postgraduate School*, NPS Archive: Calhoun, available at: https://calhoun.nps.edu/handle/10945/32871.

Naval Air Systems Command (2019a), "NATOPS Flight Manual Navy Model, CH-53E helicopter", January 15, available at: https://mynatec.navair.navy.mil/natechome.htm.

Naval Air Systems Command (2019b), "NATOPS Flight Manual Navy Model MH-60R Helicopter", January 15, available at: https://mynatec.navair.navy.mil/natechome.htm.

Ozdamar, L. (2011), "Planning helicopter logistics in disaster relief", *Transportation Research Procedia*, Vol. 33 No. 3, pp. 655-672, available at: https://www.researchgate.net/publication/225640127_Planning_helicopter_logistics_in_disaster_relief.

O'Leary, M. (2004), "The First 72 hours: a community approach to disaster preparedness", *iUniverse*, ISBN 0595310842, 9780595310845.

Page, P. (2015), "Nepal earthquake response challenges logistics experts", *WSJ Logistics Report*, available at: https://www.wsj.com/articles/nepal-earthquake-response-challenges-logistics-experts-1430343036.

Reis, F.A.D. (2018), "Military logistics in natural disasters: the use of the NATO response force in assistance to the Pakistan earthquake relief efforts", *Contexto Internacional*, Vol. 40 No. 1, doi: 10.1590/S0102-8529.2017400100004.

Salmeron, J. and Apte, A. (2010), "Stochastic optimization for natural disaster asset prepositioning", *Production and Operations Management*, Vol. 19 No. 5, pp. 561-574.

Scott, C. and Watson, B. (2018), "HADR operations in III MEF: optimizing aviation assets for effective supply distribution in disaster areas", Master's thesis, *Naval Postgraduate School*, available at: https://calhoun.nps.edu/handle/10945/61266.

United Nations (2007), "United Nations human development report 2007/2008 – fighting climate change: human solidarity in a divided world", in *United Nations Human Development Program*, Palgrave Macmillan, New York, NY.

Ures, S. (2011), "Financing naval support for humanitarian assistance and disaster response: an analysis of cost drivers and cash flows", Master's thesis, *Naval Postgraduate School*, available at: https://calhoun.nps.edu/handle/10945/5623.

USAID (2005), "Field operations guide for disaster assessment and response, Version 4.0", available at: https://www.usaid.gov/sites/default/files/documents/1866/fog_v4_0.pdf.

World Meteorological Organization (WMO) (2013), "Fact sheet: climate information for reducing disaster risks, disaster risk reduction programme", available at: http://www.wmo.int/pages/prog/drr/index_en.html.

World Food Programme (WFP) (2018), available at: https://docs.wfp.org/api/documents/WFP-0000072749/download/.

Xavier, I., Bandeira, R., Silva, L., Bandeira, A. and Campos, V. (2011), "Employing helicopters in the modelling of last mile distribution system in large-scale disasters", *Transportation Research Procedia*, Vol. 37 No. 2019, pp. 306-313, available at: https://www.sciencedirect.com/science/article/pii/S2352146518306136.

Yoho, K. and Apte, A. (2014), "Strategies for logistics in case of a natural disaster", *International Journal of Operations and Quantitative Management*, Vol. 20 No. 4, pp. 101-119.

Further reading

Google (n.d), *[Figure 1: Notional HADR Operation], Original LHD image retrieved from Google, MAR 2020.*

Naval Visibility and Management of Operating Support Costs. VAMOSC (2020), "Aviation type/model/series reporting (ATMSR): user manual", available at: https://www.vamosc.navy.mil/.

United States Agency for International Development (USAID) (2011), "Fact sheet #35: Haiti – earthquake", available at: http://pdf.usaid.gov/pdf_docs/PA00J28X.pdf (accessed 16 February 2010).

Corresponding author
Aruna Apte can be contacted at: auapte@nps.edu