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Evaluating the applicability of sea-basing to support the preparation for, and response to, rapid onset disasters

Using four case studies of the response of the international community to major rapid onset natural disasters, this paper analyses the advantages and challenges inherent in the provision of logistics support through the use of a floating warehouse, otherwise known as 'sea-basing'. Through a comparison of the costs and benefits of the use of alternative sea-basing models with the actual cost of air transport incurred, the paper demonstrates that the use of sea-basing would offer responding agencies significant cost and flexibility benefits, and that the concept has the potential to be extended significantly through the use of a bespoke vessel rather than a standard commercial container ship.

Managerial Relevance Statement

It is estimated that some 60% of the income of Non-Government Organizations (NGOs) is spent on the procurement, transport, warehousing and delivery of supplies that are needed in development/emergency response operations. This paper demonstrates how, even in the aftermath of a rapid onset disasters such as an earthquake or cyclone, the use of sea – as distinct from air – transport into the affected region could deliver a significantly more efficient response with the potential for further effectiveness enhancements. Depending on the actual

model of shipping used, the saving in transport costs is, potentially, as high as 40%. It is argued, therefore, that further detailed research into the potential use of sea-basing (or 'floating warehouses') should be undertaken as this approach represents a highly practical and sustainable way of providing support to those affected by such events.

Keywords: humanitarian logistics, sea-basing, disaster relief, inventory location, Pakistan Earthquake

Article Classification: Research Paper

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1. Introduction

Balancing the trade-off between efficiency and effectiveness is central to the management of any supply network. Achieving cost reduction based on predictable demand without compromising the surge capacity that is needed to meet the unforeseen is one of the key ways in which supply chain management can contribute to commercial success [1]. But outside the world of business, logisticians in many other fields also face the challenge of successfully managing the transition between steady state and surge situations. This is particularly true for humanitarian logisticians preparing and executing their organisations' response to a rapid onset disaster where the price of failure can be counted in lives lost rather than reduced profits. Thus, there is a general recognition that improving the logistic aspects of disaster response has much to gain from supply chain management thinking [2], [3], [4] and this, in turn, has led to a growth in academic research. For example, recent literature reviews by Overstreet, Hall, Hanna, and Rainer [5], Caunhye, Nie and Pokharel [6], Kunz and Reiner [7], and Leiras, de Brito, Peres, Bertazzo and Yoshaziki [8] give a clear indication of the breadth and depth of the investigations to date in this relatively new field.

Within the literature, different inventory management strategies have been proposed for use by the humanitarian logistician in preparation for, and in the immediate aftermath of, a rapid onset disaster – see, for example, the work of Beamon and Kotleba [9], Balcik and Beamon [10], Arora, Raghu and Vinze [11], and Afshar and Haghani [12]. To date, however, there appears to have been no discussion of the use of sea-basing as a potential pre-positioning strategy within the humanitarian logistic literature, even though the use of sea-basing has been suggested by various navies for this specific purpose [13], [14], both to deliver goods in the aftermath of natural disasters [15] and to support health services [16]. More recently, the concept of floating warehouses has also been implemented on inland waterways for the purposes of distributing goods in cities [17] [18], albeit the main aim here is not a humanitarian one. Whilst any container ship could in the larger sense be described as a "floating warehouse" [19], for our purposes, we only consider sea-basing in which the very intent is to use a vessel as a warehouse. This aim of this paper is, therefore, to explore the benefits and challenges of this concept as a means of supporting the response to a rapid onset disaster using four case studies: (a) the 2005 Pakistan earthquake; (b) Cyclone Nargis that struck Myanmar (Burma) in 2008; (c) Typhoon Haiyan (locally known as Yolanda) that devastated part of the Philippines in 2013; and (d) the 2015 Nepal earthquake.

Sea-basing can best be described as the use of a floating warehouse that is located in the vicinity of a disaster-prone area, and which can move at relatively short notice to support the immediate response phase. Although, as indicated above, sea-basing has not featured in the emerging discussion of ways in which the humanitarian logistician can respond to a disaster more efficiently and effectively, it is an established concept in military logistics (see, for example, Parker [20]). However, such military vessels are optimised for their primary role in supporting a non-permissive operation such as an amphibious landing and, thus, space is given over to facilities such as accommodation for the embarked personnel and self-defence weapons. Furthermore, whilst amphibious landing ships have the capability to use their facilities in the permissive situations described in this paper, the cost of such a vessels - for example the recently procured HMAS Canberra - is of the order of $3Bn, a figure that should be compared with the capital cost of some $10-20M for a merchant ship that is capable of carrying 500 containers, each of 20ft length – known as Twenty Foot Equivalent Units or TEUs (See discussion in Section 5 of this paper).

To achieve the above aim, the paper is structured as follows: first, a brief overview of pre-positioning in humanitarian logistics is offered, after which the concept of humanitarian sea-basing is described in greater detail. The next section outlines the initial stages of the 2005 Pakistan earthquake, before discussing the response of one particular humanitarian organisation, the International Federation of Red Cross and Red Crescent Societies (IFRC). This is followed by a comparison of the cost of providing initial relief aid using air freight with that of the sea-basing approach using a standard commercial container ship. The subsequent section compares the remaining three cases and demonstrates the enduring potential of the sea-basing concept. The final section broadens the discussion to cover the potential additional benefits of using a bespoke vessel, and the extent to which this approach would have been of theoretical value in response to disasters in the period 2005-2015.

2. Pre-positioning in Humanitarian Logistics

The aftermath of a disaster or complex emergency of any significance requires the development of a unique supply network that will either replace or enhance the pre-existing means of providing the affected population with food, water, accommodation, medicines, etc. This is often achieved by the local authorities within the country or region but, in the case of major events, their efforts are frequently supplemented by external assistance from a range of United Nations (UN) agencies and national or international non-government organisations (NGOs) - hereinafter collectively referred to as ‘aid agencies’.

The resultant practice of humanitarian logistics (HL) has been defined by Thomas and Mizushima [21, p. 60] as “the process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials as well as related information, from the point of origin to the point of consumption for the purpose of meeting the end beneficiary's requirements." Unsurprisingly, given that in 2014 alone, 271 natural disasters were reported which affected over 100M people with an estimated economic cost in excess of US$85BN [22], there is a significant drive to develop ways in which the efficiency and effectiveness of HL preparedness and response can be improved. Indeed, it is estimated that HL operations consume 60-80% of the income of aid agencies – i.e. some $US10-15Bn/year [23].

At one level, the HL challenge is somewhat easier than that facing a typical supermarket chain – not least as the number of stock keeping units (SKUs) involved is significantly less. For example, the catalogue of the International Federation of Red Cross and Red Crescent Societies (IFRC) contains some 10,000 items in three volumes, two of which are devoted to medical equipment. Tthe non-food item (NFI) range is of the order of 3,000 SKUs – which can be compared to a typical supermarket which will manage some 40-45,000 SKUs [24].

On the other hand, the core challenge of matching supply with demand is significantly more complex in the humanitarian context. Firstly this is because it involves the assessment of demand in respect of an uncertain future event in which the timing, location, impact and consequential needs of the affected population are extremely challenging to forecast. Furthermore, in the immediate aftermath of a disaster the number of people affected, their location, and their gender, age and culturally-specific needs frequently have to be assessed by the responding agencies on behalf of the beneficiaries as these individuals are primarily focussed on staying alive and keeping safe.

Secondly, there are multiple challenges to the supply side of the equation, including the likelihood of significant damage to the physical (e.g. road and bridges) and telecommunications infrastructure, multiple casualties, and potential disruptions to the normal rule of law. As a result, aid agencies are faced with the requirement to assess what items of food and non-food items to locate where and in what quantities in order to achieve the most efficient and effective response.

For each agency, the result will reflect their perception of the optimum mix between locating stock in the region, sourcing the required material locally, or transporting it into the affected country from an external source. Clearly the use of regional warehouses has significant potential benefit in that they can service a number of countries from a single depot, in much the same way that a commercial regional distribution centre will service a number of supermarkets. However, such warehouses are in a fixed location and so may well require the use of expensive air transport to achieve timely delivery of the required stock to the affected country. Such reliance on air transport is not only expensive, but can also represent a source of considerable risk if the disaster event impacts the planned point of disembarkation as was the case in 2010 Haiti earthquake, when Typhoon Haiyan struck the Philippines in 2013, and in the 2015 Nepal earthquake.

Much of humanitarian logistics literature has, therefore, focused on the question of how, where, and how much to pre-position. However, as Whybark [25] emphasises, this is not only a question of the trade-off between sourcing and holding stock, but also that of the security of stock locations and the problem of insecurities with respect of the timing of the need of items versus the stock shelf-life. Bemley, Davis and Brock [26] further consider the exposure of pre-positioned stock itself to damage from a disaster under this general heading of security. In a similar vein, Gatignon, Van Wassenhove and Charles [27] evaluate the impact of the decentralisation of stock to various locations on the performance of a humanitarian organisation in terms of serving beneficiaries quickly, more cost-effectively, and generally "better". An important factor in their evaluation of the number of facilities required is the frequency and magnitude of disasters in a region.

In the case of the actual location and capacity of a warehouse for pre-positioning other factors must also be considered such as the availability of different transportation modes and their ease of access to ports and airports [27]. Multiple mathematical models have been proposed for determining the number and location of such facilities for pre-positioning for humanitarian aid, and the optimal quantities to be held on stock (for an overview see [26]), yet alternatives to fixed stock locations have not been considered. One such an alternative would be offered by the concept of sea-basing, which is the focus of this paper.

With this introduction in mind, the next section will review the response to the 2005 Pakistan earthquake, which is the base case for our considerations.

3. The 2005 Pakistan earthquake

An earthquake of magnitude 7.6 on the Richter scale occurred on 8th October 2005 at 0850 local time in an area centred 95km (60 mi) Northeast of Pakistan's capital, Islamabad. The quake caused damage over an area of some 30,000 sq km (11,500 sq mi), and the main event was followed by 978 aftershocks of magnitude 4.0 or above over the next three weeks. The affected area was similar in size to that of Belgium or the US State of South Carolina, but is characterised by a harsh mountainous terrain with many villages located at considerable altitude (>1000 m or 3,000 ft). These are supported by a network of tracks that are frequently only passable on foot or with pack animals, albeit there is a better road network in the base of the main valleys.

The remoteness of the area, the destruction of such roads and bridges that existed, the difficulty of the terrain and the harsh winter conditions shortly after the earthquake all conspired to make the evaluation of the immediate needs of the population an extremely difficult undertaking. As a consequence, although some emergency goods arrived quite quickly from both within Pakistan and from other countries, significant volumes of international aid did not begin to reach Islamabad until some 6 days after the earthquake [28]. Thereafter much of this international aid was delivered (at least for the first month) by air freight and, indeed, the use of air transport continued well into the following year (ie some 3 months after the earthquake).

In practice, for the first month airfreight was the primary mode of transport for internationally sourced relief goods entering the country. Thus, whilst the figures are not entirely reliable as there is potential for some double counting, an analysis of a variety of sources including data published by USAID, NATO, DFID, IFRC and UNJLC indicates that just under 200 cargo planes landed at Islamabad airport in the first thirty days after the earthquake, carrying a total of around 3,900MT of supplies; a figure which increased to a total of around 10,000MT flown in by the end of 2005 [29].

4. Sea-basing for disaster relief

Whilst there are obvious limitations to the involvement of (foreign) military actors in disaster relief, military logisticians share the same basic challenge as their humanitarian counterparts as both must have the plans, systems and materiel ready to transform their operations from a steady to a surge state in a very short timeframe [30]. One way in which this can be accomplished in a military context is through the use of the sea-basing concept. This use of such support ships is operated by the Armed Forces of a number of countries to support the initial insertion of soldiers into a potentially hostile environment. However, as indicated earlier, the cost of such purpose-built vessels is significantly higher than a normal container ship, and therefore this latter option will be the focus of the following discussion.

This section of the paper discusses the potential use of sea-basing for the purposes of disaster relief and evaluates its effectiveness with data from the Pakistan earthquake. The basis of the financial analysis is to consider the hiring of a commercial vessel that should be dedicated to sea-basing and not included in the merchant fleet of any company as to be able to be flexibly routed. In doing so, it has been assumed that the sea-based vessel will be located in Singapore in its dormant state. This country is at a strategic cross-road in South East Asia, with an anchorage that is relatively safe in terms of shelter and has a minimal danger from piracy. Singapore is already very widely used to anchor numerous vessels for crew changes, repairs and whilst awaiting orders. As a result, Singapore has a comprehensive set of support services for anchored vessels which are able to provide personnel, supplies, materials, fuel and repairs as necessary.

Thus the exemplar vessel would be stocked with an appropriate selection of food, non-food items and medical items and, on the assumption that it is partially crewed with key personnel at all times, should be able to sail within 24 hours to a selected destination. The actual load would be based on the agency's best estimate of generic future requirements which can be evaluated using historic consumption data. It is recognised that this would reflect a 'push' (as distinct from a needs assessment-based 'pull') response, but as indicated earlier the non-food item catalogue only has some 3,000 SKUs and therefore it has been previously argued that "Contrary to prior literature suggesting unpredictable demand as a main problem in disaster relief supply chains, our research demonstrates that traditional methods used in commercial logistics can be applied to forecast demand for the first response phase later to be replaced by real needs information through assessments." [47]

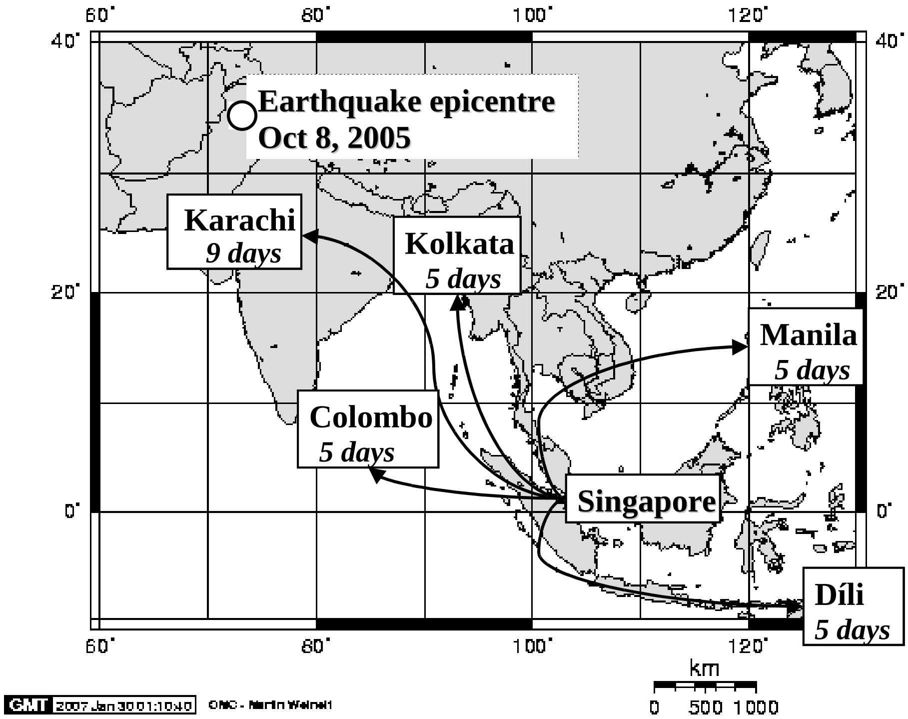

Figure 1: Transit times (at 14kt) from Singapore to selected destinations based on the Dataloy Distance Table [31] with times rounded up to the nearest whole day.

Estimated transit times at 14knots (the typical transit speed of a small size container ship) to a number of potential ports in the area are shown in Figure 1. In the context of the Pakistan earthquake, such a vessel could arrive in Karachi (the country's main port) some 9 days after leaving Singapore. To this must be added the unloading time (24 hours) and the in country transit time between Karachi and Islamabad (1,600km – 1,000mi) which would add some 2-3 days to the journey. Thus, in this scenario, the total elapsed time from the onset of the earthquake to the arrival of the goods from the vessel at Islamabad would have been some 14 days. The choice of Islamabad as the interim destination is designed to provide a comparator to the alternative of air transport which also used Islamabad as the main disembarkation point.

In both cases (sea and air) it was clearly necessary to achieve the onward transportation to the affected area, but this would be carried out in the same way for both incoming transport modes.

A time-line comparison to the actual international relief using air freight shows that although initial flights began to arrive at E+6, the bulk arrived the following week – i.e. broadly in the same timeframe as that from the use of a sea-basing approach. Furthermore, the volume potentially delivered by sea at E+14 was not matched until E+30 using air freight. With this overview in mind, the next section presents further more detailed cost and volume comparisons between the use of air freight and the sea-basing response to the Pakistan earthquake. The additional cases and the broader feasibility of sea-basing in the SE Asian region are then discussed in the sensitivity analysis section of the paper.

5. Comparing sea-basing to air freight – the base case of the Pakistan earthquake

To evaluate the potential use of sea-basing in rapid onset disaster relief, data on volumes moved into Pakistan in response to the earthquake were assembled from the operational reports of the IFRC. In addition, the authors were granted access to IFRC databases that contain the detailed quantities, weights and volumes of relief aid that was transported to the area of the earthquake. This data shows that, during the first 30 days after the earthquake, the IFRC flew in some 70 flights containing around 1,750MT of equipment and stores. Using the mass and volume data for the relevant commodities drawn from the IFRC catalogue [32], it was possible to assess the number of 20ft ISO Containers (TEUs) that this would have required.

The resultant best estimate is that the total volume of IFRC airfreight moved during this period equates to 344 TEUs. Unfortunately, the data set did not contain all of the relevant weights and volumes – for example those of the Norwegian Field Hospital (that was moved to Pakistan in the first weeks of the relief operation) were not included. Furthermore, and almost inevitably given the degree of confusion that surrounds the initial stages of such a rapid onset disaster relief operation, there is potential for mis-recording of data. Therefore, in order to present a conservative estimate of the above metrics, they have been rounded up and the base case will assume that the total volume of airfreight transported by the IFRC in the first 30 days after the earthquake equated to 400 TEUs.

As a result, the cost data for sea-basing was related to a 500TEU (nominal) standard geared container vessel with a base in Singapore, and this was compared with data from the IFRC's response to the first 30 days of the Pakistan earthquake. The reason for using a 500TEU (nominal) vessel reflects the limitations of useable vessel capacities in comparison to their nominal capacities – in practice, weight and stability restrictions mean that a 500TEU (nominal) vessel has a useable capacity of around 400 TEUs. The dimensions of such a vessel would be approximately:

Length: 130m Breadth: 20m Draught: 7.5m (when fully laden)

Displacement: 8,000 DWT Crew: 10-12 Speed: 14kt

At the same time, limiting the vessel size in this way helps to ensure that most commercial ports would have the required materials handling capabilities to load/unload such a ship, as well as sufficient water in their harbour to accommodate it. However, the selection of a 'geared' vessel means that it incorporates its own winch/crane system and is, therefore, able to unload the containers even if the dockside cranes were disabled as was the case of the port of

Haiti in 2010. This obviously provides a measure of additional redundancy in the event that, for whatever reason, the port facilities are not available.

The next stage of the analysis was to understand the transport cost for the airfreight used by the IFRC in support of the Pakistan earthquake. Whilst broadly similar, different sources offer different estimates for such costs:

Table 1. Broad order costs of IFRC air cargo over the first 30 days

Source	Base Cost	Cost to IFRC Days 1-30
Heigh [33]	$100,000/Flight	$7,000,000
NATO [34]	$117,647/Flight	$8,235,000
Goodhand [35]	$4/kg (for 1750MT)	$7,000,000

These figures have been reviewed to ensure that they reflect current (2015) cost levels and, in discussion with senior HL practitioners, there is agreement that they reflect a broad order of magnitude - although, if anything, they are on the low side. Therefore, in line with the adoption of conservative approach to this analysis, the lowest of these estimates ($7M) will be used for comparison with sea-basing options. As an aside, whilst this figure alone may appear at first sight to be significant, it should be placed alongside the IFRC's total logistics costs (including stock procurement) for the first 60 days of operations in Pakistan which are estimated to have exceeded $50M [33].

As indicated earlier, the base case container ship to be used for comparison is a 500TEU (nominal) vessel. The movement of the resultant 400 TEUs can be achieved by:

(A) Purchase of a suitable vessel (new or second hand).

(B) Hire of capacity on an existing vessel

(C) Charter of a vessel on a long-term basis.

The actual charges incurred by the owner/charter differ across the three options as shown in Table 2.

Table 2: Comparative charges for sea-basing options

	Purchase (Option A)	**Hire of Capacity (Option B)**	**Long Term Charter (Option C)**
Vessel Purchase	√		
Capacity Hire		√	
Vessel Charter			√
Crew	√		
Vessel Maintenance	√		
Vessel Insurance	√		
Fuel	√		√
Port Charges	√		√
Container On/Off Load	√		√
Container Purchase/Hire	√	√	√
Container Repatriation	√		√

<u>Option A</u> envisages the purchase of a 500TEU (nominal) vessel. The cost of such a ship has varied over the period 2005-2010 from $10M (2010) to $21M (2008), with a 10 year old vessel costing between $13M (2008) to $4M (2010) [36]. However, as indicated in Table 1, purchasing a vessel would result in additional costs (such as crewing, maintenance and ship insurance). Therefore, whilst this option might prove feasible once the sea-basing concept has been proven, it is a very risky approach at this stage of the maturity of the research and will, therefore, not be considered further.

Under <u>Option B</u>, the 400TEUs of equipment would be kept ashore, and a vessel chartered only as and when needed. That said, standing arrangements could be set up with an appropriate shipping company (it is estimated that there are 15-20 services/week operating out of Singapore to various ports in the SE Asia area [37]) that would aim to guarantee a response time – i.e. a suitable ship to be available and ready to load in Singapore within, say, 24-48 hours. Although this option would be relatively cheap (even with a guaranteed response time), it would increase the lead time between the disaster and the arrival of the relief stores by 3-5 days (vessel arrival in port + loading time), thereby compromising the flexibility of sea-basing. Given the conservative approach to the analysis within this paper, this option has been rejected for primary analysis in the light of the additional delay that would be incurred. However, it will be considered further in the sensitivity analysis (below) where alternatives to the base case are discussed.

Meanwhile, for the base case purposes, Option C is seen as the preferred alternative, and the estimated annual costs of this approach are summarised in Table 3. It should be noted that whilst the figures relating to the shipping costs have been developed from the sources as noted, that for the in-country transit costs is less robust. These are difficult to forecast as they will reflect both the distance between the port and the disaster area, and the country specific trucking rates which, typically, rise in the aftermath of an event. Furthermore, depending on the relative location of the airport, the container port and the disaster location, the differential between the air and sea freight options may be positive or negative. A final point is that trucking may be provided at reduced rates or even free of charge, as was the case for Atlas Logistique – a French NGO operating in Pakistan [29]. Nevertheless, in line with the conservative approach adopted in this analysis, a further $0.508 has been added bringing the total cost to $3.75M.

Table 3: Annual costs for Option C

Item	Base of calculation	Source of estimate	Annual Cost ($M)
Charter of 500TEU geared vessel	Average Daily rate of $5,250 over the period 2009-2013	UNCTAD [38]	1.912
Fuel/Oil etc	20 Days/Year at sea @ 20MT/Day based on an average fuel price of IFO380* between Jan 2005 and Dec 2013 = $480/MT + 345 Days/Year at anchor @ 2 MT/Day based on an average price of MDO** between Jan 2005 and Dec 2013 = $745/MT	NZ Ministry of Transport [39]	0.706
Port Charges	Based on "layup" rate of $3,000/week	Dunford and Tang [40]	0.156
Container Hire	$2.00/Container/Day	CSSC [41]	0.292
Container On and Off Load	$110/Container On + $110/Container Off	DP World [42]	0.088
Container Back Load On/Off	$110/Container On + $110/Container Off	DP World [42]	0.088
In country trucking cost	Broad order estimate		0.508
TOTAL			**3.750**

*IFO380 is the standard marine grade fuel for motive power at sea.
**MDO is the standard fuel for the operation of auxiliary systems such as electric generation when at anchor or in harbour

6. Summarising the discussion of the base case

In summary, the annual cost of a long term charter for a 500TEU geared container ship, with 20 days at sea in any given year is some $3.25M. Therefore, using the Pakistan earthquake as a case study and including an estimate of $0.5M for in country transport, this would deliver 400TEUs from Singapore to Islamabad at around E+14 at a cost of some $3.75M. This should be compared with the equivalent using airfreight in which the 400TEUs were delivered at E+30 at a cost of around $7M. Thus, even if the data in Table 3 is less than totally accurate, there is a very considerable cost-benefit to the proposed use of sea-basing.

Apart from cost considerations, the broader positive and negative aspects of sea-basing need to be discussed and, in the humanitarian context, the former are perceived to be:

- Its inherent flexibility. The choice of disembarkation location can be selected as the disaster unfolds, and in some cases (eg cyclones) the vessel could be pre-deployed towards the danger area as soon as an early warning is published, thereby reducing the elapsed time between the disaster occurring and the arrival of the relief goods.
- Avoidance of single point of failure in the supply network. Reliance on a single airport (eg Banda Aceh in the 2004 Asian tsunami) created major difficulties for the supply network when this airport became overwhelmed by the volume of aircraft (and supplies) using it. By contrast, a 'geared' container vessel can operate its own derricks to offload the cargo in cases where the harbour facilities have been substantially reduced as well as, potentially, having a larger number of port options that it can use.
- More broadly, the environmental impact of using one vessel is several orders of magnitude less that the equivalent resulting from the use air cargo planes.

Clearly the concept has a number of disadvantages which include:

- The large unit load that must be deployed. Whilst this is appropriate for responding to major disasters, it is less so for ones that require only limited assistance.
- A large volume of stock is tied up in the vessel which, apart from capital cost considerations, may create stock turnover issues.
- Deliveries depend on the infrastructure of the port of entry, as well as the port hinterland, which could be destabilised by the disaster itself, leading to ports farther away being used instead.

- Deliveries may be hampered by weather conditions. Routing problems include not only the considerations of the disaster area but also the feasibility of the route at any given time for the vessel itself.

This said, pre-positioning in fixed locations also ties up stock in potentially large quantities, and other transportation modes can be equally hampered by destabilised infrastructure (airports being destroyed, bridges down) and weather conditions.

7. Feasibility and sensitivity analyses

Whilst at first pass, a financial comparison between the provision of emergency relief through sea-basing and air freight in support of the Pakistan earthquake would appear to overwhelmingly favour the sea-based option, it is important to evaluate the feasibility of this solution. Four analyses have been carried out for this purpose:

(1) a feasibility analysis looking at the probability of disasters in the South East Asia region,

(2) an overview of three additional major disasters which would have been ameliorated by the operationalisation of sea-basing concept:

a. Cyclone Nargis that struck Myanmar (Burma) in 2008.

b. Typhoon Haiyan (locally known as Yolanda) that devastated part of the Philippines in 2013.

c. The Nepal earthquake of 2015.

(3) sensitivity analyses related to key cost drivers, and

(4) a further consideration of the potential for using existing commercial cargo capacity (ie revisiting option B).

7.1 Assessing the probability of disasters in Asia

Self-evidently, there is no ‘guarantee’ that a natural disaster will take place in any particular geographic location in any given year. However, some of the most respected data in this area has been produced by the Center for Hazards and Risk Research, and in a recent global risk analysis Dilley, Chen, Deichmann, Lerner-Lam and Arnold [43, p.3] note that although their work is unable to offer a view on the “*absolute* level of risk posed by any specific hazard of combination of hazards, [the data is] adequate for identifying areas that are at relatively higher single or multiple hazard risk.” (emphasis in original).

Nevertheless, these authors use sophisticated modelling to understand the risks of mortality, total economic loss and economic loss as a proportion of Gross Domestic Product (GDP) density. From the humanitarian perspective, the first of these three metrics is the most important and from Dilley and his colleagues’ work it can be seen that, in relation to the hazards of cyclone, flood, earthquake and landslide, the area of Southern Asia falls into the “relatively high risk” category. This is reinforced by Dilley [44, p.6] who state that: “[d]isaster-related mortality risks associated with hydro-meteorological hazards are highest across the sub-tropical zones, with drought related mortality risks being highest in semi-arid regions of Africa. *Mortality risks associated with geo-physical hazards are highest along plate boundaries, around the Pacific rim and across southern Asia. Some countries such as the Philippines and Indonesia are at a high risk from all three types of hazards.*” (emphasis added).

This perspective is reinforced by a consideration of the World Disasters Report [45] for the period 2004-2013 which shows a total of 2,651 disasters in the Asian region. Clearly not all of this average of some 265 disasters/year would have been supportable by the sea-basing approach, but the evidence would suggest that the likelihood of a natural disaster occurring in the area under consideration is considerable. Thus it is concluded that, if the sea-basing concept is indeed to be operationalised, then the geographic area described in this paper presents a highly credible basis for continued research effort.

7.2.1 Cyclone Nargis – May 2008

On 2 May 2008, Cyclone Nargis made landfall in Myanmar, crossing the south of the country over two days, and devastating the Southern areas of the country. It was one of the most devastating of cyclones to strike this part of the region and the worst disaster event in the country's history with official figures indicating that 84,500 people were killed, and a further 53,800 went missing, with as many as 2.4 million people being affected [48] [51]. Using data extracted from the minutes of the meetings of the United Nations Logistics Cluster [49], the Operations Updates of the IFRC [50], the End of Mission Report from the UN Logs Cluster [51], the following key data were compiled:

Table 4: Key dates in Cyclone Nargis Response

Day 0	2 May	Cyclone Nargis makes landfall
Day 4	6 May	UN Logistics Cluster activated
Day 6	8 May	First recorded relief flight landed
Day 10	16 May	Yangoon port re-opened
Day 22	24 May	UN Airbridge commences operations
Day 59	30 Jun	UN Airbridge ceases operations

In summary, there was a significant delay between the date when the cyclone struck and the arrival of the first response flights which reflected the delays in obtaining approval from the country's government. Thereafter, between 8th and 24th May, a number of flights are recorded on both the IFRC and Log Cluster websites [49] [50], but there is a lack of clarity over the aircraft sizes (and hence loads) – with mention being made variously of AN-26 (payload

5.5MT), AN-12 (payload 20MT), IL-76 (payload 42MT), and the use of internal payload on commercial passenger aircraft. Importantly, however, the main port in Yangoon was not operational until 16th May, and at that stage had only limited capacity.

However, 24th May marked the formal opening of the airbridge from UN Log Cluster managed Bangkok to Yangoon which was populated by 1 * AN-12 and 2 * IL-76 (reduced to 1 * IL-76 on 17th June). The airbridge ceased operations at the end of June, and during the intervening period transported 4,005MT in over 230 flights. Using the same metric as was obtained from the detailed calculations outlined at the start of Section 5, in which 1,750MT was transported by in 400 TEU (4.375MT/TEU), the amount carried by means of the airbridge would equate to 915 TEU. In effect, assuming that all of the airbridge material was transported by sea, this would equate to 3 round trips by the 500TEU (nominal) exemplar vessel.

With a transit time of 4 days between Singapore and Yangoon, and assuming a loading/unloading time at each end of the cycle of 2 days, the total elapsed time for each round trip would be 12 days. Thus, the three round trips would have been achieved in broadly the same time as the 230 flights, but the profile would have seen a significantly larger volume arriving sooner after Day 0. Furthermore, in practice, it would have been possible for the vessel to have been ‘loitering’ off Yangoon waiting for the port to re-open and thus would have allowed the first 400TEU (1750MT) to be delivered on or around Day 10, rather than Day 26.

Furthermore, in addition to the clear cost savings reduced environmental impact, much of the subsequent ‘last mile’ delivery was facilitated by barge and boat, with the majority of all cargo movements being carried out in this way, not least due to the advent of the rainy season and the deterioration of the road network [51]. Cargo transfers from ship to barge would, given their adjacent locations, likely to have been easier than from those from the using the airport facilities.

7.2.2 Typhoon Haiyan (Yolanda) – Nov 2013

Haiyan (known locally as Yolanda) was one of the strongest typhoons ever to be recorded and the deadliest to strike the Philippines in modern history with winds gusting close to 200mph (315kph). It resulted in the death of over 6,300 people, and 11million affected, many of whom were made homeless. The main region affected was the Eastern Visayas, and in particular the regional capital of Tacloban.

Data to support the following summary has been extracted from the reports of the IFRC [52] and Log Cluster [53].

Table 5: Key dates in Typhoon Haiyan (Yolanda) Response

Day 0	8 Nov	Typhoon Haiyan makes landfall in Eastern Visayas
Day 3	11 Nov	UN Logistics Cluster activated
Day 6	13 Nov	Use of Tacloban airport limited to light aircraft and those of US and Philippines military
Day 8	15 Nov	Commercial container vessel arrives Tacloban with relief supplies
Day 10	17 Nov	IFRC reports 5 flights have been received, with a total of 93MT of relief supplies
Day 18	25 Nov	IFRC reports 17 flights have been received, with a gradual shift to sea transport taking place.
Day 25	2 Dec	IFRC reports 21 flights have been received.

In summary, due to damage from the typhoon, access to the regional airport in Tacloban was restricted to light aircraft, together with some military assets from the Philippines and United States air forces. As a result, the majority of cargo flights were routed to the city of Cebu which is located on an adjacent island. As a result, it was necessary to transport the relief goods from Cebu airport to the docks, then via Ro-Ro ferry to Tacloban (some 5 hours away), before subsequent movement from the ferry to the Tacloban distribution centre.

However, it is relevant to note that port of Tacloban was not severely affected as evidenced by the arrival of a container ship on Day 8. Indeed, given the transit time from Singapore of some 5 days, Day 8 is approximately when a vessel operating under Option C would have reached Tacloban with 400 TEU (1,750MT) of relief supplies. This should be compared with the IFRC data which would indicate that a total of 21 flights (carrying approximately 500MT) of goods arrived by Day 25 – in other words just around 25% of the stores that could have arrived by sea were received 17 days later.

7.2.4 Nepal Earthquake – 25 April 2015

A series of extremely powerful earthquakes (and resultant landslides) struck central Nepal on 25th April and in the days thereafter. These resulted in significant devastation to both urban and rural communities, together with the deaths of over 9,000 and injuries to a further 20,000. As in the previous cases, the following represents a summary of the initial response to the earthquake drawn from the the reports of the IFRC [54] and Log Cluster [55].

Table 6: Key dates in Nepal Earthquake Response

Day 0	25 Apr	Earthquake strikes at 12.50 local.
Day 3	28 Apr	Severe congestion reported at Kathmandu airport, with a parallel shortage of ground handling staff and equipment. Landing slot management system severely challenged, and maximum aircraft weight limits instituted.
Day 7	2 May	Continued challenges on obtaining landing slots continue.
Day 9	4 May	Whilst the availability of landing slots has improved, larger aircraft (including C17s) are not being permitted to land due to runway damage.
Day 14	9 May	Whilst cargo handling times are improving, the airport authorities have limited landing slots to a 10 hour window.
Day 18	13 May	Log Cluster reports that 1,300MT of cargo have been received by air.
Day 19	14 May	Log Cluster reports that the land route from India is open, but that trucks are taking 7 days to complete the journey from Kolkata.
Day 30	25 May	Log Cluster reports that the flow of cargo through the airport has greatly reduced and that there is now little congestion, although several NGOs are still expecting air freight charter flights.
Day 31	26 May	Log Cluster reports that 4,100 MT of cargo has been received by air – the equivalent of some 300 fully laden C130 (Hercules) aircraft.

As will be seen from the above summary of the response, the facilities at Kathmandu airport were placed under severe pressure, not least because it normally handles a relatively light traffic load – for example, there are only 9 aircraft parking slots. In addition, Kathmandu is the country's only international airport and, hence, the only airport location where customs clearance facilities were in place. As a result, a significant amount of relief aid was routed via Kolkata and trucked overland from there – albeit this route also encountered significant challenges including those of obtaining cross-border customs clearance.

Using the generic assumptions that underpin this research, it is assessed that relief supplies using Option C would transit as follows: 5 days passage from Singapore to Kolkata; 2 days unloading at Kolkata; 7 days transit to Kathmandu; i.e. a total of 14 days – i.e The supplies would have arrived around Day 14 which would have potentially reduced the pressure on the airport facilities.

From Table 6 (above), it will also be noted that in the period from Day 18 to Day 31, 13,100MT were delivered by air. Had a sea-based ship been available, this could have been reduced by 1,750MT (based on an initial delivery on or around Day 14), with a further 1,750MT at Day 31. This equates to some 85% of the total transported by air in this period.

7.2.5 Final comparison of the base case and three additional cases

Comparing the various cases, apart from the cost calculations, the following issues become apparent: First and foremost, notwithstanding the deviation in the base case, the first relief items by air typically arrive earlier than shipments by sea to a disaster region, even in spite of reduced capacities of receiving airports (E+6 vs. E+10 in Cyclone Nargis, ex aequo E+8 in Typhoon Haiyan, and E+3 vs. E+14 in the Nepal earthquake). However, sea-basing would result in a much larger first delivery in each of the cases. The difference in capacity is not negligible; the quantities that could be delivered by E+8 in Typhoon Haiyan by sea was in fact only delivered by E+18 by air. This means larger populations being served earlier.

7.3 Cost drivers of sea-basing

The above three case studies have compared the use of air transport to the base case (Option C) that was developed from the detailed analysis of the response to the 2005 Pakistan earthquake. The aim of this section is to review the key cost drivers of sea-basing and hence understand the robustness of this base case. Two major cost drivers have been identified, the charter hire itself and the cost of fuel. Long-term charter costs for a 500TEU (nominal) geared container ship have fluctuated from \$5,000/day in 2000 to over \$10,000/day in 2005, before dropping back to \$5,500/day in 2013 [38]. While the average figure of \$7,500/day was used for the base case calculation (Table 3), for the purposes of a sensitivity analysis, the high-end of \$10,000/day will be used. The cost of the necessary fuel (380 Centistoke – IFO

380) has varied between $275/MT and $730/MT over the period 2005-2013 and so, as before, the higher figure has been used in the analysis. Similarly, a decade high figure of $1,165/MT has been used for the MDO fuel that is used to operate generators etc whilst the ship is at anchor. Finally, as acknowledged earlier in the case study, due to the paucity of robust data, the transposition from the estimated weight of airfreight to a number of TEUs (driven by volume) may be inaccurate. To overcome this, the costs of a larger (750TEU (nominal); 650 TEUs actual) vessel are also compared.

Table 7: Cost sensitivity of sea-basing

	Annual Cost (US$M)		
Cost item	**Base Case** **500 TEU (Nominal)** **400 TEU (Actual)** **Average Estimate***	**500 TEU (Nominal)** **400 TEU (Actual)** **High End Estimate****	**750 TEU (Nominal)** **650 TEU (Actual)** **Average Estimate*****
Ship Charter *	2.738	3.650	4.560
Fuel/Oil etc**	0.706	1.098	1.059
Port Charges	0.156	0.234	0.286
Container Hire	0.292	0.292	0.475
Container On and Off Load	0.088	0.088	0.143
Container Backload On & Offload	0.088	0.088	0.143
In country transport	0.432	0.750	1.000
TOTAL	**4.500**	**6.200**	**7.666**

* based on average ship charter and fuel rates used in Table 3
**based on ship charter of $10,000 daily, IFO380 @$735/MT and MDO @ $1165/MT; port charges of $4,500/week
*** based in estimated ship charter of $12,500/day; 30MT/Day of IFO380 @ $480/MT at sea and 3MT/Day of MDO @ $745/MT at anchor; port charges $5,500/week.

Based on this sensitivity analysis, it can be noted that even a high-end cost estimate for a 500TEU (nominal) vessel (at some $6.2M) continues to cost less than the equivalent airfreight ($7M). Furthermore, sea-basing only proves to be slightly more expensive if using a 750TEU (nominal) ship. However, given that such vessels have a higher passage speed (15-16kt), this would reduce the lead time for responding to a disaster by 12-24 hours depending on destination.

7.4 Hiring capacity for sea-basing

The base case (Option C), whilst clearly of significant benefit in the major emergency scenario, does not offer the flexibility to allow support for lesser scale operations. The aim of this section is, therefore, to explore the use of Option B, the comparable cost of which are:

Table 8: Estimate of the Cost of Option B (Hire of Capacity) based on Singapore to Karachi* (and return)

Cost item	**500 TEU (Nominal)** **400 TEU (Actual)** **Average Estimate ($M)**	**750 TEU (Nominal)** **650 TEU (Actual)** **Average Estimate ($M)**
Hire of Capacity (Outward Leg)**	0.440	0.715
Hire of Capacity (Return Leg)	0.200	0.325
Container Hire	0.292	0.475
In country transport	0.432	1.000
TOTAL	**1.364**	**2.515**

* As indicated in the description of Option B, Karachi was selected as the destination in view of its role as Pakistan's major commercial sea port.
** Because of the patterns of trade in the Asian area, the transport cost for Singapore to Karachi at $1,100/TEU (est) is double the return leg at $500/TEU [46].

In summary, this option is dramatically cheaper than the base case (Table 3) of moving 400 TEUs ($1.364M v $4.500M), but suffers from two disadvantages.

- Firstly, the initial load time is increased by 24-48 hours (reflecting the time needed to pack the containers with the specific stock needed for the particular emergency). In the case of the Pakistan earthquake, this would have seen the arrival of the emergency goods at E+15/16 (compared with E+14) in the base case. Nevertheless, this is delivers 400TEUs significantly faster than the air freight equivalent (E+30)

- Secondly, it relies on the availability of the necessary cargo capacity at the point of embarkation within the prescribed timescale (approx 48 hours). Whilst, theoretically, this should not present a significant risk, clearly this is a fundamental element underpinning the success of this option.

8. Extending the capabilities of sea-basing

Whilst this paper has evaluated only the simplest form of sea-basing for the purposes of disaster relief, i.e. the use of a floating warehouse, the original concept has been used with a variety of extensions in the military context. Mimicking the broad range of capabilities that are available in such a purpose built military vessel would require not only the ship itself (which almost certainly could not be chartered and would, therefore, incur a considerable capital outlay), but also a larger (and more expensive) crew skilled in the operation of relevant equipment. That said, purpose-built vessels could include enhanced capabilities and, although further research would be needed to understand how such facilities might be employed in practice, some possibilities might include:

- Provision of an ‘operations room’ with associated communications equipment for the local coordination of the relief effort.
- Medical facilities. These could be relatively limited or, through the sacrificing of some of the cargo space, could allow the installation of a field hospital. Clearly this would have to be integrated with other facilities such as a landing platform for a helicopter and/or suitable methods for transferring patients from smaller vessels. On the other hand, such a facility would only be of significant value when the disaster itself is in a location that is relatively close to the nearest sea port or area of ocean. Not surprisingly, hospital ships have therefore been indeed used in e.g. the Haiti earthquake [56] [57], though for extended

capacities, the use of navy vessels as hospital ships seems to dominate, also due to their outreach with helicopters and/or amphibious capabilities [58], [59], [57].

- Secure accommodation (and associated rest and relaxation facilities) for humanitarian teams.
- A flight deck (with or without hangar facilities) that allows for the transfer of personnel and/or equipment.
- Landing craft could also, theoretically, be carried. However, the operation of these is limited by the prevailing sea state which may be high in the aftermath of a wind event such as a cyclone.
- In addition to its own fuel requirement, the vessel could provide a bulk storage capability for fuel that can be used in support of the disaster (e.g. diesel for vehicles, generators etc). Similarly, it could carry the facilities for bulk water purification and subsequent transport in country.
- The basic container vessel could also carry vehicles (e.g. 4*4s, as well as larger equipment such as diggers and/or bulldozers) and heavy plant such as cement mixers and (small) rock crushers etc.

9. Concluding discussion

The aim of this paper was to carry out an initial evaluation of the potential for the use of sea-basing in the aftermath of a rapid onset disaster. The cost and practicality of the use of a standard 500TEU (nominal) commercial container ship were compared with similar data from the IFRC's support to the 2005 Pakistan earthquake. This analysis showed that, had it been operational at the time of the earthquake, then a sea-based response could have delivered 400 TEUs of relief goods within 15 days of the disaster at a cost of some $4.5M. This should be compared with the 30 days that it actually took the IFRC to fly in a similar volume of supplies at a cost of some $7M.

The sensitivity of the sea-based cost assumptions was tested and, in the worst case, the cost of this option rose to $7.6M – a figure that remains broadly comparable with airfreight. In addition, the concept was evaluated in three additional cases, those of the response to Cyclone Nargis (Myanmar) 2008; Typhoon Haiyan (Philippines) 2013; and the Nepal earthquakes (2015). In each case, the use of sea basing would have delivered a very high percentage of the goods supplied by air in a profile that would have seen a swifter response and with less environmental impact.

To be cost–effective, it is however recognised that a major disaster must take place within the operational area approximately once every two years. Whilst in recent history this requirement has, unfortunately, been all too well fulfilled, there is no guarantee that a similar frequency of such disasters will pertain in the future – albeit, as noted in the introduction to the paper, the trend is towards a greater impact of natural disasters. Nevertheless, the proposed operational area is highly geologically active leading to volcanoes, earthquakes and tsunamis; it is also subject to other natural disasters such as fires, floods and famine. It is also the area that has seen the highest percentage of natural disasters with 46% of those reported in 2014, and 64% of all deaths reported in the decade 2004-2013 occurring in the region [22]. Thus an assumption that a major disaster will continue to occur at least once every two years does not seem unreasonable.

It is also recognised that the geographical closeness of the actual disaster site to the sea is another limiting factor, but this can be offset by the potential availability of a number of disembarkation locations and avoidance of the ‘single point of failure’ (e.g. the difficulties of supporting a relief operation from a single airport such as Banda Aceh in the 2004 Asia tsunami or Kathmandu in 2015), or one where the impact of the event has restricted the use of the preferred airport as was the case in Cyclone Nargis, Typhoon Haiyan and the Nepal earthquake.

Finally, and perhaps most critically of all, the sea-basing concept invites the donor community to finance a capability which, like an insurance policy, may never be used. This challenges the historic behaviour of donors who have shown a marked reluctance to fund such preparation phase activities in humanitarian logistics. It would be possible to mitigate the high cost of the base case by use of capacity taken up from the commercial container transport market, and this has the potential to reduce the cost of transporting the 400 TEUs to some $2M. However such an approach introduces a major element of risk in that it removes the guaranteed availability inherent in the base case under which the vessel is held on a long term charter.

Thus, whilst this initial study has clearly demonstrated a *prima facie* case for the use of the sea-basing concept, further research is needed to investigate each of the constraints and limitations described above and to evaluate the efficacy of the model in a broader number of scenarios and geographic locations in order to provide comparative data.

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