Cargo Operations in Humanitarian Response

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Coupling Humanitarian Air Transport and Storage: Lessons from Haiti Applied to Typhoon Haiyan Response in the Philippines
ABSTRACT

Air congestion and storage capacity are two critical logistical challenges that occur in almost every major humanitarian crisis. Drawing on experiences from the Indian Ocean Tsunami in 2004-2005 and the 2010 earthquake in Haiti and observations from ongoing response to Typhoon Haiyan in the Philippines, this paper proposes a coupled air transportation and cargo storage approach that relies on regional hubs. The approach is discussed in general and as it might apply for Haiyan response. An optimization problem is outlined, and two proposed applications of the approach are identified.
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INTRODUCTION

Major humanitarian crises draw assistance from domestic and international entities spanning government, military, private, and non-profit sectors. Often, disaster-affected areas are naturally isolated or become isolated as a result of the disaster. Coordination and cooperation are always a challenge, particularly in the logistics of response including needs assessments, procurement, transportation, storage, and distribution.

Humanitarian logistics is a relatively new field, and much work remains to understand and address its challenges. This paper studies two particular logistical challenges—air transportation and storage capacity—on their own and as they relate to each other. It does this through the lens of the recent disaster in the Philippines, Typhoon Haiyan, applying lessons from past disasters to develop a general operational strategy.

PROBLEM STATEMENT

Based on situation reports and meeting notes from the UN Logistics Cluster (9) and the Yale-Tulane Planning and Response program (24), two of the biggest logistical challenges in delivering aid to the Philippines were:

1. Extremely limited storage capacity and
2. Congestion at airports causing delays in cargo delivery.

These are common challenges in humanitarian response.

SITUATION OVERVIEW

On November 8th, 2013, Typhoon Haiyan made landfall on the Philippines, impacting the Eastern, Western, and Central Visayas regions. Tacloban City, Leyte province, a city of approximately 200,000 people was devastated with most homes destroyed. Approximately 12.3 million people were affected, with nearly 700,000 people displaced. At least 5,800 people were killed and 27,000 people were injured (24).

International assistance poured in through the UN, voluntary organizations, and military organizations. Tacloban was the focal point of most assistance; because resources are so limited there, many agencies have set up operational centers in nearby Cebu (10).

Tacloban is served by the Daniel Z. Romualdez airport (DZR), which is classified as a major domestic airport by the Civil Aviation Authority of the Philippines. The airport has a single runway with an estimated 10,030 movements and 1,140,000 passengers per year. The airport includes a single-story terminal building with one boarding gate. Approximately 6,544 MT of cargo come through Tacloban annually (15). DZR was nearly destroyed by Haiyan but was reopened for C-130 (military transport) type planes on 11/11 (1 and 9). Two other airports in the Eastern Visayas were unusable after the storm (17) (Figure 2).

Because of congestion and devastation at Tacloban, the Mactan-Cebu International Airport (CEB) in nearby Cebu became the primary hub for international aid (9). CEB has a single runway and has approximately 61,872 movements and 6.1 million passengers per year moving approximately 51,723 MT of cargo annually. The airport includes a passenger terminal with an annual capacity of 4.5 million passengers (less than the current demand) and a cargo area. Several cargo airlines, including FedEx Express, operate through CEB (17) (Figure 3).
CEB faced significant congestion as well, and some flights were being diverted to Francisco Bangoy International Airport in Davao, Mindanao (9), an unaffected international airport south of the affected area (16).

Both DZR and CEB were constrained by lack of heavy equipment for loading, unloading, and transportation. Both were also constrained by storage space (9).

The largest airport in the Philippines is the Ninoy Aquino International Airport (NAIA) in Manila. NAIA has 2 runways serving 32 million passengers, 80,000 international flights, and 156,000 domestic flights annually. It also sees 460,135 MT of cargo annually. The airport has three large terminals and is a gateway facility for DHL (18) (Figure 4).

In the weeks after Haiyan, ground transportation from Manila to Tacloban took 1.5 to 2 days in light vehicles, and 2.5 days in trucks with additional delays caused by congestion. Significant congestion was reported near ferry points. Ferries added 2 to 5 hours to travel time plus additional delays caused by congestion (9).

**DISCUSSION OF OTHER MODES**

Ground and water transport options existed in the Philippines in addition to air transport. Although a more detailed discussion of port and road capacity is out of the scope of this project, they are discussed briefly here to provide some context. An illustration of the logistical complexity of the area, including ground, seaport, and airport characteristics, is included in the appendix.

The affected region consists of many islands and inter-island travel largely relies on ferry service rather than on bridges. Even in non-emergency states, only about 20% of the roads are paved (21). Immediately after Haiyan, debris, and in some cases even cadavers, blocked many roads (10). Although some of the roads were cleared, debris removal operations often take weeks or months. In addition, ferry points were extreme bottlenecks, causing delays and backups down roads (9).

In addition, there are several cargo ports throughout the affected region. These were not used on a large scale in the initial response for a variety of reasons including unknown capacity and logistical complexities. After the first week, the UN Logistics Cluster had begun to compile information about nearby ports with the help of Maersk (22).

Although sea and ground transport became more viable options after the first few weeks, air was the best choice for cargo delivery in the weeks after the storm.

**THE PROBLEM OF AIR CONGESTION**

Because Haiyan response is ongoing, logisticians have not had the time to parse the causes of delays and other difficulties at airports. However, observations from meeting notes align with observations during the 2010 Haiti response, therefore it is likely that some or all of the same phenomena are occurring at both Tacloban and Cebu.

The most basic air congestion problem was simply the volume of traffic—the demand was higher than the capacity of the airports. Particularly in the first few days, aid agencies reacted quickly to send supplies without necessarily considering the logistical complexities of doing so. In addition to this, after Haiyan, an additional level of complexity was added by the number of displaced, disaster-affected individuals trying to get out of Tacloban (2).
Figure 1: Overview of impacted area: Highly affected Visayas regions, Manila, Davao (which received many diverted flights), and Subang, Malaysia (home to UN depot)
Figure 2: Tacloban Airport Diagram (11)

Figure 3: Cebu Airport Diagram (7)
Figure 4: Manila Airport Diagram (8)
Air traffic control was a less significant issue than was time on the ground (TOG). Particularly at smaller airports with limited parking capacity (like Tacloban and Cebu), each minute an aircraft spends on the ground being loaded or unloaded was a minute that another aircraft could not be unloaded. In Haiti, the physical parking capacity and the loading and unloading capacity (people and equipment) were the major capacity constraints. As a result, research efforts focused on ways to limit TOG for each aircraft (13).

Aircraft type is a major determinant in both TOG and efficiency. Smaller aircraft have less cargo capacity than narrow-body or wide-body aircraft; though they take less time to unload, the tons per hour per parking space observed in Haiti was less than half that of narrow-body cargo planes (Table 1). In other words, small aircraft are 50% less efficient than narrow-body aircraft such as C-130s. Although wide-body aircraft have the maximum cargo capacity, the efficiency achieved by narrow-body aircraft in terms of TOG and cargo throughput is very close to that achieved by wide-body aircraft (13). This point is key in Tacloban, where the airport can only support narrow-body aircraft.

<table>
<thead>
<tr>
<th>Type</th>
<th>Tons/aircraft</th>
<th>TOG (min)</th>
<th>Tons/hour/space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>5</td>
<td>62</td>
<td>4.9</td>
</tr>
<tr>
<td>Narrow</td>
<td>20</td>
<td>116</td>
<td>10.4</td>
</tr>
<tr>
<td>Wide</td>
<td>35</td>
<td>179</td>
<td>11.7</td>
</tr>
</tbody>
</table>

Reliability was also a major challenge. Veatch and Goentzel estimated a no-show rate of approximately 20% at the Haiti airport. A high no-show rate makes planning incredibly difficult and often resulted in large spans of time that the airport was not used to its full capacity (13).

These challenges made for very long delays and frequent diverts in Haiti (also observed in the Philippines (9)). It was therefore very difficult to ensure that the most-needed cargo made it to the airport and was unloaded in a timely manner.

**THE PROBLEM OF STORAGE CAPACITY**

Storage capacity refers to physical storage space, security, personnel, equipment, and documentation systems. The physical space is the largest and most obvious constraint, and is often a limiting factor in disaster response. It is rarely the case that a disaster-affected region has adequate permanent storage facilities to handle the influx of humanitarian aid. Mobile storage units (Wikhalls) are one way that humanitarian assistance agencies can increase physical storage capacity (9). Storage facilities must be secured against looting by physical means and also often with security guards (5).

In addition, storage facilities require management staff, personnel to sort, load, and unload, and a tracking system. In humanitarian relief efforts this is critical for several reasons. First, the rapid influx of goods requires a system that can keep up. Second, many goods that arise are not immediately useful or useful at all, and therefore all arriving goods must be sorted to identify high priority items, items that may be useful but are not immediately so, and items that are not usable or useful. Third, many agencies have specific supply chain requirements that require detailed tracking throughout the delivery process (5). The challenges of cargo and donations management have been thoroughly outlined by several researchers.
PROPOSAL

This project involves expanding upon the proposed regional hub approach proposed by Veatch and Goentzel (13) after the 2010 Haiti earthquake for the purposes of easing air traffic and storage requirements. The expansion would consist of the complete or partial coupling of transport processes with cargo and inventory processes to address the two challenges outlined above.

The approach has two primary components:

1. Using one or more remote airport(s) as a hub to consolidate deliveries to the affected areas, minimizing delays and diverts as well as minimizing no-show potential and
2. Developing a just-in-time cargo delivery strategy so that goods are stored remotely and delivered to the affected area only when needed.

COORDINATING ENTITY

This proposal has been written with the assumption that a single coordinating entity will be able to oversee and implement its elements. Often, one or more military organizations assume this role as the US Military did in Haiti in 2010. The United Nations (UN) Logistics Cluster (Log Cluster) is another mechanism through which this is might be achieved, and this document is written with the Log Cluster in mind. It should be noted that many government, civilian, and military organizations participate in the Log Cluster, and therefore the Log Cluster may be a representation of several different entities. Further, it may be the case that multiple entities wind up in a coordinating role as in the case of Indonesia. Of course, it may also be the case that so many entities are involved that coordination on this scale is impossible.
The challenges and complexities of interagency coordination in disaster response are well-documented and are out of the scope of this report.

AIR HUB CONCEPT

The hub concept is relatively simple: organizations ship to an airport in the same region, and cargo is then shuttled to the crisis area by one or a few regular carriers. This results in better airport operations, including higher reliability and faster unloading time in the crisis area. It also gives the shipper less control (13). Note that the term “air hub” is used in this paper to refer to an airport.

The air hub approach was used after the Indian Ocean Tsunami in 2005, and was described in an after-action report as follows:

Strategic air deliveries of other foods and [non-food items] were made. After some initial deliveries directly to airports in Indonesia, most relief supplies were channeled through Subang air base in Malaysia to shorten the line of supply and to relieve the extraordinary congestion in Medan and Banda Aceh. Long-range deliveries from around the world were made into Subang, which was managed by a combination of the Malaysian Air Force, WFP and UNJLC. Cargoes from UN agencies and many other partners were then flown by smaller aircraft into Aceh Province. The decision to open the regional air hub at Subang was a key strategic decision. It was closed at the end of February having served its purpose.  

Veatch and Goentzel’s proposed approach involves more than just a physical hub; in addition, it involves a scheduling strategy that seeks to maximize tons delivered rather than number of flights. This allows for some consolidation and ensures optimal use of aircraft entering the affected areas.

In addition, reliability can be increased by instituting regularly scheduled flights from the hub to the destination. This will minimize the number of no-shows, optimizing use of the airport. In addition, it can help planning efforts on the parts of the shippers (aid agencies), hub managers, and operators in the field (13).

JUST-IN-TIME CARGO DELIVERY

The second part of this proposal is an add-on to Veatch and Goentzel’s proposed approach. To limit the amount of storage space required, all goods are stored at or near the air hub and delivered only when they are needed. This could mean that agencies requesting particular goods for the hub must show that they will distribute the goods immediately or that they have the capacity to store the goods as needed.

This approach has the additional benefit of reducing security concerns, as the risk of dangerous looting will be lower in an area with less disaster damage.

A further refinement could include procedures for classifying and repackaging goods at cargo hubs for additional efficiency. This would require a much higher level of manpower and coordination and would likely face major commodity ownership/chain of custody challenges and is therefore not discussed in more detail here.

One outstanding question associated with this cargo management strategy relates to the level of inventory maintained in the field. For certain life-sustaining items such as food, water, and shelter supplies, it may be necessary to maintain some base level of inventory as a buffer against unanticipated surges in demand and the wait time between a request for delivery and actual delivery. This buffer level would be dependent on the scale of
need and the time between the need identification and delivery of commodities. This problem is further discussed below.

**SELECTION CRITERIA**

This section discusses general requirements for an air and storage hubs. For maximum efficiency, the two hubs would be collocated or very close to one another.

**AIR HUB REQUIREMENTS**

An ideal air hub would have:

- Slot availability for regular and emergency departures (i.e. normally does not operate close to capacity);
- Physical capacity to handle a mix of aircraft, including wide-body planes;
- Physical space to handle unloading reloading of larger planes;
- Ample parking space;
- Sufficient personnel or surge capacity to enable large scale loading and unloading;
- Equipment for loading, unloading, and transport;
- Relatively low risk of significant damage from natural hazards or other hazards;
- Ample storage space and/or proximity and accessibility to storage hub.

One point of discussion raised by Yang is the use of charter versus commercial flights in humanitarian aid (25). Yang reaches the conclusion that, for large cargo quantities chartered flights are more efficient whereas for smaller quantities commercial flights are more efficient. Although an airport with ongoing regular commercial service may not meet all of the criteria above and would almost certainly not meet the storage hub requirements below, there may be some benefits to using a commercial airport as a regional hub in addition to another airport.

**STORAGE HUB REQUIREMENTS**

An ideal storage hub would have:

- Large amounts of flexible storage space;
- Personnel or surge capacity to enable large scale operations;
- Labeling and tracking capabilities;
- Loading and unloading equipment;
- Proximity and accessibility to the air hub.

Note that the personnel and equipment constraint is often more challenging than the physical constraints. Often these are provided by a military organization.

**AIRPORT SELECTION FOR HAIYAN RESPONSE**

The criteria listed above were used to identify potential air and storage hubs for Haiyan response focused on Tacloban and the surrounding areas. Tacloban and Cebu airports are profiled to highlight their limited capacity. The Manila airport is profiled because it is the largest commercial airport in the Philippines and was being used as a hub. Two additional air fields, Subic Bay and Clark Air Base, are profiled based on expert guidance. Finally, the
airport in Subang, Malaysia is profiled due to its proximity to the UNHRD warehouse and its previous use as an air hub in 2005.

**Airport: Tacloban**

This airport is in the heart of the devastated area. Its one runway was reopened a few days after Haiyan and can only serve narrow-body aircraft. Storage and loading/unloading capacity are extremely limited (11, 15).

**Airport: Cebu**

The closest unaffected airport to the hardest hit area, Cebu has extremely limited storage capacity and loading/unloading capacity. It is massively congested, and many flights are being delayed or diverted (7,17).

**Airport: Manila**

The largest major airport near the affected area, this airport is already being used as the through point for much aid. It is already congested and has limited storage capacity and limited loading/unloading capacity (8, 18).

**Airport: Subic Bay**

Another former US military base, this airport once served as a FedEx hub and has some limited commercial traffic. Therefore there is likely ample storage and ample air/land capacity for loading and unloading. Staffing and equipment may be an issue (19).

**Airport: Clark Air Base**

A former military base located outside of manila, this air base has ample parking, storage, and loading/unloading space. It also is being used by the US Military as its hub for humanitarian relief, therefore it has already been stood up for this purpose and has sufficient staff to serve as an air hub (9, 14).

**Airport: Subang**

Located in Malaysia, this airport is proximate to the UNHRD emergency warehouse and was used as a regional hub for aid after the 2004 Indian Ocean Tsunami (20).

Capacities of these airports are discussed in Table 2.
### AIRPORT CAPACITIES

**Table 2: Philippines Airports**

<table>
<thead>
<tr>
<th>Airport Code</th>
<th>Manila</th>
<th>Tacloban</th>
<th>Cebu</th>
<th>Clark Field</th>
<th>Subic Bay</th>
<th>Subang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runway Description</td>
<td>2 asphalt runways, 1 2000 m and 1 3400 m</td>
<td>1 asphalt runway 2100 m long</td>
<td>1 concrete/asphalt runway, 3300 m long</td>
<td>Two 3200 m parallel concrete runways</td>
<td>1 asphalt runway, 2700 m</td>
<td>1 asphalt runway, 3800 m</td>
</tr>
<tr>
<td>Cargo Storage</td>
<td>Limited, and mostly already in use</td>
<td>None</td>
<td>Some cargo storage, though apparently full now</td>
<td>Ample—many empty hangars</td>
<td>Ample—formerly naval base and FedEx hub; cargo space is therefore available</td>
<td>Storage available at UN HRD Hub</td>
</tr>
<tr>
<td>Arrival/Departure Capacity</td>
<td>One of the busiest airports in Asia; limited additional capacity</td>
<td>Extremely congested during Haiyan response</td>
<td>Extremely congested during Haiyan response</td>
<td>Not normally used</td>
<td>Limited air traffic during normal operations</td>
<td>Fairly busy airport during normal operations</td>
</tr>
<tr>
<td>Parking Capacity</td>
<td>Some parking</td>
<td>Extremely limited</td>
<td>Large aircraft maintenance area could allow for some parking capacity</td>
<td>Ample</td>
<td>Likely ample</td>
<td>Some parking, but limited additional spots</td>
</tr>
<tr>
<td>Loading/Unloading Capacity</td>
<td>May be some capacity at Pal Hangar, but limited</td>
<td>Extremely limited</td>
<td>May be some capacity, but tight especially with high volume</td>
<td>Ample, particularly with staffing from US Military</td>
<td>Likely ample</td>
<td>May be some capacity from ongoing cargo operations</td>
</tr>
<tr>
<td>Current Utilization</td>
<td>Some normal traffic continues, and already significant congestion of passenger and cargo traffic</td>
<td>C-130's are allowed in; significant congestion cause massive delays and diverts</td>
<td>Significant congestion due to humanitarian flights causing delays and diverts</td>
<td>Not typically operational, currently being used by US Military</td>
<td>Limited commercial traffic, therefore likely underutilized</td>
<td>Normal operations</td>
</tr>
<tr>
<td>Operators</td>
<td>Philippines airport authority</td>
<td>Humanitarian community</td>
<td>Mactan-Cebu International Airport Authority</td>
<td>US Military is using it as its hub for humanitarian relief</td>
<td>Subic Bay Metropolitan Authority</td>
<td>Malaysia Airports Holdings</td>
</tr>
<tr>
<td>Equipment Available</td>
<td>Some available, not much</td>
<td>Loading/unloading equipment limited</td>
<td>Loading/unloading equipment limited</td>
<td>Some provided by US Military</td>
<td>Unknown</td>
<td>Some available</td>
</tr>
</tbody>
</table>
Figure 6: Airport Locations (10)
GENERAL OPERATIONS

Basic operations are as follows and are discussed for an airport that is not constrained by regular commercial traffic:

- Every day, there are a set number of flights from the air hub to Cebu and a set number of flights to DZR on a set aircraft type (such as C-130) with a set storage capacity (in weight and volume).
- Agencies may submit requests to the UN Log Cluster have their cargo delivered on a certain day and must show as a condition of shipment that they will a) use or distribute the cargo immediately or b) have their own capacity to store it.
- Cargo that has not been requested or cannot be stored in the field is stored in the storage hub.
- The Log Cluster coordinator distributes requests across scheduled flights, and determines whether additional flights are needed.
- Because flights are loaded from air or storage hub, the coordinator has a more accurate picture of how much of an airplane one request will fill and can maximize aircraft utilization.

Operations must be slightly more complex than this, however; flexibility is required to enable the prioritization of critical cargo, emergency deliveries, political pressures, and more. Veatch and Goentzel propose two approaches to prioritization, which may be used separately or in tandem. The first approach is to prioritize cargo by type, always giving preference to critical items. This could be helpful especially in the initial response, when items such as food, water, and shelter are in critically short supply. However, there may be some challenges associated with identifying which goods are considered to be critical. First, need-specific information is very hard to come by, particularly in the first few days. Second, it is not always obvious which are the most critical needs. Third, since
humanitarian response is a collective effort across multiple entities, different organizations may define “critical” needs differently.

The second approach is to prioritize by entity type, which can be done in a few different ways. One way would be to always give first priority to the home government, then to other agencies according to some hierarchy. This presents some obvious challenges in terms of determining the precise structure of that hierarchy. Another way is to assign a certain percentage of available slots to certain entity types, for instance military humanitarian aid, international response community, government aid, etc (13). In this case, a slot could mean:

- An entire air slot, meaning the entity has its own aircraft or uses one entire aircraft coming from the hub;
- A portion of the regularly scheduled departing flight.

Regardless of the approach used, general operations would entail assigning slots according to the designated priority structure, then using some other system to assign remaining slots to requesting entities. The likeliest approach would be to gift first priority to critical or time-sensitive requests, then to allocate remaining slots on a first-come, first-served basis.

One factor for consideration could be the ability of slot “owners” to game the system by trading or selling their slots. On the one hand, this could be a desirable characteristic, as it would enable local objectives to be prioritized and accomplished. On the other hand, if the local government is weakened or corrupt, it could result in overly emphasizing cargo that does not contribute to the goal of humanitarian assistance.

**HAIYAN OPERATIONS**

For simplicity of discussion, this paper assumes that Tacloban is the only destination for aid. Note that other hard-hit areas may be served by other airports, many of which are similar to DZR. This concept can easily be extended to apply to multiple destinations using the same air and cargo hubs by modifying flight schedules or adding additional aircraft.

The likeliest hub for Haiyan response was Clark Field, which was, in fact, used as a hub by the US Military.

Aircraft operations from Clark Field:

- 590 miles from Clark Field to Tacloban (4), approx. 1.5 hr flight
- For a C-130, TOG is 116 min (13)=2 hr—including unloading but not loading
  - Total round trip time = 5 hr
  - One C-130 can make 2 trips per day and move 42 MT of cargo per day (13)
- Number of trips required depends on cargo requirements
  - Assume start with 2 C-130’s (9)->4 trips per day, 84 MT per day
- Schedule arrivals regularly, e.g. 0800, 1100, 1400, and 1700 daily

Note that these operations can easily be scaled up or down with additional aircraft.

Another option for a hub is Subang, Malaysia, where the UN stockpiles emergency items. Although this location is very far from the Philippines (1700 miles), it could serve as a way to consolidate donations and deliveries from international donors on other continents. Subang was also used as a hub in the response to the Indian Ocean Tsunami.
Operations from Subang, Malaysia:

- 1700 miles from Subang to Tacloban (4), approx 3.5 hr flight
- Same assumption: 2 hr TOG
- Total round trip time: 9 hr
- One C-130 can make 1 round trip per day and move 21 MT of cargo per day

Because Clark Field has much more physical capacity than Subang, one approach might be to use Subang for specific items such as food and water and to use Clark Field as a more general hub.

**CHALLENGES**

This approach has several challenges, many of which have already been highlighted. These challenges include but are not limited to:

- **Process ownership:** The process outlined above requires a coordinating entity to set priorities, schedules, and processes. There is not always an obvious coordinator in this role, and there may be multiple entities who want to be the coordinator.
- **Buy-in:** Once the process is set, all responding entities must buy into the process. That means agreeing to deliver goods to a hub rather than to the center of aid. This could be particularly challenging for organizations who are inexperienced in humanitarian aid and do not understand the reasoning behind an air hub. It could also be challenging for organizations who need to show donors that their money is directly helping people in need.
- **Control:** This system would represent a significant loss of control to aid organizations; there would be one or more additional intermediaries between donors and recipients. This could be more than just an organizational or political challenge; in some instances, such as with medical supplies, there may be chain of custody requirements that would be difficult to adapt to this system.
- **“Temporary” warehousing:** It is often the case that a site designated as temporary storage is not really temporary. Often, many donations are made that are not useful in humanitarian response, and when the response is over, those goods remain in the “temporary” warehouse.
- **Aircraft availability:** It is not a given that aircraft will be available for these operations. Often use of aircraft is donated by a military entity or a private logistics company; however these cannot be guaranteed.
- **Personnel availability:** Once sites have been selected, there must be adequate staff to manage warehouses and load and unload aircraft. In many cases, military entities will be best able to provide personnel.
- **Equipment:** Similarly, air and storage hubs must have appropriate equipment for loading, unloading, and storage.

**FURTHER RESEARCH**

Veatch and Goentzel developed queuing models for airport operations after Haiti with the purpose of identifying the slot management strategies that would minimize time on the ground and maximize tons delivered. Based on this project, that model could be expanded to allow for the coupling of transportation and storage management strategies.
As described above, one application of a queuing model could be to identify the ideal inventory level maintained in the field to account for unanticipated spikes in demand and wait times between delivery requests and actual delivery. The inventory level would be a function of the scale of need and delivery time. Scale of need could be determined by the geographic extent, population affected, or other factors. For the purposes of analysis, it may be necessary to hold initial scale constant. Delivery time is dependent on time to process the request, availability of aircraft, storage capacity, throughput capacity at the storage hub, and slot availability at the destination.

**APPLICATIONS**

In addition to the research described above, this proposed approach could have two primary audiences. First, as part of its humanitarian arm, DHL runs a program called “Get Airports Ready for Disaster” (GARD). This program is a multi-day course that helps airport managers in high-risk areas prepare for catastrophic humanitarian events and includes an airport readiness assessment (3). That assessment could be expanded to include an evaluation of potential regional air and storage hubs based on the criteria developed above.

The second audience would be the United Nations Humanitarian Response Depot (UNHRD), which maintains five warehouses throughout the world to stockpile emergency supplies (6). The approach proposed here could be incorporated into operations plans for those hubs, including developing capacity to take in additional deliveries and identifying partner airports.

**CONCLUSION**

Air and storage capacity are often critical logistical constraints in humanitarian response. Regional hubs that can allow for temporary storage of less critical items and allow for the consolidation of shipments can reduce air congestion, increase reliability, and limit storage requirements in impacted areas. The extent to which cargo delivery and air operations can or should be coupled should be examined further through network optimization and other approaches. Ongoing readiness programs such as UNHRD warehouses and the DHL GARD program should consider incorporating the identification of partner airports to serve as hubs.
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11. UN Logistics Cluster, Tacloban Airport Diagram, 11/14/2013, 
16. Wikipedia, Francisco Bangoy International Airport, 
18. Wikipedia, Ninoy Aquino International Airport, 

The diagram below illustrates operational access constraints in the Visayas regions approximately three weeks after Typhoon Haiyan. This information was not available in the first few days and weeks after the storm. The diagram is included here to illustrate the operational complexity of humanitarian response, particularly in an area such as the Philippines (http://www.logcluster.org/ops/phl13a/visayas_access-constraints_131125).