What Previous Disasters Teach: The (Really) Hard Lessons of Katrina and Haiti for Humanitarian Logistics

José Holguín-Veras, Ph.D., P.E.
Professor, Director
Center for Infrastructure, Transportation, and the Environment
jhv@rpi.edu
Acknowledgment

- Other contributors:
  - Tricia Wachtendorf
  - Miguel Jaller, Noel Pérez, Lisa Destro, RPI

- Research was supported by NSF’s:
  - NSF-RAPID CMMI-1034635 “Investigation on the Comparative Performance of Alternative Humanitarian Logistic Structures”
  - CMMI-0624083 “DRU: Contending with Materiel Convergence: Optimal Control, Coordination, and Delivery of Critical Supplies to the Site of Extreme Events”
  - CMS-SGER 0554949 “Characterization of the Supply Chains in the Aftermath of an Extreme Event: The Gulf Coast Experience”
Outline

- Private sector vs. Humanitarian logistics
- Unique complications and challenges in disasters
- The phenomenon of convergence
- The National Response Plan
- Katrina’s logistical debacle or How not to do it
- The Port au Prince Earthquake: More Hard Lessons
- Implications
- Suggestions
Private sector vs. Humanitarian logistics
### Two different environments

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Commercial logistics</th>
<th>Humanitarian logistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective pursued</td>
<td>Minimization of total logistic costs</td>
<td>Minimization of human suffering</td>
</tr>
<tr>
<td>Commodity flows generated</td>
<td>Self-contained</td>
<td>Determined by material convergence</td>
</tr>
<tr>
<td>Decision making structure</td>
<td>Structured interactions under control of a decision maker collaborating towards a common goal</td>
<td>Non-structured interactions, unknown thousands decision makers competing, interfering, collaborating; different goals</td>
</tr>
<tr>
<td>Knowledge of demand</td>
<td>Known with some certainty</td>
<td>Unknown and dynamic</td>
</tr>
<tr>
<td>Periodicity and volume of logistic activities</td>
<td>Repetitive, large volumes</td>
<td>One in a lifetime events, smaller volumes</td>
</tr>
<tr>
<td>State of supporting systems</td>
<td>Stable system</td>
<td>Impacted and dynamic system</td>
</tr>
</tbody>
</table>
Background on Material Convergence and Humanitarian Logistics
Fritz and Mathewson (1956) defined convergence as “the movement or inclination towards a point”

They created a comprehensive:

- personnel convergence, i.e., movements of individuals;
- informational convergence, i.e., “movement or transmission of symbols, imageries, and messages...”;
- material convergence, i.e., “...the actual movement of supplies and equipment...”

Emergency Logistics intertwined with convergence

Not much research in either field
What is the problem?

- The efficiency of the flow of high-priority goods depend on the flow of low priority cargoes.
- Equivalent to trying to move two different liquids through a pipe.
Is it really that bad?

- Let’s take a look at previous experiences
  - 1953 Arkansas tornado
  - 1992 Hurricane Andrew
  - 2001 World Trade Center
  - 2005 Gulf Coast
  - 2010 Haiti

- Indeed, we could list as examples **ALL** major disasters
1953 Arkansas tornado

“... (the day following the tornado) all this clothing and food and all this vast store of supplies started moving into Searcy for distribution to the tornado areas....There was no place to put it ... No buildings to put it in ... That created a big problem ... So much was worthless rags. They had some pretty good ones. Somebody sent an old doggone big carton of falsies. We got a tuxedo, a nice one ...

“...It was coming by Railway Express, by truck, by plane, by freight car... Enormous amount of floor space, but that was filled in two hours—filled ceiling high. One other big building...probably a hundred feet long and sixty feet wide, with 14 feet ceiling... filled in 12 hours.” ... sixty percent of it was not good; it shouldn’t have come to the area at all...”

(NORC report No. 52, pp. 281)
“Excessive donated clothing created major problems... some of the clothing was not appropriate for the tropical climate of Dade county (e.g., winter coats).... Often, truck drivers with loads of clothes drove straight to severely damaged areas... Upon arrival, they often did not know where to deliver the donated clothes, so they unloaded them on the side of the road. The heat and usual afternoon summer rains quickly turned the piles into heaps of stinking, rotting cloth.” ... “Excessive food donations created further emergency management problems.” (Neal, 1994, pp. 24)
2001 World Trade Center

- “Chris Ward is snaking through a tunnel of cardboard crates, past boxes ... past thousands of shampoo containers organized by size....The problem is, very little of it was needed... little of the cargo reached the intended recipients, as they simply had no use for it...The propensity of Americans to ship stuff to national disasters has become such an overpowering reflex that rescue workers now have to divert considerable resources to ensure the largess does not get in the way. Some even describe the torrent of sundries as a “second tier disaster.”” (Newsweek, 2002)

- “[There] were examples of much needed materials, but we also saw donations of unnecessary goods ... the five tractor-trailer loads of pumpkins donated to Ground Zero around Halloween that needed to be redirected to public schools .... We heard of people driving machinery and equipment to the site, leaving it for use, and then becoming upset when it was not returned even though the items were never documented, processed, or requested.” (Wachtendorf and Kendra, 2004, pp. 5).
“Donation management is the most difficult part of every disaster,” he said of the unsorted mountains of clothes. "We have a little bit of everything."”…. (Caller-Times, 2005).

“Sometimes generosity can go awry.”….. In Katrina's immediate aftermath…. collection sites along the Mississippi Gulf more than dump sites”…. (Times-Piscayune, 2005).
“At the top are planes bringing in water and water production equipment. Next is equipment for distributing supplies, followed by food and then medical personnel and medicine” (NYT, 2010)

Dominican officials reported having to deal with dozens of planes that landed in Santo Domingo with donations and no consignee, that have to be unloaded and their cargo sorted out and transported to Haiti at their expense

Ten containers with refrigerators, of no use due to lack of power.
“Nobody seemed to know exactly what was on the boat, or who actually sent it. One rumor was that it was from Costa Rica.…” The boat, it turned out, had mostly packs of water bottles, which is nice and everything, but water isn't really what Haiti needed right after the quake. There was plenty of water. Sanitation equipment or rice would have definitely been more useful. This is one example of aid that just might have been hurting more than it was helping.” (National Public Radio, 2010).
Caritas DR: The two sides (12 vs. 2 employees)
The National Response Plan (USA)
Key responsibilities

- Local government (1\textsuperscript{st} day)
  - Identify, secure man-power to man points of distribution
  - Organize local population

- State government (2\textsuperscript{nd} day)
  - Preposition critical supplies
  - Deploy resources to assist the locals

- Federal government (3\textsuperscript{rd} day)
  - Bring resources to the impacted area
  - Identify, secure man-power to man mobilization centers, and staging areas
  - Coordinate the overall response
Schematic of the process (FEMA)

- Logistic centers (LC)
- Mobilization centers (MOB)
- Federal and State Staging Areas (SA)
- Points of distribution (POD)

Major flows:

- From LC to MOB
- From MOB to SA
- From SA to PODs

Impacted area
Katrina’s logistical debacle or
How not to do it
1. Magnitude of the event and the requirements

- The largest natural disaster in U.S. history:
  - Devastated 100 miles around the eye
  - Property damages ascending to $96 billion
  - Total economic impact may reach $200 billion
  - One of the deadliest hurricanes to ever hit mainland U.S., with 1,577 confirmed deaths and 226 people still missing as of May 2006
  - Flooded 80% of New Orleans
  - The government federal disaster declarations covered 90,000 square miles, an area almost the size of the United Kingdom
The American Red Cross (ARC) started preparing:

- Prepositioned 500,000 meals ready to eat (MREs)
- Identified 15 sites for large kitchens for mass feeding
- Opened several shelters in the region
- Deployed vehicles and staff to the disaster area
- Raised more than $2 billion, 2/3 of charitable groups
- Led the efforts of more than 220,000 staff and volunteers

When New Orleans flooded, ARC was overwhelmed: “...I don’t think Red Cross ever had to work with so many outside agencies in coordination...”
2. Collapse of the communication infrastructure

- Nearly three million people without electricity/phone
- 911 emergency call centers were severely impacted
- Out of service: 50% radio stations, 44% of TV stations
- 50,000 utility poles were toppled in Mississippi alone
- “[the] entire infrastructure was wiped out [and] there were no communications...until five days after the storm [when] we got satellite phones.”
- “…the main communication came back and forth by helicopter. Sort of like a New Age Pony Express.” No one knew “…if things had been delivered, and if they had been delivered, who accepted it.”
- The Internet-based inventory system (E-Team) used by the State of Louisiana to process emergency requests collapsed
3. Lack of integration between computer systems

- Local and state governments used a commercial software (E-Team) for procurement and tracking
- FEMA relied on a custom-made system called NEMIS (National Emergency Management Information System)
- E-TEAM and NEMIS did not communicate
- E-Team requests had to be individually read and manually inputted into NEMIS
- Federal staff could not check information on individual requests, local/state staff could not check the status of their requests...
4. Lack of planning for handling of donations

- The volunteers and staff available at staging areas were not enough to manage the large influx of goods received.
- “...another thing we need in our plan is donated goods. There needs to be a section within FEMA, or the State, or somebody, besides VOAD in conjunction with VOAD that needs to be responsible for donated goods.”
Volunteers complained that communication with the government was inefficient and that they did not know what the priorities and needs were.

Donations of low-priority goods hampered critical activities: clothing being the most problematic.

Incoming trucks loaded with clothing sometimes dropped their cargo at parking lots.
5. Limited asset visibility

- Asset visibility was seriously obstructed at both ends of the supply chain
- Locals could not estimate the quantity and type of critical supplies needed
- FEMA had difficulties determining supplies needed, the resources it had available, and the specific location of a resource at a given point of time
- Because of lack of GPS, nobody knew where trucks were. Example: the Superdome trucks
6. Understaffing and lack of training

- FEMA had around 500 vacancies (20% of the 2500 agency positions) with eight out of its ten regional directors working in an acting capacity.
- FEMA turned to other federal agencies to staff FEMA positions in Mississippi and Louisiana.
- Not all local staff were proficient users of E-Team.
- The volunteer groups had problems: “…every time a new group comes in, you have to train [them].
- Few individuals had logistic training.
7. Inefficiencies in pre-positioning resources

- Not enough critical supplies were prepositioned
- The locals did not even think about prepositioning
- It was suggested that the state did not preposition the critical supplies called for by its own emergency plan because it was waiting for the Federal emergency declaration to avoid using State funds
- The federal declaration of emergency was issued one day before landfall
- FEMA started to preposition but there was no time. The activities were suspended because of Katrina.
8. Procurement

- Procurement delays may be the single most important factor explaining the slow flow of critical supplies after the initial response.
- “...delivery times were horrible. Small quantities were OK [however delivery of] large quantities [was] very bad (two weeks).”
- This same respondent described delivery of large quantities taking 2-6 weeks after requisition, while the delivery of medical supplies took 1-3 weeks as the staff were unfamiliar with the supplies and where to acquire them.
Popular wisdom in action ...
Finding: Volunteer organizations saved the day

- Horrendous as it was, the Katrina debacle would have been much worse if not for the outstanding work of the volunteer organizations that:
  - pre-positioned supplies
  - sent experienced and motivated leaders
  - demonstrated great creativity, ingenuity and flexibility in the face of disaster
  - 80 million pounds = 2,000 semitrailers
The Lessons from Katrina

- Competent Humanitarian Logistic staff is needed
  - Training exercises, table top exercises are a must
- Locals must prepare, they are the first responders
- Prepositioning of critical supplies is absolutely vital
- Donation management is a must
  - If not managed → Donations will produce delays
  - If managed → Precious resources will be distracted
- Technical:
  - Reliable, robust, interoperable communication systems
  - Procurement must be up to the task
- Volunteers saved the day
The Port au Prince Earthquake: More Hard Lessons
A complex tragedy

- Technical factors
  - Magnitude of the event
  - Vulnerability of the population
  - Local leadership was directly impacted by the event
    - Haitian Government
    - United Nations
    - Catholic Church

- A watershed in humanitarian logistics
  - Agency-centric efforts faced major logistical problems
  - Existing collaboration networks worked well
A large earthquake
Impact a very vulnerable population

<table>
<thead>
<tr>
<th>Rank</th>
<th>Event</th>
<th>Location</th>
<th>Date</th>
<th>Death Toll (Estimate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1931 China floods</td>
<td>China</td>
<td>July-November, 1931</td>
<td>1,000,000–4,000,000</td>
</tr>
<tr>
<td>2</td>
<td>1887 Yellow River flood</td>
<td>China</td>
<td>Sept.-Oct., 1887</td>
<td>900,000–2,000,000</td>
</tr>
<tr>
<td>3</td>
<td>1556 Shaanxi earthquake</td>
<td>Shaanxi Province, China</td>
<td>January 23, 1556</td>
<td>830,000</td>
</tr>
<tr>
<td>4</td>
<td>1970 Bholas cyclone</td>
<td>East Pakistan (Bangladesh)</td>
<td>November 13, 1970</td>
<td>500,000</td>
</tr>
<tr>
<td>5</td>
<td>1839 India Cyclone</td>
<td>India</td>
<td>November 25, 1839</td>
<td>300,000</td>
</tr>
<tr>
<td>6</td>
<td>2004 Indian Ocean tsunami</td>
<td>Indian Ocean</td>
<td>December 26, 2004</td>
<td>295,600</td>
</tr>
<tr>
<td>7</td>
<td>526 Antioch earthquake</td>
<td>Antioch (now Turkey)</td>
<td>May 20, 526</td>
<td>250,000</td>
</tr>
<tr>
<td>8</td>
<td>1976 Tangshan earthquake</td>
<td>Tangshan, Hebei, China</td>
<td>July 28, 1976</td>
<td>242,000</td>
</tr>
<tr>
<td>9</td>
<td>1920 Haiyuan earthquake</td>
<td>Haiyuan, China</td>
<td>December 26, 1920</td>
<td>240,000</td>
</tr>
<tr>
<td>10</td>
<td>1975 Banqiao Dam flood</td>
<td>Zhumadian, China</td>
<td>August 7, 1975</td>
<td>90,000–230,000</td>
</tr>
<tr>
<td>11</td>
<td>1138 Aleppo earthquake</td>
<td>Syria</td>
<td>October 11, 1138</td>
<td>Unknown, up to 230,000</td>
</tr>
<tr>
<td>12</td>
<td>2010 Haiti earthquake</td>
<td>Haiti</td>
<td>January 12, 2010</td>
<td>230,000+</td>
</tr>
</tbody>
</table>
Major damage to critical infrastructure
Widespread damage
Blocked streets...
Road damage PaP to Carrefour
Chaotic traffic conditions, notice where we drove
The human toll...
The Bottom Line
Initial Findings: Immediate Impacts

- The earthquake severely disrupted the centers of power (Government, United Nations, Catholic Church) and in doing so posed a huge obstacle to aid efforts that did not have alternative paths to distribute critical supplies.

- Two structures emerged: Agency centric efforts, Collaborative multi-agent
  - Vastly different levels of performance: one delivered the goods without major problems, the other did not
  - Vastly different safety levels: one experienced numerous safety problems, the other did not
Foreign aid flowing directly to Port au Prince could not link up with the locals.

Physical and social links with local distribution networks were severely disrupted by the earthquake.

The aid flows that connected to the local networks from the rest of Haiti and Dominican Republic reached the victims with minimal problems.

Entry points

Local physical / human distribution networks
Agency centric efforts
Agency centric efforts could not do the last mile...

- USA’, UN’s, and Haitian Government, all had major problems with the delivery to the people in need
  - The cargo arrived at the major terminals
  - Had major problems in delivering the aid to the needy
- Could not find enough trucks to distribute aid: “At the top are planes bringing in water and water production equipment. Next is equipment for distributing supplies, followed by food and then medical personnel and medicine” (NYT, 2010)
  - Not enough trucks? Lazy truckers?
  - Predominance of human powered transport?
The failure mechanism explains the truck mystery

- Foreign aid groups could not find their interlocutors:
  - Government agencies,
  - MINUSTAH (UN Mission for Stabilization of Haiti)
- No visible large trucking companies they could link up with, they did not know whom to contact
- No registry of trucking companies
- Lack of cooperation from the local business class
- Desperation leads to air drops
- Appeal to the Dominican Government
- Clinton Foundation donated 200 trucks
- Haitian truckers complained, truck registry created two weeks after the disaster
Bottlenecks at the entry points

Foreign aid flowing directly to Port au Prince could not link up with the locals.

Aid from the rest of Haiti and Dominican Republic reached the victims with minimal problems.

Physical and social links with local distribution networks were severely disrupted by the earthquake.

Local physical / human distribution networks
The sad outcome...
Asking for help…obviously no aid had come

“We need medicines, something to eat…”

“We are asking for food, water, medicine, temporary shelter and clothing. Are we not also humans?”
Collaborative Multi-Agent Networks
Did all relief efforts experience similar problems?

- No
- Four examples that worked extremely well
  - Evangelical Churches’ Social Service
  - Caritas Dominican Republic
  - Dominican Red Cross
  - Dominican Government

- Disclaimer:
  - There must be other great examples
  - These are the ones JHV was able to identify and see in action
Case 1: Evangelical Churches’ Social Service

- Before the earthquake, Evangelical Pastors from both Dominican and Haitian side were involved in a Dialogue—sponsored by the Norwegian Government—to foster peace and development.
- When the earthquake struck, they redirected this network towards humanitarian logistic efforts.
- It worked amazingly well!
Case 2: Caritas (social arm of the Catholic Church)

- Caritas DR had a long history of involvement in humanitarian work in Haiti, together with Caritas Haiti
- As in the case of the Evangelical Churches, they turned the religious/social network toward humanitarian logistics
- They knew each other, and had a structure to take advantage of
- It worked amazingly well!
Case 3: Dominican Red Cross (DRC)

- The DRC has traditionally trained staff at the Haitian Red Cross, more than a thousands trainees in the last four years
- On January 12, 2010 there were 500 Haitian citizens being trained by the DRC
- 250 of them—with local knowledge—were sent immediately to Haiti to handle the DRC logistics
- It worked amazingly well!
Case 4: Dominican Government’s efforts

- The earthquake struck at 5PM, and at 7PM the President met with Cabinet members to discuss relief efforts.
- The Disaster Management Law was followed, and the Center for Emergency Operations was activated.
- The Commander set up to find a suitable partner in the Haitian Government, after a lot of trouble he found the Minister of Women Affairs and struck a deal:
  - The Dominican Government delivers the aid to PaP
  - The Minister of Women Affairs takes care of local deliveries and to find enough trucks
- It worked amazingly well!
They also sent substantial aid (first to arrive)
- Ten industrial kitchens (10,000 meals/day each)
- Water purification equipment + Tankers + Drilling equipment
Common features of these successful examples

- They enjoyed the trust of the locals (the groups had pre-disaster legitimacy)
- They organized the local population
- The locals, including criminals, protected them:
  - No safety incidents reported
  - Only incident of theft (two containers stolen) was resolved with one phone call (the containers were returned 45 minutes later, unopened)
- They found all the truck and manpower needed
Contrasting performances...
Agency centric efforts...

- All agency-centric efforts experienced problems
  - Cannot connect the aorta to capillary vessels
  - Lack of manpower leads to few points of distribution:
    - Trying to deliver aid to thousands
    - Some individuals have to walk miles to get aid
    - This to lack of trust and loss of social order
  - Lack of knowledge of local conditions, street/path networks, needs is a major problem
Could a foreigner new to the area deliver aid here?
In contrast... collaboration networks

- The efforts discussed, based on existing collaboration networks and/or local knowledge, worked quite well
  - The members in the network know/trust each other (from before the disaster)
  - They possess local knowledge about street/path network, needs, etc.
  - They have the manpower, equipment, to deliver at the local level
  - The population trust them
Last mile deliveries
Some issues with collaboration networks

- Challenging coordination
- Potentially biased identification of needs
- Accountability could be an issue
- However, are there any alternatives?
Implications

- Humanitarian Logistics do not simply “happen,” we have to make it happen
- The multiplicity of agents involved lead to coordination challenges
  - No time to find out who is who
  - Different philosophies
  - Exercises are needed
- Tapping into existing collaboration networks is a must, because they:
  - Know the local conditions, have the manpower and the trust of the population
Key concept

- The fundamental idea is to:
  - Formalize a Humanitarian Logistics Collaborative Network comprised of Government, social/religious networks
  - This Collaborative would be the backbone of the end distribution efforts
  - Government aid and efforts would focus on the transportation of the large volumes of cargo (from Logistic Centers and the like, to Staging Areas), that will flow into the proposed collaborative network
“A naufrage is not the time to learn how to swim...”

(Statement from an emergency responder referring to the need to get the humanitarian logistic system ready before a disaster strikes)
## The Lessons from Haiti

- **The immense value of the human-social networks**
  - Pre-existing human networks did very well
  - Newcomers struggle

- **The Humanitarian Logistics community must refocus its planning efforts**
  - Too focused on transport of large flows to staging areas
  - Almost no focus on local distribution

- **Outside Agency-centric efforts are doomed to be ineffective**
  - Not enough man-power
  - Not enough local know-how
Suggestions

1. Create a Humanitarian Logistics Collaborative Network: Government, social/religious networks
2. Create a Humanitarian Logistics Training Program: to train population, staff, National Response Plan, and define proper roles for the key agents
3. Create a Robust Emergency Logistics Network
4. Regional Blanket Purchasing Agreements
5. Implement Measures to Increase Asset Visibility
6. Regional Compacts for Pre-positioning Supplies
7. Implement Proactive Donation Plans

End
Humanitarian Logistics Collaborative Network

- To be comprised of all reputable relief networks, including:
  - Red Cross
  - Social arms of the major churches
  - NGOs with local presence
  - etc.

- They would be in charge of the local distribution
- They have the manpower, the knowledge of local conditions, and have the trust of the population
Research in Progress at the Humanitarian Logistics Group at Rensselaer
Our approach

- Multi disciplinary
  - Social Scientists
  - Transportation Modelers
  - Economists
  - Logisticians

- Multifaceted
  - Field work and Characterization
  - Mathematical modeling
Research in progress at Rensselaer

- Diagnosis and characterization:
  - How humanitarian logistics take place (real life studies)
  - Quantification:
    - Aimed at obtaining empirical estimates
    - Provide support to analytical modeling
    - Immediate resource requirements, donation patterns

- Basic research on analytical modeling
  - Considering social costs of logistic actions
  - Incorporating Material Convergence
Developed models to forecast immediate resource requirements

Water and ice (Aug 28 - Sept 28)

Food, MREs (Aug 28 - Sept 22)
Material Convergence is Explainable (Destro)

### Monetary donations (nonlinear model)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance in miles from donation origins to impacted area</td>
<td>9.917</td>
<td>12.61</td>
</tr>
<tr>
<td>Ratio of Population 25+ years with high school to Population 25+</td>
<td>-0.832</td>
<td>-7.20</td>
</tr>
<tr>
<td>Family income per capita for organization headquarters</td>
<td>0.333</td>
<td>21.72</td>
</tr>
<tr>
<td>Percentage of civilian unemployed population in labor force 16+ years located in the Midwest region</td>
<td>-0.317</td>
<td>-2.13</td>
</tr>
<tr>
<td>Constant</td>
<td>9.917</td>
<td>12.61</td>
</tr>
</tbody>
</table>

F = 144.75, $R^2 = 44.6\%$, $R^2_{Adj} = 44.3\%$, n = 724

### In-kind donations (nonlinear model)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance in miles from donation origins to impacted area</td>
<td>-0.433</td>
<td>-3.76</td>
</tr>
<tr>
<td>Donors that are Organization Headquarters</td>
<td>3.181</td>
<td>16.28</td>
</tr>
<tr>
<td>Ratio of Population &lt; 20 years to Total Population</td>
<td>-0.525</td>
<td>-2.39</td>
</tr>
<tr>
<td>Median rent</td>
<td>0.298</td>
<td>4.75</td>
</tr>
<tr>
<td>Percentage of civilian unemployed population in labor force 16+ years</td>
<td>-0.278</td>
<td>-3.32</td>
</tr>
<tr>
<td>Population density of the Midwest region</td>
<td>0.201</td>
<td>2.17</td>
</tr>
<tr>
<td>Constant</td>
<td>9.511</td>
<td>11.17</td>
</tr>
</tbody>
</table>

F = 57.93, $R^2 = 39.6\%$, $R^2_{Adj} = 38.9\%$, n = 537
Material Convergence and Optimal Allocation of Resources During Emergencies (Jaller)

\[
\begin{align*}
\text{MAX} & \left( Z_{\text{HP}}^{T-N_{1,j,l}, N_{T,j,l}, \lambda_{H}, \lambda_{N}, \lambda_{N}, \phi_{H}, \phi_{N}, \lambda_{N}, \lambda_{N}, I_{1,j,l}} \right) = \Pi(\bullet) - \Omega(\bullet) \\
\Pi(H_{\text{HP}}^{T-N_{1,j,l}, N_{T,j,l}, \lambda_{H}, \lambda_{N}, \lambda_{N}, \phi_{H}, \phi_{N}, \lambda_{N}, \lambda_{N}, I_{1,j,l}}) & = \pi_{\text{HP}} \sum_{j,l} \left( S_{j,l}^{\text{HP}} + S_{j,l}^{N,\text{HP}} \right) + \pi_{\text{LP}} \left( \sum_{j,l} \lambda_{j,l}^{N} N_{j,l}^{T} \left( 1 - \phi_{\text{HP}} \right) + \sum_{l,j,l} \lambda_{j,l}^{N} N_{l,j,l}^{T} \left( 1 - \phi_{\text{HP}} \right) \right) \\
\Omega(H_{\text{HP}}^{T-N_{1,j,l}, N_{T,j,l}, \lambda_{H}, \lambda_{N}, \lambda_{N}, \phi_{H}, \phi_{N}, \lambda_{N}, \lambda_{N}, I_{1,j,l}}) & = \sum_{j,l} \left( ( 1 - \lambda_{j,l}^{H} ) H_{\text{HP}}^{T} \phi_{j}^{H, T} + ( 1 - \lambda_{j,l}^{N} ) N_{j,l}^{T} \phi_{j}^{N, T} + \delta_{j,l}^{\text{HP}} I_{j,l}^{\text{HP}} + \delta_{j,l}^{N,\text{HP}} I_{j,l}^{N,\text{HP}} \right) \\
& + \sum_{j,l} \left( \delta_{j,l}^{N,\text{LP}} \lambda_{j,l}^{N} N_{j,l}^{T} \left( 1 - \phi_{\text{HP}} \right) + c_{j}^{\text{HP}} y_{j}^{\text{HP}} + c_{j}^{N} y_{j}^{N} \right) \\
& + \sum_{j,l} \left( ( 1 - \lambda_{j,l}^{N} ) N_{l,j,l}^{T} \phi_{l}^{N, T} + \delta_{j,l}^{N,\text{LP}} \lambda_{j,l}^{N} N_{l,j,l}^{T} \left( 1 - \phi_{\text{HP}} \right) + c_{l}^{N} y_{l}^{N} + c_{j}^{K} k_{j}^{l} \right)
\end{align*}
\]

\[\begin{align*}
\text{Subject to:} \\
& c_{j}^{\text{HP}} \sum_{j} y_{j}^{\text{HP}} + c_{l}^{N} \sum_{l} y_{l}^{N} + c_{j}^{N} \sum_{j} y_{j}^{N} \leq B_{t}, \forall t \\
& H_{\text{HP}}^{T} = \sum_{j,l} R_{j,l} + \sum_{j,l} \phi_{j,l}^{H} N_{j,l}^{T} + \left( 1 - \lambda_{j,l}^{H} \right) H_{T}^{T}, \forall j,l \\
& N_{1,j,l}^{T} = \sum_{l} N_{l,j,l} k_{l}^{l} + \left( 1 - \lambda_{j,l}^{N} \right) N_{j,l}^{T}, \forall l, j, t \\
& \left( 1 - \lambda_{j,l}^{N} \right) N_{l,j,l}^{T} + \left( 1 - \lambda_{j,l}^{H} \right) N_{j,l}^{T}, \forall j, l, t \\
& S_{j,l}^{N,\text{HP}} = I_{j,l}^{N,\text{HP}} + \lambda_{j,l}^{N} N_{j,l}^{T} \phi_{j,l}^{H} - I_{j,l}^{N,\text{HP}}, \forall j,l,t \\
& S_{j,l}^{\text{HP}} + S_{j,l}^{N,\text{HP}} \leq D_{j,l}, \forall j,l \\
& \lambda_{j,l}^{H} H_{j,l}^{T} \phi_{j,l}^{H} \left( y_{j,l}^{H} \right) \leq H, \forall j,l \\
& \lambda_{j,l}^{N} \sum_{l} N_{l,j,l}^{T} \phi_{l}^{N, T} \left( y_{l}^{N} \right) \leq H, \forall l, j, t \\
& \lambda_{j,l}^{N} N_{j,l}^{T} \phi_{j,l}^{N, T} \left( y_{j,l}^{N} \right) \leq H, \forall j, l, t
\end{align*}\]
Inventory Allocation and Distribution Considering Social Costs (Perez)

Minimize \[ \sum_{m \in M} \sum_{k \in K} \sum_{t} \sum_{c \in C} \sum_{i} \sum_{j}^{m} \tau_{ij} \cdot \phi_{ij}^{km} + \sum_{c \in C} \sum_{i} \sum_{j}^{m} \phi_{ij}^{km} \cdot P_{i,j-1} \cdot (1 - \alpha_{ci,i-1}) \cdot \Gamma(t - t'_{ci,i-1}) \]

+ \[ \sum_{c \in C} \sum_{i} \sum_{j}^{m} \alpha_{ci} \cdot (1 - \alpha_{ci,i}) \cdot \Gamma(T - T'_{ci,i}) \]  

s.t.

\[ I_{ci,t-1} + a^S_{ci} = I_{ci,tn} + \sum_{m \in M} \sum_{k \in K} \sum_{A_{m}} \sum_{i} \sum_{j}^{m} x_{ijt} \quad \forall i \in SN, c \in C, t \in 1...T \]  

\[ I_{ci,t-1} + a^S_{ci} + \sum_{m \in M} \sum_{k \in K} \sum_{A_{m}} \sum_{i} \sum_{j}^{m} x_{ijt} \cdot P_{i,j} \cdot \alpha_{ci,j-1} = I_{ci,tn} + \sum_{m \in M} \sum_{k \in K} \sum_{A_{m}} \sum_{j}^{m} x_{ijt} \quad \forall i \in DN, c \in C, t \in 1...T \]  

\[ \phi_{ij,t} \cdot q_{c} \leq x_{ijt}^{ckm} \quad \forall c \in C, (i, j) \in A_{m} : j \in DN, m \in M, k \in K, t \in 1...T \]  

\[ I_{ci} - u_{c} \left( P_{ci} - \frac{1}{2} \right) \leq \alpha_{ci} \cdot B \quad \forall i \in DN, c \in C, t \in 1...T \]  

\[ (u_{c} \cdot P_{ci}) \alpha_{ci} \leq I_{ci} \quad \forall i \in DN, c \in C, t \in 1...T \]  

\[ \sum_{m \in M} \sum_{k \in K} \sum_{A_{m}}^{j} \sum_{i} \sum_{j}^{m} x_{ijt} \cdot P_{i,j} \cdot \alpha_{ci,j-1} \leq \phi_{ci,t} \cdot B \quad \forall c \in C, i \in DN, t \in 1...T \]
Inventory Allocation and Distribution (Cont.)

\[ (u_c P_a) \phi_{cit} \leq \sum_{m \in M} \sum_{k \in K} \sum_{(j,i) \in A_m} x_{ckm} \sum_{j,i,t} \sum_{m} \phi_{cit} \quad \forall \ c \in C, i \in DN, t \in 1..T \]  \hspace{1cm} (8)

\[ t'_{cit} = t'_{ci,t-1} + \alpha_{cit} (t - t'_{ci,t-1}) \quad \forall \ c \in C, i \in DN, t \in 1..T \]  \hspace{1cm} (9)

\[ t_0 \phi_{cit} - t'_{ci,t-1} \leq t_{c}^{\text{max}} \quad \forall \ c \in C, i \in DN, t \in 1..T \]  \hspace{1cm} (10)

\[ \sum_{(j,i) \in A_m} v_{km}^{klm} \leq 1 \quad \forall \ i \in N, t \in 1..T, k \in K, m \in M \]  \hspace{1cm} (11)

\[ \sum_{(i,j) \in A_m} v_{km}^{klm} \leq 1 \quad \forall \ i \in N, t \in 1..T, k \in K, m \in M \]  \hspace{1cm} (12)

\[ \sum_{u=1}^{u_{zt}} \left[ z_{lu}^{km} + \sum_{(j,i) \in A_m} v_{klm}^{jkm} \right] - \sum_{u=1}^{u_{zt-1}} \sum_{(i,j) \in A_m} v_{lmu}^{lkm} \geq \sum_{(i,j) \in A_m} \varphi_{lmu}^{lkm} \]  \hspace{1cm} \forall \ i \in N, t \in 1..T, k \in K, m \in M \]  \hspace{1cm} (13)

\[ \sum_{c} w_c x_{ij}^{ckm} - Q_{ij}^{km} \varphi_{ij}^{km} \leq 0 \quad \forall (i, j) \in A_m, c \in C, k \in K_m, m \in M, t \in 1..T \]  \hspace{1cm} (14)

\[ x_{ij}^{ckm} \geq 0, I_{cit} \geq 0, t'_{ci,t-1} \geq 0, \alpha_{cit} = \text{binary}, \phi_{cit} = \text{binary}, \varphi_{ij}^{km} = \text{binary} \]  \hspace{1cm} (15)
The traditional method minimizes penalties by delivering to distant nodes as late as possible within the delivery window, thus increasing the social costs to the system.

High social costs for the traditional method due to the timing of the deliveries to distant nodes.

Considering social costs in the routing strategy minimizes the impact (suffering) on victims.
Conclusions

- There is an urgent need to reformulate Humanitarian Logistics so that it appropriately considers a proper metric of human suffering and material convergence.
- Explicit consideration of social costs leads to different delivery strategies than the ones produced by formulations inspired by private logistics.
- Explicit consideration of Material Convergence is critical to ensure an efficient flow of critical supplies.
Questions?
### Input parameters:

- **$T$**: length of the planning horizon
- **$N$**: set of all nodes in the network
- **$DN$**: set of demand and transshipment nodes, $DN \subset N$
- **$SN$**: set of supply nodes, e.g., warehouses, depots and distribution centers, $SN \subset N$
- **$A_m$**: set of arcs linking nodes in the transportation network for mode $m \in M$
- **$C$**: set of commodities to be distributed
- **$M$**: set of transportation modes
- **$K_m$**: set of vehicle types for transportation mode $m \in M$
- **$u_c$**: consumption rate, i.e., standard amount of commodity type $c \in C$ required to sustain an affected person for one unit of time
- **$\tau_{ij}^m$**: travel time required to traverse arc $(i, j) \in A_m$ by transportation mode $m \in M$
- **$t_{c}^{\text{max}}$**: maximum deprivation time a person could survive without commodity $c \in C$
- **$P_i$**: population (number of victims) in node $i \in DN$ at time $t$
- **$q_c$**: minimum delivery quantity for commodity $c \in C$
- **$Q_{km}$**: load capacity for vehicle type $k \in K_m$, mode $m \in M$
- **$c_{km}$**: travel cost per unit of time for vehicle type $k \in K_m$, mode $m \in M$
- **$w_c$**: unit weight of commodity $c \in C$
- **$\delta_{cm}$**: amount of commodity $c \in C$ added from external sources (e.g., donations) to node $i \in N$ at time $t$
- **$B$**: a big number

#### Definitions:

- **$v_{km}^{\text{in}_i}$**
  - 1 if vehicle $k \in K_m$ of mode $m \in M$ is located at node $i \in N$ at time $t = 0$
  - 0 otherwise

- **$z_{km}^{\text{in}_i}$**
  - 1 if vehicle $k \in K_m$ of mode $m \in M$ is added to the fleet at node $i \in N$ at time $t$
  - 0 otherwise
Decision variables:

\[ x_{ijt}^{ckm} : \text{amount of commodity type } c \in C \text{ shipped from node } i \text{ to node } j \text{ at time } t, \]
\[ \text{using vehicle } k \in K_m \text{ of transportation mode } m \in M \]

\[ I_{cit} : \text{inventory level, i.e., amount of commodity type } c \text{ carried over from time } t \]
\[ \text{to time } t+1 \text{ at node } i \]

\[ t'_{cit} : \text{last time at which people in node } i \in DN\text{ consumed commodity } c \in C \]
\[ \text{previous to current time } t. \]

\[ \alpha_{cit} \begin{cases} 
1 & \text{if } I_{cit} \geq u_c P_{ct} \text{ (node } i \text{ has enough inventory of commodity } c \text{ for at least on)} \\
0 & \text{otherwise (a shortage for commodity } c \in C) \end{cases} \]

\[ \phi_{cit} \begin{cases} 
1 & \text{if commodity } c \text{ arrives to node } i \text{ at time } t \text{ (by any transportation mode)} \\
0 & \text{otherwise} \end{cases} \]

\[ \psi_{ijt}^{km} \begin{cases} 
1 & \text{if vehicle } k \in K_m \text{ leaves from node } i \text{ to destination } j \text{ at time } t; \ (i,j) \in A_m \text{ and } m \in M \\
0 & \text{otherwise} \end{cases} \]
Questions?
Questions?