HUMANITARIAN LOGISTICS IN THE TOHOKU DISASTERS 2011

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1. Introduction
Disasters and Catastrophes

• **Disasters**
  - A limited part of region is impacted by natural events
  - Local supplies exist
  - Private sector can quickly respond to supply
  - Small demands compared with supplies

• **Catastrophes**
  - Major part of region is impacted by natural events
  - Local supplies are minimal
  - Supply chain of private sector is severely impacted and private sector cannot respond for weeks after the event
  - Huge increase in demands of surviving population and response itself (e.g. 80,000 displaced people vs. 5,000 meals per day in Ishinomaki City just after Tohoku EQ)
Humanitarian logistics

• Humanitarian Logistics is defined 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 alleviating the suffering of vulnerable people

(Thomas, 2003)
## Commercial and Humanitarian Logistics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Commercial Logistics</th>
<th>Post-Disaster Humanitarian Logistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Minimization of private (logistics) costs</td>
<td>Minimization of social costs (logistic + deprivation)</td>
</tr>
<tr>
<td>Origination of commodity flows</td>
<td>Self-contained</td>
<td>Impacted by material convergence</td>
</tr>
<tr>
<td>Knowledge of demand</td>
<td>Known with some certainty</td>
<td>Unknown/dynamic, lack of information/access to site</td>
</tr>
<tr>
<td>Decision making structure</td>
<td>Structured interactions controlled by few decision makers</td>
<td>Non-structured interactions, thousands of decision makers</td>
</tr>
<tr>
<td>Periodicity/volume of logistic activities</td>
<td>Repetitive, relatively steady flows, “large” volumes</td>
<td>One in a lifetime events, large pulse, “small” volumes</td>
</tr>
<tr>
<td>Supporting systems (e.g. transportation)</td>
<td>Stable and functional</td>
<td>Impacted and dynamically changing</td>
</tr>
</tbody>
</table>

Source: Holguin-Veras et al, 2012
2. Findings based on the interviews

• Interviews to:
  • Ministry of Land, Infrastructure, Transport and Tourism (Tohoku Regional Office)
  • Prefectures (Iwate, Miyagi, Fukushima)
  • Municipalities (Ishinomaki, Kesennuma)
  • Freight carriers (Yamato, Sagawa)
  • Retailers (Aeon)

• Date:
  • 15 May - 20 May, 29 August - 1 September 2011
Lessons learned (1)

1) The disaster response plans, particularly at the prefecture and city levels, failed to consider and prepare for worst case scenarios as they only focused on small disasters, that they could handle on their own.

2) Not having disaster response plans that, in detail, considered humanitarian logistics hampered public sector response as local officials had to confront the crisis without any guidance about how to proceed.
Lessons learned (2)

3) The lack of training and realistic exercises on humanitarian logistics significantly diminished the effectiveness of the public sector response to the disaster.

4) The lack of technologies and systems to quickly assess the conditions of the transportation network and other critical infrastructure hampered the response process.
Lessons learned (3)

5) The lack of efficient communications with the field was a negative factor in the response that made the assessment of local needs a difficult task.

6) The private sector in the construction, transportation, and retail sectors played a key role in the response as they brought to bear expertise and assets that benefited the response, though in some cases their participation was improvised and unanticipated.
Lessons learned (4)

7) In catastrophic events, the bulk of the relief supplies has to be transported from the outside of the impacted area.

8) The most challenging part of the entire humanitarian logistics process was the local distribution. For that reason, disaster planning must pay special attention to it so that all potential participants are prepared to deal with the challenge.
Lessons learned (5)

9) Lack of fuel (for the return trips) prevented the volunteer participation of numerous trucking companies on the humanitarian logistics effort during the initial days of the crisis

10) Non/low priority donations created a lot of problems as they consumed significant amounts of resources, were not needed, and arrived at a time at which there were more important activities to undertake
3. Modelling relief distribution

Background

- Large scale earthquake
  - 11th March 2011 Great East Japan earthquake disasters
  - M9.0 earthquake and tsunami

Damage to infrastructure
450,000 displaced people
Background

• Large scale earthquake
  • 11th March 2011 Great East Japan earthquake disasters
  • M9.0 earthquake and tsunami

Number of refuge centres

About 2,000 refuge centres at peak

(Source: Cabinet Office)
Background

- Large scale earthquake
  - 11th March 2011 Great East Japan earthquake disasters
  - M9.0 earthquake and tsunami
- Relief distribution of emergency goods to refuge centres

Supporting the life of impacted people, reducing the secondary damage

However…

Insufficient pre-planning, a number of problems
Background

- Large scale earthquake
  - 11th March 2011 Great East Japan earthquake disasters
  - M9.0 earthquake and tsunami

- Relief distribution of emergency goods to refuge centres

- Complicated inventory management
- Shortage of goods, fuel
- Shortage of delivery trucks and drivers

Insufficient pre-planning of relief distribution of emergency goods
Background

- Large scale earthquake
  - 11th March 2011 Great East Japan earthquake disasters
  - M9.0 earthquake and tsunami

- Relief distribution of emergency goods to refuge centres
  - Complicated inventory management
  - Shortage of goods, fuel
  - Shortage of delivery trucks and drivers

- Need to determine the pre-planning of relief distribution in a regional disaster prevention plan identifying the amount of goods, the number of trucks
Background

- Large scale earthquake
  - 11th March 2011 Great East Japan earthquake disasters
  - M9.0 earthquake and tsunami
- Relief distribution of emergency goods to refuge centres
  - Complicated inventory management
  - Shortage of goods, fuel
  - Shortage of delivery trucks and drivers
- Need to determine the pre-planning of relief distribution in a regional disaster prevention plan identifying the amount of goods, the number of trucks
- Mathematical programming models

Quantitative analysis
Mathematical programming models
Analysis
Relief distribution plan
Objectives

Establishing multi-objective optimisation models for improving pre-planning of relief distribution of emergency goods after disasters and applying them in Ishinomaki city cases

(1) Develop multi-objective optimisation models
(2) Evaluate performance of algorithms
(3) Apply in Ishinomaki city cases
(4) Compare calculation results with the reality
(5) Analyse for improving pre-planning
Modelling-1

Starting term
- Push type supply (smaller than needs)
- Self defence force

Active term
- Pull type supply (various needs)
- Private freight carriers and Self defence force

Transition term
- Reducing supply
- Transition to normal situation
  - (~6 months)

Target of modelling

(2,3 days)
Target of modelling

Active terms (after 3 days – 2, 3 months)
Various needs
Various delivery systems

Companies, individuals, municipalities outside the impacted areas

Senders’ depot
Primary depot
Secondary depot
Refuge centres

Nation
Prefecture
Municipality

Flow of information
Flow of emergency goods

Order of sending
Order of sending
Order of sending

Order of sending

request
request
request
request

transport
transport
transport
transport

Less difficult
difficult

Focusing on last mile delivery by trucks

Active terms (after 3 days – 2, 3 months) Various needs Various delivery systems
Objectives of relief distribution of emergency goods

- Allocate appropriate amount of goods to refuge centres

Modelling-2

Target of modelling

- Active term (2.3 days – 2.3 months)
- Last mile delivery by trucks
- Foods (rice ball and bread)

Objectives of relief distribution of emergency goods

- Allocate appropriate amount of goods which are small than demands to refuge centres

Objective function $f_1$

$$\text{Minimize} \sum_{i \in N} p_i (d_i - q_i)$$

Minimising penalty of total shortage of supply

At refuge centre $i$

- $d_i$: demand
- $q_i$: delivered goods
- $p_i$: penalty to shortage of supply (priority)
- $(d_i - q_i)$: shortage of supply

Decision variable
Modelling-2

Target of modelling
- Active term (2,3 days – 2,3 months)
- Last mile delivery by trucks
- Foods (rice ball and bread)
- Last mile delivery by trucks
- Foods (rice ball and bread)

Objectives of relief distribution of emergency goods
- Allocate appropriate amount of goods to refuge centres

Objective function $f_1$

Minimize $\sum_{i \in N} p_i (d_i - q_i)$

Minimising penalty of total shortage of supply

Number of trucks and visiting order to reduce fuel consumption

Objective function $f_2$

Minimize $\sum_{k \in K} \sum_{(i,j) \in A} c_{ij} x_{ijk} / E_k$

Minimising total fuel consumption

Allocate appropriate amount of goods which are smaller than demands to refuge centres

Decision variable $x_{ijk}$: distance travelled

: fuel efficiency
Formulation

\[ Z_{opt} = \text{Minimize} \left\{ \sum_{i \in N} p_i (d_i - q_i), \sum_{k \in K} \sum_{(i,j) \in A} c_{ij} x_{ijk} / E_k \right\} \]

Subject to

\[ \sum_{k \in K} \sum_{j \in V} x_{ijk} = 1 \quad \forall i \in N, \]

\[ \sum_{j \in V} x_{ijk} \leq 1 \quad \forall k \in K, \]

\[ \sum_{i \in N} q_i \sum_{j \in V} x_{ijk} \leq Q \quad \forall k \in K, \]

\[ \sum_{i \in N} q_i \leq T \quad \forall k \in K, \]

\[ q_{\text{min}} \leq q_i \leq d_i \]

Non-Dominated Sorting Genetic Algorithms (NSGA-II) for multi-objective optimisation

Penalty for total shortage of supply

Total fuel consumption

Total supply in impacted area

Minimum delivery to refuge centre

Integer
Case studies

- Target area: Ishinomaki city

**Obtain lessons learned from Great Tohoku Disasters**
- Analyse number of trucks and location of depot
- Compare calculation results and reality

**Obtain knowledge useful for the future disaster prevention plan**
- Assume some impacts
- Present effective relief distribution under the shortage of goods and fuels
Setting of case 1

Road network

- Shortest path between refuge centres on Ishinomaki road network
- Almost same as the roads where trucks can pass on 31st March
Setting of case 1

Road network
- Shortest path between refuge centres on Ishinomaki road network
- Almost same as the roads where trucks passed on 31st March

Refuge centres
- 21st March: 110,419,922 displaced people
- 11th April: 152,309,930 displaced people

Demand was assumed to be 3 meals for each person
Setting of case 1

- **Road network**
  - Shortest path between evacuation centers (distance)
  - As of March 31, the accessible roads are almost the same.

- **Location of depot**
  - 3 candidates
    - Sport park, former vegetable market, Ushio house

- **Evacuation centers**, needs:
  - March 21: 110 locations, 41,922 people, needs 125,766 items
  - April 11: 152 locations, 30,930 people, needs 92,790 items

JSDF and private freight carrier used this depot. After the sport park was closed, a private freight carrier used this depot. The hypothetical depot was also set.
Setting of case 1

Road network
- Shortest path between refuge centres on Ishinomaki road network
- Almost same as the roads where trucks can pass on 31st March

Refuge centres
- 21st March: 110, 41,922 displaced people
- 11th April: 152, 30,930 displaced people

Location of deport
- 3 candidates
- Sport park, former vegetable market, Ushio house ground
Planning of delivery trucks (case1)

How many trucks of what capacity…
Planning of location of depots (case 1)

Where and how many depots….
Results-1 (case1)

Analysis of capacity of trucks

- **Penalty of total shortage of supply**
- **Total fuel consumption**
- **Number of trucks**

<table>
<thead>
<tr>
<th>Trucker Capacity</th>
<th>Total Fuel Consumption (mL)</th>
<th>Penalty of Total Shortage of Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ton truck</td>
<td>45,000</td>
<td>65,000</td>
</tr>
<tr>
<td>4 ton truck</td>
<td>40,000</td>
<td>55,000</td>
</tr>
<tr>
<td>10 ton truck</td>
<td>35,000</td>
<td>45,000</td>
</tr>
</tbody>
</table>

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Results-2 (case 1)

Analysis on the location of depots

- Penalty of total shortage of supply
- Total fuel consumption
- Number of trucks

<table>
<thead>
<tr>
<th>Number of Depots</th>
<th>Total Fuel Consumption (mL)</th>
<th>Penalty of Total Shortage of Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 depot</td>
<td>50,000</td>
<td>30,000</td>
</tr>
<tr>
<td>2 depots</td>
<td>40,000</td>
<td>20,000</td>
</tr>
<tr>
<td>3 depots</td>
<td>30,000</td>
<td>10,000</td>
</tr>
</tbody>
</table>
Comparison of calculation results with reality on the number of trucks

- 1 depot at sport park

Calculation results
- 12 4-ton trucks

Reality
- 20 trucks (JSDF and private freight carrier)
Outline of case studies

- Target area: Ishinomaki city

Obtain knowledge useful for the future disaster prevention plan

- Assume some impacts
- Present effective relief distribution under the shortage of goods and fuels
Setting for case 2

Road network

- Same as case 1

Depots

- 1 depot at sport park

Assume that all residents are impacted

- 50% of residents go to refuge centres (30% in Tohoku disasters)
- 44 refuge centres including elementary schools, high schools, hospitals and old people’s home
Sufficiency rate

Sufficiency rate $s_i(\%)$: rate of satisfaction of demand at refuge centre $i$

- $s_i$: sufficiency rate at refuge centre $i$
- $q_i$: supply at refuge centre $i$
- $d_i$: demand at refuge centre $i$

$s_i = \frac{q_i}{d_i} \times 100$
Case 2

Case 2-0
Amount of goods proportional to the number of displaced people

Case 2-1
Amount of goods based on priority

Case 2-2
Analysis for multi-terms (4 days)
Case 2-0

- Deliver emergency goods proportional to the number of displaced people

Sufficiency rate is 44.2% for all refuge centres.
Case 2-1

• Determine the amount of delivery $q_i$ based on the priority rate
• The priority rate $p_i$ is ….

- Hospital, old people’s home: 1.2
- Ordinary refuge centres in the affected area by tsunami: 1.1
- Other ordinary refuge centres: 1.0

Legend
Penalty of total shortage of supply
Case 2-1

- Determine amount of delivery $q_i$ based on the priority
- Set the priority rate: $p_i$
- Objective function

Both objective function decreased
Case 2-1

- Determine the amount of goods $q_i$ delivered based on priority
- Set the priority $p_i$
- The objective function value decreased

There are refuge centres whose sufficiency rate is less than 20%
Case 2-2

- Set the sufficiency rate for the next day based on sufficiency at the current day

### Rule for determining the priority

<table>
<thead>
<tr>
<th>Sufficiency rate for the current day (%)</th>
<th>Priority for the next day</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0~20.0</td>
<td>1.2 Hospital, Old peoples’ home</td>
</tr>
<tr>
<td>20.0~40.0</td>
<td>1.2 Hospital, Old peoples’ home</td>
</tr>
<tr>
<td>40.0~60.0</td>
<td>1.2 Hospital, Old peoples’ home</td>
</tr>
<tr>
<td>60.0~80.0</td>
<td>1.2 Hospital, Old peoples’ home</td>
</tr>
<tr>
<td>80.0~100.0</td>
<td>1.2 Hospital, Old peoples’ home</td>
</tr>
</tbody>
</table>
Case 2-2 (day 1)

Sufficiency rate (Day 1)
Case 2-2 (day 2)

Sufficiency rate (Day 2)
Case 2-2 (day 4)

Sufficiency rate (Day4)

Eiichi Taniguchi, Kyoto University
No refuge centres whose sufficiency rate is under 20%.

Sufficiency rate for 4 days

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Case 2-2 (Change of priority and amount of goods delivered)

Delivering goods reflecting the priority has been achieved

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Case 2-2 (Sufficiency rate for 4 days)

The sufficiency rate for 4 days is:

- High in hospitals and old people’s home
- Average in ordinary refuge centres
Case 2-2 (total fuel consumption during 4 days)

Total fuel consumption can be reduced while keeping good sufficiency rate.

Reduction by 23%
4. Conclusion

• It is important to highlight:
  • the need to bring large amounts of outside resources to the impacted area to satisfy the needs of survivors and the response process
  • the importance of prepositioning critical supplies
  • the magnitude and complexity of the humanitarian logistics challenge and particularly of the local distribution, undoubtedly the most difficult part
Conclusion

• the necessity to integrate all segments of society—the military, public sector, the various strata of the private sector—to ensure the most efficient response permitted by the circumstances

• the need to proactively manage and control the flows of non/low/high priority supplies that accompany large disasters

• The failure to prepare for the worst case scenario hampered the ability of all layers of government to respond to the challenge
Conclusion

• Catastrophic events require humanitarian logistics that are orders of magnitude larger and more complex than the ones required in, the more frequent, smaller disasters

• The importance of proper and effective donation management
Conclusion

- Regarding relief distribution of emergency goods after disasters
  - We developed multi-objective optimisation models
  - Applied to Ishinomaki city which was impacted by the Great Tohoku disasters
  - Comparison between calculation results and reality
  - Applied to problems considering the state of destruction
    - Appropriate allocation of delivering goods to refuge centres in the condition of shortage of supply
    - Can decrease fuel consumption keeping the sufficiency of refuge centres
    - Possible to apply these models in the impacted areas with the fuel consumption constraint