An Integrated Disaster Relief Supply Chain Network Model With Time Targets and Demand Uncertainty

Anna Nagurney[1]
John F. Smith Memorial Professor
Amir H. Masoumi[2]
Assistant Professor
and
Min Yu[3]
Assistant Professor

1 - Department of Operations and Information Management
Isenberg School of Management, University of Massachusetts, Amherst, MA 01003

2 - Department of Management & Marketing
School of Business, Manhattan College, Riverdale, NY 10471

3 - Operations & Technology Management Group
Pamplin School of Business Administration, University of Portland, Portland, OR 97203

Outlook

- Background and Introduction
- Integrated Network Model for Disaster Relief Supply Chains
- Numerical Example and Results
- Summary and Conclusion

Background: Natural Disasters

The number of natural disasters and the sizes of the populations affected by such events have been growing (Schultz, Koenig, and Noji (1996) and Nagurney and Qiang (2009)).

Background: Natural Disasters

The number of natural disasters and the sizes of the populations affected by such events have been growing (Schultz, Koenig, and Noji (1996) and Nagurney and Qiang (2009)).

Scientists are warning that we can expect more frequent extreme weather events in the future.

Background: Natural Disasters

The number of natural disasters and the sizes of the populations affected by such events have been growing (Schultz, Koenig, and Noji (1996) and Nagurney and Qiang (2009)).

Scientists are warning that we can expect more frequent extreme weather events in the future.

For instance, tropical cyclones which include hurricanes in the US are expected to be stronger as a result of global warming (Sheppard (2011) and Borenstein (2012)).

Background: Natural Disasters

The amount of damage and loss following a disaster depends on the vulnerability of the affected region, and on its ability to respond (and recover) in a timely manner, also referred to as resilience.

Background: Natural Disasters

The amount of damage and loss following a disaster depends on the vulnerability of the affected region, and on its ability to respond (and recover) in a timely manner, also referred to as resilience.

Hence, being prepared against potential disasters leads to reduced vulnerability and a lower number of fatalities.

Background: Natural Disasters

The amount of damage and loss following a disaster depends on the vulnerability of the affected region, and on its ability to respond (and recover) in a timely manner, also referred to as resilience.

Hence, being prepared against potential disasters leads to reduced vulnerability and a lower number of fatalities.

"During a natural disaster, one has only two options: **to become a victim, or to become a responder**" (Alvendia-Quero (2012)).

Background: Disaster Relief Supply Chains

The *complexity* of disaster relief supply chains originates from *several inherent factors*:

- **Large demands** for relief products,
- Level of **uncertainty**,
- **Irregularities** in the size, the timing, and the location of relief product demand patterns,
- Disaster-driven supply chains are typically **incident-responsive**, and
- Develop new networks of relationships within **days** or even **hours**, and have very **short life-cycles**.

Background: Criticality of *Time*

TIME plays a substantial role in the construction and operation of disaster relief networks.

Background: Criticality of *Time*

TIME plays a substantial role in the construction and operation of disaster relief networks.

FEMA's key benchmarks in response and recovery:

- To meet the survivors initial demands within 72 hours,
- To restore basic community functionality within 60 days, and
- To return to as normal of a situation within 5 years.

Relevant Literature

- Okuyama, Y. (2003). Economics of natural disasters: A critical review. Paper presented at the 50th North American Meeting, Regional Science Association International Philadelphia, Pennsylvania.
- Beamon, B., Kotleba, S. (2006) Inventory management support systems for emergency humanitarian relief operations in South Sudan. *International Journal of Logistics Management* 17(2), 187–212.
- Tzeng, G.-H., Cheng, H.-J., Huang, T. (2007) Multi-objective optimal planning for designing relief delivery systems. *Transportation Research E* 43(6), 673–686.
- Nagurney, A., Qiang, Q. (2009) *Fragile Networks: Identifying Vulnerabilities and Synergies in an Uncertain World*. John Wiley & Sons, Hoboken, New Jersey.

- Sheu, J.-B. (2010) Dynamic relief-demand management for emergency logistics operations under large-scale disasters. *Transportation Research E* 46, 1–17.

- Nagurney, A., Yu, M., Qiang, Q. (2011) Supply chain network design for critical needs with outsourcing. *Papers in Regional Science* 90(1), 123–143.

- Ortuño, M.T., Tirado, G., Vitoriano, B. (2011) A lexicographical goal programming based decision support system for logistics of humanitarian aid. *TOP* 19(2), 464–479.

- Qiang, Q., Nagurney, A. (2012) A bi-criteria indicator to assess supply chain network performance for critical needs under capacity and demand disruptions. *Transportation Research A* 46(5), 801–812.

- Nagurney, A., Masoumi, A., Yu, M. (2012) Supply chain network operations management of a blood banking system with cost and risk minimization. *Computational Management Science* 9(2), 205–231.

- Rottkemper, B., Fischer, K., Blecken, A. (2012) A transshipment model for distribution and inventory relocation under uncertainty in humanitarian operations. *Socio-Economic Planning Sciences* 46, 98–109.

- Huang, M., Smilowitz, K., Balcik, B. (2012) Models for relief routing: Equity, efficiency and efficacy. *Transportation Research E* 48, 2-18.

- Ortuño, M. T., Cristóbal, P., Ferrer, J. M., Martín-Campo, F. J., Muñoz, S., Tirado, G., Vitoriano, B. (2013) Decision aid models and systems for humanitarian logistics: A survey. In *Decision Aid Models for Disaster Management and Emergencies*, Atlantis Computational Intelligence Systems, vol. 7, Vitoriano, B., Montero, J., Ruan, D., Editors, Springer Business + Science Media, New York, 17–44.

Mathematical Model

We propose an integrated supply chain network model for disaster relief.

Mathematical Model

We propose an integrated supply chain network model for disaster relief.

Our mathematical framework is of system-optimization type where the organization aims to satisfy the uncertain demands subject to the minimization of total operational costs while the sequences of activities leading to the ultimate delivery of the relief good are targeted to be completed within a certain time.

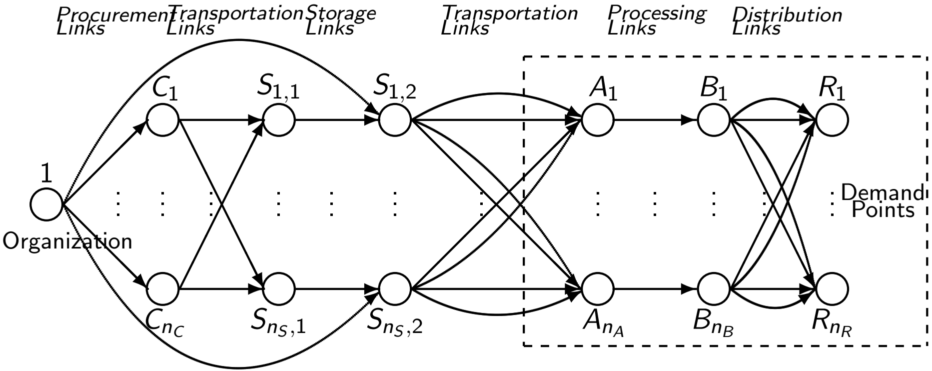

Figure 1: Network Topology of the Integrated Disaster Relief Supply Chain

$G = [N, L]$: supply chain network graph,

N: set of nodes,

L: set of links (arcs).

Mathematical Model

Notations:
$\mathcal{P}_k$: set of paths connecting the origin (node 1) to demand point k,
$\mathcal{P}$: set of all paths joining the origin node to the destination nodes, and
n_p: total number of paths in the supply chain.

Mathematical Model

Notations:
$\mathcal{P}_k$: set of paths connecting the origin (node 1) to demand point k,
$\mathcal{P}$: set of all paths joining the origin node to the destination nodes, and
n_p: total number of paths in the supply chain.

Total Operational Cost Function

$$\hat{c}_a(f_a) = f_a \times c_a(f_a), \qquad \forall a \in L, \tag{1}$$

where:
f_a: flow of the disaster relief product on link a, and
$c_a(f_a)$: unit operational cost function on link a.

Probability Distribution of Demand

$$P_k(D_k) = P_k(d_k \leq D_k) = \int_0^{D_k} \mathcal{F}_k(t)dt, \qquad k = 1, \ldots, n_R, \qquad (2)$$

where:

d_k: actual value of demand at point k,

P_k: probability distribution function of demand at point k,

$\mathcal{F}_k$: probability density function of demand at point k.

Probability Distribution of Demand

$$P_k(D_k) = P_k(d_k \leq D_k) = \int_0^{D_k} \mathcal{F}_k(t)dt, \qquad k = 1, \ldots, n_R, \qquad (2)$$

where:

d_k: actual value of demand at point k,

P_k: probability distribution function of demand at point k,

$\mathcal{F}_k$: probability density function of demand at point k.

Demand Shortage and Surplus

$$\Delta_k^- \equiv \max\{0, d_k - v_k\}, \qquad k = 1, \ldots, n_R, \qquad (3a)$$

$$\Delta_k^+ \equiv \max\{0, v_k - d_k\}, \qquad k = 1, \ldots, n_R, \qquad (3b)$$

where:

v_k: “projected demand” for the disaster relief item at point k.

Expected Values of Shortage and Surplus

$$E(\Delta_k^-) = \int_{v_k}^{\infty} (t - v_k)\mathcal{F}_k(t)dt, \qquad k = 1, \ldots, n_R, \tag{4a}$$

$$E(\Delta_k^+) = \int_{0}^{v_k} (v_k - t)\mathcal{F}_k(t)dt, \qquad k = 1, \ldots, n_R. \tag{4b}$$

Expected Values of Shortage and Surplus

$$E(\Delta_k^-) = \int_{v_k}^{\infty} (t - v_k)\mathcal{F}_k(t)dt, \qquad k = 1, \ldots, n_R, \qquad (4a)$$

$$E(\Delta_k^+) = \int_{0}^{v_k} (v_k - t)\mathcal{F}_k(t)dt, \qquad k = 1, \ldots, n_R. \qquad (4b)$$

Expected Penalty due to Shortage and Surplus

$$E(\lambda_k^-\Delta_k^- \;+\; \lambda_k^+\Delta_k^+) = \lambda_k^- E(\Delta_k^-) + \lambda_k^+ E(\Delta_k^+), \qquad k = 1, \ldots, n_R, \quad (5)$$

where:

λ_k^-: unit penalty associated with the shortage of the relief item at point k,

λ_k^+: unit penalty associated with the surplus of the relief item at point k.

Path Flows

$$x_p \geq 0, \qquad \forall p \in \mathcal{P}. \tag{6}$$

x_p: flow of the disaster relief goods on path p joining node 1 with a demand node.

Path Flows

$$x_p \geq 0, \qquad \forall p \in \mathcal{P}. \tag{6}$$

x_p: flow of the disaster relief goods on path p joining node 1 with a demand node.

Relationship between Path Flows and Projected Demand

$$v_k \equiv \sum_{p \in \mathcal{P}_k} x_p, \qquad k = 1, \ldots, n_R. \tag{7}$$

Path Flows

$$x_p \geq 0, \qquad \forall p \in \mathcal{P}. \tag{6}$$

x_p: flow of the disaster relief goods on path p joining node 1 with a demand node.

Relationship between Path Flows and Projected Demand

$$v_k \equiv \sum_{p \in \mathcal{P}_k} x_p, \qquad k = 1, \ldots, n_R. \tag{7}$$

Relationship between Link Flows and Path Flows

$$f_a = \sum_{p \in \mathcal{P}} x_p \ \delta_{ap}, \qquad \forall a \in L. \tag{8}$$

δ_{ap} is equal to 1 if link a is contained in path p and is 0, otherwise.

Capturing Time Aspect in Formulation

Completion Time

$$\tau_a(f_a) = g_a f_a + h_a, \qquad \forall a \in L, \tag{9}$$

where:

τ_a: completion time of the activity on link a. Note: $h_a \geq 0$, and $g_a \geq 0$.

Capturing Time Aspect in Formulation

Completion Time

$$\tau_a(f_a) = g_a f_a + h_a, \qquad \forall a \in L, \tag{9}$$

where:

τ_a: completion time of the activity on link a. Note: $h_a \geq 0$, and $g_a \geq 0$.

Completion Time on Paths

$$\tau_p = \sum_{a \in L} \tau_a(f_a)\delta_{ap} = \sum_{a \in L}(g_a f_a + h_a)\delta_{ap}, \qquad \forall p \in \mathcal{P}. \tag{10}$$

Where:

τ_p: completion time of the sequence of activities on path p.

$$h_p = \sum_{a \in L} h_a \delta_{ap}, \qquad \forall p \in \mathcal{P}. \tag{11}$$

Hence,

$$\tau_p = h_p + \sum_{a \in L} g_a f_a \delta_{ap}, \qquad \forall p \in \mathcal{P}. \tag{12}$$

h_p: sum of the uncongested terms h_as on path p.

$$h_p = \sum_{a \in L} h_a \delta_{ap}, \qquad \forall p \in \mathcal{P}. \tag{11}$$

Hence,

$$\tau_p = h_p + \sum_{a \in L} g_a f_a \delta_{ap}, \qquad \forall p \in \mathcal{P}. \tag{12}$$

h_p: sum of the uncongested terms h_as on path p.

Time Targets

$$\tau_p \leq T_k, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R, \tag{13}$$

T_k: target for the completion time of the activities on paths corresponding to demand point k determined by the organization's decision-maker.

$$\sum_{a \in L} g_a f_a \delta_{ap} \leq T_k - h_p, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{14}$$

$$T_{kp} = T_k - h_p, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{15}$$

T_{kp}: target time for demand point k with respect to path p.

$$\sum_{a \in L} g_a f_a \delta_{ap} \leq T_{kp}, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{16}$$

$$\sum_{a \in L} g_a f_a \delta_{ap} \leq T_k - h_p, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{14}$$

$$T_{kp} = T_k - h_p, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{15}$$

T_{kp}: target time for demand point k with respect to path p.

$$\sum_{a \in L} g_a f_a \delta_{ap} \leq T_{kp}, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{16}$$

Late Delivery (Deviations) with Respect to Target Times

$$\sum_{a \in L} g_a f_a \delta_{ap} - z_p \leq T_{kp}, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{17}$$

z_p: amount of deviation with respect to target time T_{kp} corresponding to the "late" delivery of product to point k on path p.

Non-negativity

$$z_p \geq 0, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{18}$$

Non-negativity

$$z_p \geq 0, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{18}$$

Time Constraint

$$\sum_{q \in \mathcal{P}} \sum_{a \in L} g_a x_q \delta_{aq} \delta_{ap} - z_p \leq T_{kp}, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{19}$$

Non-negativity

$$z_p \geq 0, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{18}$$

Time Constraint

$$\sum_{q \in \mathcal{P}} \sum_{a \in L} g_a x_q \delta_{aq} \delta_{ap} - z_p \leq T_{kp}, \qquad \forall p \in \mathcal{P}_k; \quad k = 1, \ldots, n_R. \tag{19}$$

$$\hat{C}_p(x) = x_p \times C_p(x) = x_p \times \sum_{a \in L} c_a(f_a) \delta_{ap}, \qquad \forall p \in \mathcal{P}, \tag{20}$$

$\hat{C}_p(x)$: total operational cost function on path p.
C_p: unit operational cost on path p.

$\gamma_k(z)$: **tardiness penalty function** corresponding to demand point k.

Optimization Formulation

$$\text{Minimize} \sum_{p \in \mathcal{P}} \hat{C}_p(x) \; + \; \sum_{k=1}^{n_R} (\lambda_k^- E(\Delta_k^-) + \lambda_k^+ E(\Delta_k^+)) + \sum_{k=1}^{n_R} \gamma_k(z), \quad (21)$$

subject to: constraints (6), (18), and (19).

$\gamma_k(z)$: **tardiness penalty function** corresponding to demand point k.

Optimization Formulation

$$\text{Minimize} \sum_{p \in \mathcal{P}} \hat{C}_p(x) + \sum_{k=1}^{n_R} (\lambda_k^- E(\Delta_k^-) + \lambda_k^+ E(\Delta_k^+)) + \sum_{k=1}^{n_R} \gamma_k(z), \quad (21)$$

subject to: constraints (6), (18), and (19).

Feasible Set

$$K = \{(x, z, \omega) | x \in R_+^{n_p}, z \in R_+^{n_p}, \text{ and } \omega \in R_+^{n_p}\}, \quad (23)$$

where x is the vector of path flows, z is the vector of time deviations on paths, and ω is the vector of Lagrange multipliers corresponding to (19).

Variational Inequality Formulation

The optimization problem (21), subject to its constraints (6), (18), and (19), is equivalent to the variational inequality problem: determine the vector of optimal path flows, the vector of optimal path time deviations, and the vector of optimal Lagrange multipliers $(x^*, z^*, \omega^*) \in K$*, such that:*

$$\sum_{k=1}^{n_R} \sum_{p \in \mathcal{P}_k} \left[\frac{\partial \hat{C}_p(x^*)}{\partial x_p} + \lambda_k^+ P_k(\sum_{q \in \mathcal{P}_k} x_q^*) - \lambda_k^- (1 - P_k(\sum_{q \in \mathcal{P}_k} x_q^*)) \right.$$

$$\left. + \sum_{q \in \mathcal{P}} \sum_{a \in L} \omega_q^* g_a \delta_{aq} \delta_{ap} \right] \times [x_p - x_p^*] + \sum_{k=1}^{n_R} \sum_{p \in \mathcal{P}_k} \left[\frac{\partial \gamma_k(z^*)}{\partial z_p} - \omega_p^* \right] \times [z_p - z_p^*]$$

$$+ \sum_{k=1}^{n_R} \sum_{p \in \mathcal{P}_k} \left[T_{kp} + z_p^* - \sum_{q \in \mathcal{P}} \sum_{a \in L} g_a x_q^* \delta_{aq} \delta_{ap} \right] \times [\omega_p - \omega_p^*] \geq 0, \quad \forall (x, z, \omega) \in K, \tag{24}$$

where

$$\frac{\partial \hat{C}_p(x)}{\partial x_p} \equiv \sum_{a \in L} \frac{\partial \hat{c}_a(f_a)}{\partial f_a} \delta_{ap}, \quad \forall p \in \mathcal{P}_k; \; k = 1, \ldots, n_R. \tag{25}$$

Solution Method and Numerical Examples

Solution Algorithm

Explicit Formulae for the Euler Method Applied to the Variational Inequality (24)

At iteration $\tau+1$:

$$x_p^{\tau+1} = \max\{0, x_p^\tau + a_\tau(\lambda_k^-(1 - P_k(\sum_{q\in\mathcal{P}_k} x_q^\tau)) - \lambda_k^+ P_k(\sum_{q\in\mathcal{P}_k} x_q^\tau) - \frac{\partial \hat{C}_p(x^\tau)}{\partial x_p}$$

$$- \sum_{q\in\mathcal{P}} \sum_{a\in L} \omega_q^\tau g_a \delta_{aq}\delta_{ap})\}, \qquad \forall p \in \mathcal{P}_k; \quad k = 1,\ldots,n_R, \tag{31}$$

$$z_p^{\tau+1} = \max\{0, z_p^\tau + a_\tau(\omega_p^\tau - \frac{\partial \gamma_k(z^\tau)}{\partial z_p})\}, \qquad \forall p \in \mathcal{P}_k; \quad k = 1,\ldots,n_R, \text{ and} \tag{32}$$

$$\omega_p^{\tau+1} = \max\{0, \omega_p^\tau + a_\tau(\sum_{q\in\mathcal{P}} \sum_{a\in L} g_a x_q^\tau \delta_{aq}\delta_{ap} - T_{kp} - z_p^\tau\},$$

$$\forall p \in \mathcal{P}_k; \qquad k = 1,\ldots,n_R. \tag{33}$$

A Large Scale Numerical Example

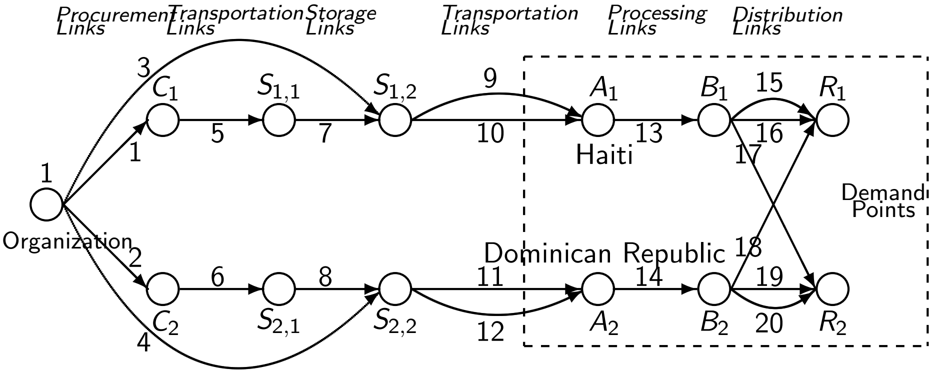

Figure 2: Network Topology of the Larger Disaster Relief Supply Chain Numerical Example

Unit shortage and surplus penalties at demand points R_1 and R_2:

$$\lambda^-_{R_1} = 10,000, \ \lambda^+_{R_1} = 100,$$

$$\lambda^-_{R_2} = 7,500, \ \lambda^+_{R_2} = 150.$$

Target times of delivery at demand points:

$$T_{R_1} = 72, \ T_{R_2} = 70.$$

Tardiness penalty functions at demand points:

$$\gamma_{R_1}(z) = 3(\sum_{p \in \mathcal{P}_{R_1}} z_p^2), \quad \gamma_{R_2}(z) = 3(\sum_{p \in \mathcal{P}_{R_2}} z_p^2).$$

Unit shortage and surplus penalties at demand points R_1 and R_2:

$$\lambda^-_{R_1} = 10,000, \ \lambda^+_{R_1} = 100,$$

$$\lambda^-_{R_2} = 7,500, \ \lambda^+_{R_2} = 150.$$

Target times of delivery at demand points:

$$T_{R_1} = 72, \ T_{R_2} = 70.$$

Tardiness penalty functions at demand points:

$$\gamma_{R_1}(z) = 3(\sum_{p \in \mathcal{P}_{R_1}} z_p^2), \quad \gamma_{R_2}(z) = 3(\sum_{p \in \mathcal{P}_{R_2}} z_p^2).$$

The Euler method (cf.(31)–(33)) for the solution of variational inequality (24) was implemented in FORTRAN on a PC at the University of Massachusetts Amherst. We set the sequence as $\{a^\tau\} = .1(1, \frac{1}{2}, \frac{1}{2}, \ldots)$, and the convergence tolerance was 10^{-6}.

Table 2: Functions and the Optimal Flows on Links in the Numerical Example

Link	$\hat{c}_a(f_a)$	$\tau_a(f_a)$	f_a^*
1	$3f_1^2 + 2f_1$	0	19.22
2	$2f_2^2 + 2.5f_2$	0	20.02
3	$5f_3^2 + 4f_3$	$3f_3 + 3$	0.00
4	$4.5f_4^2 + 3f_4$	$4f_4 + 2$	0.00
5	$f_5^2 + 2f_5$	0	19.22
6	$f_6^2 + .5f_6$	0	20.02
7	$2.5f_7^2 + 3f_7$	0	19.22
8	$3.5f_8^2 + 2f_8$	0	20.02
9	$7f_9^2 + 5f_9$	$2f_9 + 2$	19.22
10	$4f_{10}^2 + 6f_{10}$	$10f_{10} + 6$	0.00
11	$2.5f_{11}^2 + 4f_{11}$	$7.5f_{11} + 5$	0.23
12	$4.5f_{12}^2 + 5f_{12}$	$1.5f_{12} + 1.5$	19.79
13	$2f_{13}^2 + 4f_{13}$	$2f_{13} + 2$	19.22
14	$f_{14}^2 + 3f_{14}$	$1.5f_{14} + 1$	20.02
15	$4f_{15}^2 + 5f_{15}$	$3f_{15} + 3$	13.95
16	$2.5f_{16}^2 + 2f_{16}$	$5f_{16} + 4$	5.28
17	$3f_{17}^2 + 4f_{17}$	$6.5f_{17} + 3$	0.00
18	$4f_{18}^2 + 4f_{18}$	$7f_{18} + 5$	6.85
19	$3f_{19}^2 + 3f_{19}$	$4f_{19} + 5$	5.68
20	$3.5f_{20}^2 + 5f_{20}$	$3.5f_{20} + 4$	7.49

Table 3: Path Definitions, Target Times, Optimal Path Flows, Time Deviations, and Lagrange Multipliers for the Numerical Example

	Path Definition	T_{kp}	x_p^*	z_p^*	ω_p^*
$\mathcal{P}_{R_1}$: Set of Paths Corresponding to Demand Point R_1	$p_1 = (1, 5, 7, 9, 13, 15)$	65	13.95	53.66	321.99
	$p_2 = (1, 5, 7, 9, 13, 16)$	64	5.28	39.23	235.39
	$p_3 = (1, 5, 7, 10, 13, 15)$	61	0.00	19.32	115.90
	$p_4 = (1, 5, 7, 10, 13, 16)$	60	0.00	4.83	28.99
	$p_5 = (2, 6, 8, 11, 14, 18)$	61	0.06	18.67	112.03
	$p_6 = (2, 6, 8, 12, 14, 18)$	64.5	6.79	43.12	258.75
	$p_7 = (3, 9, 13, 15)$	62	0.00	56.66	339.99
	$p_8 = (3, 9, 13, 16)$	61	0.00	42.23	253.39
	$p_9 = (3, 10, 13, 15)$	58	0.00	22.34	134.05
	$p_{10} = (3, 10, 13, 16)$	57	0.00	7.84	47.03
	$p_{11} = (4, 11, 14, 18)$	59	0.00	20.71	124.24
	$p_{12} = (4, 12, 14, 18)$	62.5	0.00	45.24	271.46
$\mathcal{P}_{R_2}$: Set of Paths Corresponding to Demand Point R_2	$p_{13} = (1, 5, 7, 9, 13, 17)$	63	0.00	13.87	83.25
	$p_{14} = (1, 5, 7, 10, 13, 17)$	59	0.00	0.00	0.00
	$p_{15} = (2, 6, 8, 11, 14, 19)$	59	0.13	0.00	0.00
	$p_{16} = (2, 6, 8, 11, 14, 20)$	60	0.04	0.00	0.00
	$p_{17} = (2, 6, 8, 12, 14, 19)$	62.5	5.55	19.91	119.44
	$p_{18} = (2, 6, 8, 12, 14, 20)$	63.5	7.45	22.40	134.43
	$p_{19} = (3, 9, 13, 17)$	60	0.00	16.90	101.41
	$p_{20} = (3, 10, 13, 17)$	56	0.00	0.00	0.00
	$p_{21} = (4, 11, 14, 19)$	57	0.00	0.00	0.00
	$p_{22} = (4, 11, 14, 20)$	58	0.00	0.00	0.00
	$p_{23} = (4, 12, 14, 19)$	60.5	0.00	21.96	131.77
	$p_{24} = (4, 12, 14, 20)$	61.5	0.00	24.48	146.85

Numerical Example: A Variant

We assumed that the organization will now procure the items locally and, hence, the time functions associated with the direct procurement links 3 and 4 are now greatly reduced. The remainder of the input data remains as in the previous example.

As in Table 4, now both the storage links for pre-positioning (links 7 and 8) and for post-disaster procurement (links 3 and 4) have positive flows.

Table 4: Numerical Example Variant - Optimal Link Flows

Link	$\hat{c}_a(f_a)$	$\tau_a(f_a)$	f_a^*
1	$3f_1^2 + 2f_1$	0	12.02
2	$2f_2^2 + 2.5f_2$	0	11.21
3	$5f_3^2 + 4f_3$	$.1f_3 + 1$	7.35
4	$4.5f_4^2 + 3f_4$	$.1f_4 + 1$	8.88
5	$f_5^2 + 2f_5$	0	12.02
6	$f_6^2 + .5f_6$	0	11.21
7	$2.5f_7^2 + 3f_7$	0	12.02
8	$3.5f_8^2 + 2f_8$	0	11.21
9	$7f_9^2 + 5f_9$	$2f_9 + 2$	19.37
10	$4f_{10}^2 + 6f_{10}$	$10f_{10} + 6$	0.00
11	$2.5f_{11}^2 + 4f_{11}$	$7.5f_{11} + 5$	0.24
12	$4.5f_{12}^2 + 5f_{12}$	$1.5f_{12} + 1.5$	19.86
13	$2f_{13}^2 + 4f_{13}$	$2f_{13} + 2$	19.37
14	$f_{14}^2 + 3f_{14}$	$1.5f_{14} + 1$	20.10
15	$4f_{15}^2 + 5f_{15}$	$3f_{15} + 3$	14.04
16	$2.5f_{16}^2 + 2f_{16}$	$5f_{16} + 4$	5.33
17	$3f_{17}^2 + 4f_{17}$	$6.5f_{17} + 3$	0.00
18	$4f_{18}^2 + 4f_{18}$	$7f_{18} + 5$	6.84
19	$3f_{19}^2 + 3f_{19}$	$4f_{19} + 5$	5.72
20	$3.5f_{20}^2 + 5f_{20}$	$3.5f_{20} + 4$	7.53

Summary and Conclusions

A network optimization model was developed for the supply chain management of a disaster relief (humanitarian) organization in charge of procurement and distribution of relief items to a geographic region prone to natural disasters. The model:

Summary and Conclusions

A network optimization model was developed for the supply chain management of a disaster relief (humanitarian) organization in charge of procurement and distribution of relief items to a geographic region prone to natural disasters. The model:

- allows for the integration of two distinct policies by disaster relief organizations: (1) pre-positioning the supplies beforehand (2) procurement of necessary items once the disaster has occurred;

Summary and Conclusions

A network optimization model was developed for the supply chain management of a disaster relief (humanitarian) organization in charge of procurement and distribution of relief items to a geographic region prone to natural disasters. The model:

- allows for the integration of two distinct policies by disaster relief organizations: (1) pre-positioning the supplies beforehand (2) procurement of necessary items once the disaster has occurred;
- includes penalties associated with shortages/surpluses at the demand points with respect to the uncertain demand, and

Summary and Conclusions

A network optimization model was developed for the supply chain management of a disaster relief (humanitarian) organization in charge of procurement and distribution of relief items to a geographic region prone to natural disasters. The model:

- allows for the integration of two distinct policies by disaster relief organizations: (1) pre-positioning the supplies beforehand (2) procurement of necessary items once the disaster has occurred;
- includes penalties associated with shortages/surpluses at the demand points with respect to the uncertain demand, and
- enables prioritizing the demand points based on the population, geographic location, etc., by assigning different time targets.

Thank You!


The Virtual Center for Supernetworks
Supernetworks for Optimal Decision-Making and Improving the Global Quality of Life
Director's Welcome
About the Director
Projects
Supernetworks Laboratory
Center Associates
Media Coverage
What's New
Downloadable Articles
Visuals
Audio/Video
Books
Commentaries & OpEds
The Supernetwork Sentinel
Congratulations & Kudos
Network Models in Economics and Finance Athens, Greece, June 2013
The Virtual Center for Supernetworks is an interdisciplinary center at the Isenberg School of Management that advances knowledge on large-scale networks and integrates operations research and management science, engineering, and economics. Its Director is Dr. Anna Nagurney, the John F. Smith Memorial Professor of Operations Management.
Mission: The Virtual Center for Supernetworks fosters the study and application of supernetworks and serves as a resource on networks ranging from transportation and logistics, including supply chains, and the Internet, to a spectrum of economic networks.
The Applications of Supernetworks Include: decision-making, optimization, and game theory; supply chain management; critical infrastructure from transportation to electric power networks; financial networks; knowledge and social networks; energy, the environment, and sustainability; risk management; network vulnerability, resiliency, and performance metrics; humanitarian logistics and healthcare.
Announcements and Notes
Photos of Center Activities
Photos of Network Innovators
Friends of the Center
Course Lectures
Fulbright Lectures
UMass Amherst INFORMS Student Chapter
Professor Anna Nagurney's Blog
Network Classics
Doctoral Dissertations
Conferences
Journals
Societies
Archive
Announcements and Notes from the Center Director Professor Anna Nagurney
Updated: October 2, 2013
Follow
Professor Anna Nagurney's Blog
RENeW
Research, Education, Networks, and the World: A Female Professor Speaks
Sustaining the Supply Chain
Mathematical Moments Podcast
PBS VIDEO
America Revealed
New Book
Networks Against Time
Photos of Center Activities
The Braess Paradox
Translation
Information
Photos
Publications
You are visitor number
00083477
to the Virtual Center for Supernetworks.
WGBY Connecting Point
Humanitarian Logistics: Networks for Africa
The New York Times
ENERGY FOR TOMORROW CONFERENCE