MODELLING OF SIMPLE RELIEF SUPPLY CHAINS

F.T. Oduro
Department of Mathematics, KNUST, Kumasi, Ghana

David Asamoah
Department of Information Systems and Decision Sciences, KNUST School of Business

Jonathan Annan
Department of Information Systems and Decision Sciences, KNUST School of Business

ABSTRACT

In this paper the modeling problem we focused on has to do with the transportation of assorted commodities by means of appropriate modes of travel from a set of locations which are supply/ demand points of relief supply chain to/from a single location which represents the theatre of a disaster or humanitarian emergency. Our model deals with the simplest generic supply chain configurations of convergent and divergent network structures as well as that of their conjoint network and is formally not different from the linear programming formulation of the transportation problem or more generally the Minimum Cost Network Flow Problem. It is nonetheless a viable and usable alternative to other kinds of multi commodity, multi modal models for disaster management. Beyond this, the purpose of our study is to capture in a model the essential features of (relief) supply chain management (i.e. coordinated information and materials flows over a network) in order to enable implementation of a decision support system.

Keywords: Modelling, Disaster Management, Relief Supply Chain, Supply Chain Management, Network Flow Problem

1. INTRODUCTION

Disaster relief management has become topical in recent times (Kovacs and Spens, 2007). The need for relief organizations to co-operate, integrate, plan and coordinate their activities in a manner that is similar to the commercial supply chain management paradigm (Xu and Beamon, 2006) (termed as Relief Supply Chain Management-RSCM) has been discussed by a number of authors (Price, 2003; Oloruntoba and Gray, 2006). The authors take the viewpoint that a supply chain is basically a network. This of course is a convenient position for the purposes of mathematical modelling or operations research (Altay and Green, 2006). It is also an appropriate position when one considers also the imperatives of supply chain management particularly because of the requirement of chain wide (global) optimization as opposed to sub optimization (Beamon and Chen, 2001). Our position philosophically is that of the systems approach to logistics research (Spens and Kovacs, 2006) and we go further in this vein to propose that supply chain management should be model driven. This makes sense especially if one takes into account management information systems which are virtually indispensable tools of modern supply chains. Thus the RSCM is ideally regarded as driven by a model via the implementation of a computer based decision supply system.

Logistics problems arising from disasters, e.g., drought and earthquakes, in spite of their critical importance have, especially in the area of relief distribution, elicited only a limited amount of related research (Sheu, 2007). Some pioneering studies (Kembell-Cook and Stephenson, 1984; Knott, 1987; Ardekani and Hobeika, 1988; Long and Wood, 1995), have been quite recent and specifically, studies that have involved various linear programming type models (Knott, 1988; Rathi et al., 1992; Fiedrich et al., 2000) have been even more recent. Some of the researchers who have used linear programming tools have generally formulated relief transportation issues as multi-commodity, multi-modal flow problems with time windows (Rathi et al., 1992; Haghani and Oh, 1996; Bannister, 2006). The driving force behind this kind of research has of course been the development of the concept of supply chains and that in turn has been fuelled by the emergence of computer based management information systems. Hence, there has also been a trend to incorporate knowledge-based rules into a linear programming model, particularly with regard to the problem of vehicle scheduling for relief supply to a disaster area (Knott, 1988). This study presents a deterministic static chain-based relief logistics flows in three scenarios applicable during the crucial rescue period after the occurrence of, say, a serious natural disaster. Our models deal with the simplest generic supply chain configurations of convergent and divergent network structures as well as that of the co-joined networks and are formally not different from the linear programming formulation of the transportation problem or more generally the Minimum Cost Network Flow Problem.

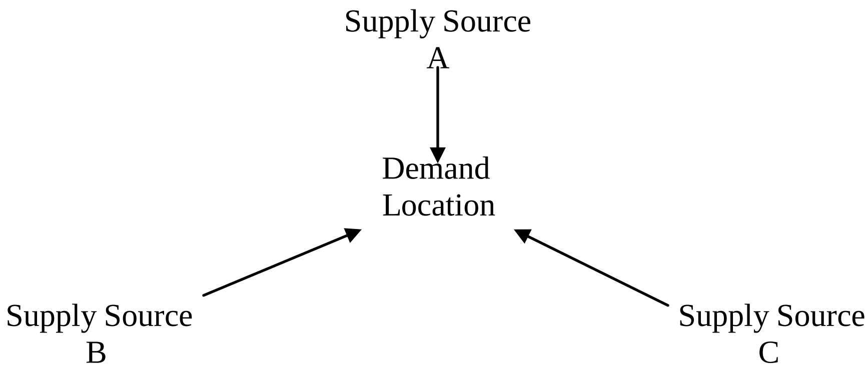
2. THE MODELS

We shall subsequently present the models as follows:
1) A two-layer convergent relief supply chain network
2) A two-layer divergent relief supply chain network
3) A three-layer relief supply network which is the co-joint of the above networks

2.1 A Two-Layer Convergent Relief Supply Chain Network

One of the simplest supply chains is the convergent supply chain network. In the context of commercial supply chains such a configuration is often observed in the manufacturing sector. For the purposes of a relief supply scenario it involves a set of suppliers cooperating with a relief organization to send relief items to a disaster location using various vehicles or modes of transportation.

Figure 2: A Convergent Relief Supply Chain Network



We now convert the above network flow problem into an equivalent one by replacing the capacitated arcs by capacitated nodes linked to the original source nodes. In other words vehicles become destinations in the ensuing transportation problem. The model is detailed as follows:

Decision Variables

X_{ijk} epresents the number of trips of vehicle j , carrying commodities of type k from supply source i to the disaster location.

Parameters

t_{ij} represents the time taken by vehicle type j to travel from the supply source i to the disaster location.

D_{kj} represents the carrying capacity of vehicle type j in respect of commodity type k.

S_{ik} represents the capacity of supply source I in respect of commodity type k.

S_i represents the total capacity in common units of supply source i in respect of all commodity types.

D represents the total demand at the disaster location of in respect of all commodity types.

q_{kj} represents the quantity of commodity type k that can be carried by vehicle type j.

Objective function

Minimize the total travel time $T = \sum_i \sum_j \sum_k t_{ij} X_{ijk}$

Subject to the constraints

$$\sum_j X_{ijk} = S_{ik}$$

$$\sum_i X_{ijk} = D_{jk}$$

Assuming a balanced transportation problem we have

$$\sum_i \sum_j \sum_k q_{jk} X_{ijk} = S = D$$

Where S the total supply from all sources of all commodities is given by

$$\sum_i S_i = S$$

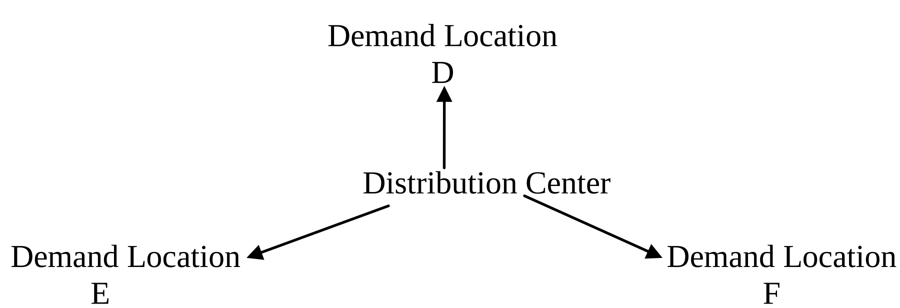
Where $\sum_j \sum_k q_{jk} X_{ijk} = S_i$

The assumption of a balanced transportation problem or a conservation of flow means that if there is in actual fact an excess of demand to supply there will result fictitious of dummy supply sources with total capacities reflecting the shortfall. Similarly, if there is in actual fact an excess of supply to demand there will result fictitious of dummy vehicles with total carrying capacities reflecting the surplus.

2.2 A Two-Layer Divergent Relief Supply Chain Network

Another of the simplest supply chains is the divergent supply chain network. In the context of commercial supply chains it is also often found in the manufacturing sector. For the purposes of relief supply operations, it could involve the distribution of relief items from a single distribution centre directly to locations where they are needed by means of various modes of transportation. It could also represent evacuation of vulnerable persons from a disaster location to various safe havens. Another important scenario could be its use for reverse logistics in accordance with the requirements of a green supply chain (Beamon, 1999; Beamon and Fernandes, 2004; Kovacs, G., 2004; Kovacs and Rikharosson, 2006).

Figure 2: A Divergent Relief Supply Chain Network



As before, we now convert the above network flow problem into an equivalent one by replacing the capacitated arcs by capacitated nodes linked to the original sink nodes. In other words vehicles become origins in the ensuing transportation problem.

The model is detailed as follows:

Decision Variable

Y_{mnp} represents the number of trips of vehicle type m , carrying commodities of type p to the nth demand destination.

Parameters

s_{mn} represents the time taken by vehicle type m to travel from the distribution centre to the nth destination.

C_{mp} represents the carrying capacity of vehicle type m in respect of commodity type p.

R_{np} represents the demand of the nth destination in respect of commodity type p.

R_n represents the total demand in common units of the nth destination in respect of all commodity types.

R represents the total demand at all destinations in respect of all commodity types.

p_{mp} represents the quantity of commodity type p that can be carried by vehicle type m.

Objective function

Minimize the total travel time $T = \sum_m \sum_n \sum_p s_{mn} Y_{mnp}$

Subject to the constraints

$$\sum_m Y_{mnp} = R_{np}$$

$$\sum_n Y_{mnp} = C_{mp}$$

Assuming a balanced transportation problem we have

$$\sum_m \sum_n \sum_p p_{mp} Y_{mnp} = R = C$$

Where R the total demand at all destinations for all commodities and is given by

$$\sum_n R_n = R$$

Where $\sum_j \sum_k p_{mp} Y_{mnp} = R_n$

The assumption of a balanced transportation problem or a conservation of flow means that if there is in actual fact an excess of demand to supply there will result fictitious of dummy vehicles with total capacities reflecting the shortfall. Similarly, if there is in actual fact an excess of supply to demand there will result fictitious of dummy destinations with total demand reflecting the surplus.

2.3 A Three-Layer Conjoint Of The Convergent And Divergent Relief Supply Chain Networks

Beyond the simplest supply chains we could integrate the convergent and the divergent supply chain networks. Here we assume that the source node of the convergent supply chain is merged with the single sink node of the divergent commercial supply chains to obtain a three layer conjoint chain. There is now a single node which is both a source and a sink and could represent a location in a relief supply chain which is both a point of embarkation and a point of disembarkation at which vehicles arriving from supply sources off load cargo and vehicles departing for certain destinations up load cargo or personnel such as evacuees. In other words vehicles become origins and destinations in the second layer in the ensuing transhipment problem.

The model is detailed as follows and is obviously a combination of the decision variables, parameters, constraints and objective functions of the two models described previously.

Objective function

Minimize $$T = \sum_{k=1} \sum_{j=1} \sum_{i=1} \mathrm{t}_{\mathrm{ij}} \mathrm{X}_{\mathrm{ijk}}$$

Subject to the constraints

$$\sum_{j} X_{ijk} = S_{ik}$$

$$\sum_{i} X_{ijk} = D_{jk}$$

Assuming a balanced transportation problem we have

$$\sum_{i} \sum_{j} \sum_{k} q_{jk} X_{ijk} = S = D$$

Where S the total supply from all sources of all commodities is given by

$$\sum_{i=1}^{I} S_i = S$$

Where

$$\sum_{j=1}^{J} \sum_{k}^{K} q_{jk} X_{ijk} = S_i$$

Decision Variables

X_{ijk} represents the number of trips of vehicle j , carrying commodities of type k from supply source i to the distribution centre.

Y_{mnp} represents the number of trips of vehicle type m , carrying commodities of type p to the nth demand destination from the distribution centre.

Parameters

t_{ij} represents the time taken by vehicle type j to travel from the supply source i to the distribution centre.

s_{mn} represents the time taken by vehicle type m to travel from the distribution centre to the nth destination.

D_{kj} represents the carrying capacity of vehicle type j in respect of commodity type k.

C_{mp} represents the carrying capacity of vehicle type m in respect of commodity type p.

S_{ik} represents the capacity of supply source i in respect of commodity type k.

R_{np} represents the demand of the nth destination in respect of commodity type p.

S_i represents the total capacity in common units of supply source i in respect of all commodity types.

R_n represents the total demand in common units of the nth destination in respect of all commodity types.

D represents the total demand at the distribution centre of in respect of all commodity types.

R represents the total demand at all destinations in respect of all commodity types.

q_{kj} represents the quantity of commodity type k that can be carried by vehicle type j.

p_{mp} represents the quantity of commodity type p that can be carried by vehicle type m.

Objective function

Minimize the total travel time $T = \sum_i \sum_j \sum_k t_{ij} X_{ijk} + \sum_m \sum_n \sum_p s_{mn} Y_{mnp}$

Subject to the constraints

$$\sum_j X_{ijk} = S_{ik}$$

$$\sum_i X_{ijk} = D_{jk}$$

$$\sum_m Y_{mnp} = R_{np}$$

$$\sum_n Y_{mnp} = C_{mp}$$

Assuming a balanced transhipment problem we have

$$\sum_i \sum_j \sum_k q_{ij} X_{ijk} - \sum_m \sum_n \sum_p p_{mp} Y_{mnp} = 0$$

The assumption of a balanced transhipment problem or conservation of flow means that if there is in actual fact an excess of demand to supply there will result fictitious of dummy vehicles arriving at the distribution centre and/or supply sources with total capacities reflecting the shortfall. Similarly, if there is in actual fact an excess of supply to demand there will result fictitious of dummy destinations and or dummy vehicles leaving the distribution centre with total demand and/or carrying capacity reflecting the surplus.

This formulation illustrates the integration of supply chains particularly with regard to issues of performance (Beamon and Chen, 2001) and also reflects an emergency logistics distribution model described by Bannister (2007) in the context of a Military Lift Problem. Here we have an illustration of the similarities (and hence natural possibilities for collaboration) between humanitarian logistics and military logistics operations especially during complex emergencies (Ebersol, 1995).

3. CONCLUSION

In this paper, we have proposed deterministic static models relating to the time-optimal transportation of assorted relief commodities by means of appropriate modes of travel from a set of locations which are supply/demand points of a relief supply chain to/from a single location which represents a centre of distribution in the theatre of a disaster or humanitarian emergency. We dealt with the simplest generic supply chain configurations of convergent and divergent network structures as well as that of their conjoint network and is formally not different from the linear programming formulation of the transportation problem or more generally the Minimum cost

Network Flow problem. It is nonetheless a viable and usable alternative to other much more complex kinds of multi commodity, multi modal models for disaster management found in the literature. Moreover, our study captures and illustrates in the modeling process, the essential features of (relief) supply chain management (i.e. coordinated information and material flows over a network.

It is also suggestive of a fairly implemented decision support system for disaster management.

Further work is ongoing with regard to constructing time dependent stochastic extensions of the models so that inventory control issues (Beamon and Kotleba) can be dealt with.

4. References

Altay, N. and Green, G. W., (2006). OR/MS Research in disaster operations management. European Journal of Operational Research 175, 475–493.

Ardekani, S.A. and Hobeika, A., (1988). Logistics problems in the aftermath of the 1985 Mexico City earthquake. Transportation Quarterly 42, 107–124.

Bannister D., (2007). Analysis of the Military Lift Problem. Honours Thesis in Operations Research. Department of Mathematics, The Universoty of Melbourne.

Beamon, B. M., (1999). Designing the green supply chain. Logistics Information Management, 12 (4) 332 – 342.

Beamon, B. M. and Chen, V.C.P., (2001). Performance analysis of conjoined supply chains. *International Journal of Production Research*, 39 (14), 3195 - 3218.

Beamon, B. M., and Fernandes, C., (2004). Supply chain network configuration for product recovery. Production Planning and Control, 15 (3), 270 – 281.

Beamon, B. M., and Kotleba, S.A., (2006). Inventory modelling for complex emergencies in humanitarian relief operations. *International Journal of Logistics* 9, 1–18.

Ebersol, J.M., (1995). Mohonk criteria for humanitarian assistance in complex emergencies. Disaster Prevention and Management 4 (3), 14–24.

Haghani, A.,and Oh, S.C., (1996). Formulation and solution of a multi-commodity, multi-modal network flow model for disaster relief operations. Transportation Research Part A 30 (3), 23 1–250.

Kembell-Cook, D. and Stephenson, R., (1984). Lessons in logistics from Somalia. Disasters 8 (1), 57–66.

Knott, R., (1987). The logistics of bulk relief supplies. Disasters 11(2), 113–115.

Kovacs, G.,(2004). Framing a demand network for sustainability. *Progress in Industrial Ecology – an International Journal.* 1(4), 397 – 410,

Kovacs, G., Rikharosson, P., 2006. Accounting for reverse logistics activities. Corporate Ownership and Control. 4(1), 309 – 316.

Kovacs, G., and Spens, K.M., (2007). Humanitarian logistics in disaster relief operations. Journal of Physical Distribution and Logistics Management 37 (2), 99–114.

Knott, R., (1988). Vehicle scheduling for emergency relief management: a knowledge-based approach. Disasters 12 (4), 285–293.

Long, D.C. and Wood, D.F., (1995). The logistics of famine relief. Journal of Business Logistics (1), 213–229.6

Oloruntoba, R., and Gray, R., (2006). Humanitarian aid: an agile supply chain? Supply Chain Management: An International Journal, 11 (2), 115 – 120.

Price, T., (2003), Delivering on Humanitarian Logistics. Georgetown Business. 15 (2), 13–15.

Rathi, A.K., Church, R.L., and Solanki, R.S., 1992. Allocating resources to support a multicommodity flow with time windows. Logistics and Transportation Review 28 (2), 167–188.

Sheu, J.B., 2007. A fuzzy-based customer classification method for advanced demand-responsive logistical distribution operations. Fuzzy Sets and Systems 139 (2), 431–450.

Spens, K.M., and Kovacs, G., (2006). A content analysis of research approaches in logistics research. *International Journal of Physical Distribution and Logistics Management*, 36(5), 374 – 390.

Xu, L., and Beamon, B.M., (2006). Supply Chain Coordination and Cooperation Mechanisms: An Attribute-Based Approach, *Journal of Supply Chain Management*, Winter, pp. 4-12.