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A Crowdsourced Approach for Supply Chain Network Optimization Using Hub and Spoke Model

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Abstract

Crowdsourced delivery is considered a possible solution to the last-mile on-demand delivery challenge. This paper aims to identify and analyze an optimized & efficient supply chain network solved with hub and spoke model using a crowdsourced approach. For this approach, a well-known retail company of Bangladesh is considered that automatically creates matches between parcel delivery tasks and ad hoc drivers. This platform is a chain of Bangladeshi department stores specializing in Bengali ethnic wear and handicrafts. The secondary data is collected from the company. The performance of the crowdsourced last-mile delivery is investigated with regard to service level and assets utilization. The main focus of the resulting model is to minimize the total transportation cost and how crowdsourcing will affect the whole chain. Hub and spoke distribution paradigm is a form of transport topology optimization in which traffic planners organize routes as a series of "spokes" that connect outlying points to a central "hub". The supply chain network includes a number of manufacturers, suppliers, distributer locations and demand points which need to be located not just randomly but as a result of careful calculation to minimize the overall cost and increase the supply chain surplus. The presented model and analysis are the results of an experiment of the supply chain network of the platform toward engaging in social network-reliant package delivery. The hub and spoke model is an excellent approach to make the whole system more robust and agile by receiving products from many different origins, consolidating the products and sending them directly to destinations. Crowdsourcing is the process of obtaining ideas, services or information by soliciting feedback from a large group of people. Here in this paper, the effects of crowdsourcing on the supply chain is emphasized by using a linear programming model in MATLAB. The result will be evaluated and analyzed for further improvement and practical use.

Keywords
Crowdsourced, last-mile delivery, transportation cost, supply chain network, hub and spoke model

1. Introduction

A supply chain is a network between a company and its suppliers to produce and distribute a specific product to the final buyer. The supply chain network involves a series of steps involved to get a product or service to the customer. The steps include moving the raw materials, transforming them into finished goods, transporting and distributing them to the end user. The entities involved in the supply chain include manufacturers or producers, vendors, warehouses, transportation companies, distribution centers, and retailers and customers. Here, crowdsourced approach using Hub and Spoke model is used to allocate the manufacturers, warehouse, distribution center and courier location. This model is used to manage the transportation route in a multi-echelon network to reduce the overall transportation cost. For minimizing transportation cost across echelons, simultaneously allocation of the warehouses to meet all of the customer service goals is described. The main objective in such factory, sales and warehouse allocation problems is to select the placement of a facility so that the demanded constraints are met. The problem often consists of selecting a factory location that minimizes total weighted distances from suppliers and customers, where weights are representative of the difficulty of transporting materials.

Usually, in hub location problems, there are a number of nodes with corresponding number of demands that flow moves among these nodes throughout the network. One important feature in a hub location problem is the assignment pattern of the non-hub nodes to the hubs. There are two ways to assign: Single allocation hub location problem and multiple allocation hub location problem. In a single allocation model, several nodes will be selected as a hub and other nodes, namely non-hub nodes (spoke), only connected to a single hub. In this model there is no direct link among non-hub nodes and flow just distributed in the network through the hubs' linking. In the multiple allocation model, several nodes will be selected as a hub and other nodes, namely non hub nodes (spoke), can connect to more than one hub (Boukani, Farhang, Mir, & Pishvaee, 2014).Besides, crowdsourcing is a powerful business marketing tool that allows an organization to leverage the creativity and resources of its own audience in promoting and growing the company. From designing marketing campaigns to researching new products to solving difficult business roadblocks, an organization's consumers can likely provide important guidance and answers. Crowdsourcing increases the productivity of a company while minimizing labor expenses. The Internet is a time-proven strategy for soliciting feedback from an active and passionate consumer base.

The basic concept behind this term is to use a large group of people for their skills, ideas and participation to generate content or help facilitate the creation of content or products. Crowd sourcing is using collective intelligence gathered from the public and using that information to complete business-related tasks. These tasks are normally completed by the company or a third party service provider but through the power of crowdsourcing, the public assists in the completion of these tasks. It also allows a company to gain insight into their customers and what they desire. The main tasks of crowdsourcing are:

- Collecting the information, opinions, or work from a group of people, usually sourced via the Internet.
- Allowing companies to save time and money while tapping into people with different skills or thoughts from all over the world.
- Seeking work or information from a group.

Crowdsourcing is a type of participative online activity in which an individual, an institution, a non-profit organization, or company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task. The undertaking of the task, of variable complexity and modularity, and in which the crowd should participate bringing their work, money, knowledge and/or experience, always entails mutual benefit (Gatautis & Vitkauskaite, 2014). Multi-mode distribution network is focused here which is solved by mixed-integer linear programming. The problem is to find the optimal production and distribution levels among a set of factories, warehouses, and sales outlets. The model first generates random locations for factories, warehouses, and sales outlets. One constraint on the model is that the demand is met, meaning the system produces and distributes exactly the quantities in the demand. There are capacity constraints on each factory and each warehouse. Part of the problem is to determine the cheapest mapping of sales outlets to warehouses. The problem of designing a crowdsourced network through a hub location problem (HLP) consists of origin, hub, and destination nodes. In a hub network, a set of intermediate nodes are located as hubs, and origin and destination nodes (spokes) are allocated to these hubs. Hubs are responsible for consolidating, transferring and distributing flows through the network to gain economics profits. Therefore, it is necessary to design a reliable logistics network that remains available and efficient in the presence of all sorts of disruptions. When a hub node is completely disrupted, that hub becomes unavailable and spokes originally allocated to it have to be reallocated to other (operational) hub nodes that usually require higher connection costs. In case of partial disruption, although the hub node may be still available, the service rate or the capacity of the hub is degraded to a lower level. In case of service rate degradation, hubs become congested and incoming flow must spend more time and have to wait to be processed (Mohammadi, Tavakkoli-Moghaddam, Siadat, & Dantan, 2016).

The terms are described by employing linearization method. The model is converted to a mixed integer linear programming which can be efficiently solved via MATLAB. The rest of this paper is organized as follows: in section 2, literature review is described. In section 3, methodology and the mathematical programming formulation are introduced. In section 4, there are result and discussion on the formulation of the model in the form of mixed integer linear programming. Section 5 ends with conclusion. And at last, there are references.

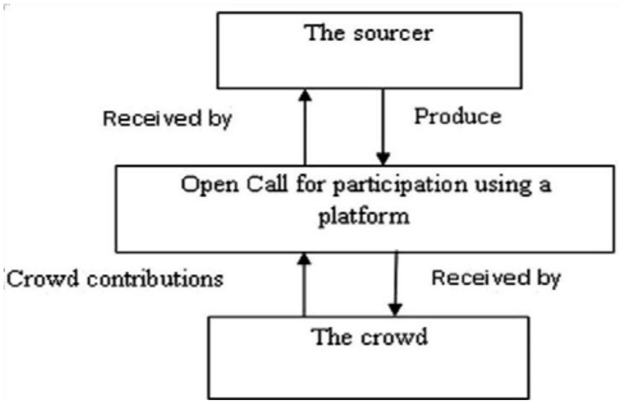

Figure 1: Crowdsourced Diagram

2. Research Background

This paper attempts to investigate a methodology to design crowdsourced hub-and-spoke model. This model is used to allocate the warehouse and distribution center to reduce the transportation cost. Here the first goal aims to determine whether the issues of hub location allocation could be dealt with separately, the second goal targets the amount of cost-saving that might be achieved by simultaneously addressing the problems namely the hub location allocation (Azizi, Chauhan, Salhi, & Vidyarthi, 2016). Some researches including six types of models are discussed.

Castillo et al. (Castillo, Bell, Rose, & Rodrigues, 2017) performed a stochastic discrete event simulation model informed by secondary data and discussions with managers from courier companies in major American cities. Using a contingency theory lens, the research contributes a nascent understanding of how CSL performs in terms of logistics effectiveness by simulating same-day delivery services from a distribution center to 1,000 customer locations throughout New York City under dynamic market conditions and by comparing the results to those of a traditional dedicated fleet of delivery drivers. The findings are analyzed to suggest how firms may find strategic benefit using CSL. A systems-level understanding of the CSL phenomenon as a component of a firm’s last mile distribution strategy is developed. Finally, a future research agenda is presented to stimulate further investigation of the CSL phenomenon.

Estellés-arolas et al. (Estellés-arolas & González-ladrón-de-guevara, 2012) provided a wide definition that covers the majority of existing crowdsourcing processes. Through the analysis of all the authors’ definitions, eight characteristics common to any given crowdsourcing initiative were found: the crowd; the task at hand; the recompense obtained; initiator of the crowdsourcing activity; what is obtained by them following the crowdsourcing process; the type of process; the call to participate; and the medium. For each one of these elements an analysis based on the collected definitions was undertaken and a conclusion formulated, attempting to make each element as global as possible while trying to maintain the upmost precision as well.

Lang et al. (Lang, Bharadwaj, & Di, 2016) introduced crowdsourcing as an innovative tool that can enhance market information processing, and in turn, improve prediction of market-oriented outcomes (e.g., sales). A forecasting tournament is tested with employees at a Fortune 100 consumer packaged goods firm, and examined the extent to which predictions based on the “wisdom of the crowd” outperform those generated by traditional forecasting approaches. Crowdsourcing produced results is found superior to the firm's incumbent approaches almost three-fourths of the time across a broad range of business decisions. Additionally, a survey is conducted with participants to open up the “black box” of crowdsourcing. The differences are found in information acquisition and interpretation in the underlying mechanisms. It can explain the improved prediction accuracy found through crowdsourcing. In another research, Lin et al. (Lin, Schwartz, Michalski, Shakamuri, & Campbell, 2012) discussed about crowds techniques that is applicable to the analysis of supply chain integrity. The development of a semi-automated supply chain integrity risk analysis framework is discussed to assist the supply chain security analysts in assessing the level of risk associated with a component of a mission critical system. This capability can provide the system designer a more rigorous and efficient approach to assess the security of the components in the design.

Pilloni et al. (Pilloni, 2018) discussed about the common denominator of the enhancements, i.e., data collection and analysis. As data and information will be crucial for Industry 4.0, crowd sensing and crowdsourcing will introduce new advantages and challenges, which will make most of the industrial processes easier with respect to traditional technologies. The main objectives are represented by improvements in: production efficiency, quality and cost-effectiveness; workplace health and safety, as well as quality of working conditions; products' quality and availability, according to mass customization requirements. The common denominator of the enhancements are also discussed, i.e., data collection and analysis. As data and information will be crucial for Industry 4.0, crowdsensing and crowdsourcing will introduce new advantages and challenges, which will make most of the industrial processes easier with respect to traditional technologies. In another research, Simula et al. (Simula & Vuori, 2012) examined how business-to-business (B2B) firms can interact with different groups of contributors in order to receive new ideas, feedback and solutions for improving their products and services. Based on theoretical conceptualization, combined with empirical evidence, a layered framework is proposed for approaching crowdsourcing in a B2B context. The empirical results of the paper reveal benefits but also practical challenges to overcome before crowdsourcing can be effectively utilized in the B2B sector.

In another research, a technique is described for jointly providing privacy and reliability through stochastic perturbation of micro task definitions and fusion rules to combine the work of several workers. A mathematical model of a crowdsourcing system using this technique is proposed and precise threshold conditions on loss of privacy when workers collude are provided. Tradeoffs between privacy, reliability, and cost are determined (Varshney, 2012).

Arslan et al. (Arslan, Agatz, Kroon, & Zuidwijk, 2018) studied the concept of crowdsourced delivery that aims to use excess capacity on journeys that already take place. A service platform is considered that automatically creates matches between parcel delivery tasks and ad hoc drivers. The platform also operates a fleet of dedicated vehicles to serve the tasks that cannot be served by the ad hoc drivers. The matching of tasks, drivers, and dedicated vehicles in real time gives rise to a new variant of the dynamic pickup and delivery problem. A rolling horizon framework is considered and developed to solve the matching problem each time new information becomes available. To investigate the potential benefit of crowdsourced delivery, a wide range of computational experiments was conducted. The experiments provide insights into the viability of crowdsourced delivery under various assumptions about the behavior of the ad hoc drivers. The results suggest that the use of ad hoc drivers has the potential to make the last mile more cost efficient and can provide system-wide vehicle-mile savings up to 37% compared to a traditional delivery system with dedicated vehicles.

Amrollahi et al. (Amrollahi, 2015) reviewed the related literature on crowdsourcing methods as well as relevant case studies and extracted the activities which they referred to as part of crowdsourcing projects. The systematic review of the related literature and an in depth analysis of the steps in those papers were followed by a synthesis of the extracted activities resulting in an eleven-phase process model. This process model covers all of the activities suggested by the literature. This paper then briefly discussed the activities in each phase and concludes with a number of implications for both academics and practitioners. In another research, Evans et al. (Evans & Gao, 2016) provided a review of recently published literature relating to crowdsourcing in the manufacturing industry and offered suggestions for the future direction of crowdsourcing research in manufacturing and product development.

Hossain et al. (Hossain, 2012) has identified various motivational factors and classified them so that researchers can have more empirical studies to understand better. Moreover, the findings can be used for the companies who are planning to launch similar crowdsourcing platforms to tap users' talents. In another research, Pedersen et al. (Pedersen, Kocsis, & Tarrell, 2013) reported on a literature survey of crowdsourcing research, focusing on top journals and conferences in the Information Systems (IS) field. Contributions include providing a synopsis of crowdsourcing research to date, a common definition for crowdsourcing, and a conceptual model for guiding future studies of crowdsourcing. Existing IS literature application is showed to the elements of that conceptual model: Problem, People (Problem Owner, Individual, and Crowd), Governance, Process, Technology, and Outcome.

3. Research Method

The problem is to determine the optimal number and location of facilities that minimize total transportation cost. Since operational and storage costs are minimal compared to transportation cost, they are not considered in either model for the sake of simplicity. To consolidate inbound shipments from manufacturers, only full truck load shipments are used.

3.1 Problem Identification

The structure of the current supply chain is illustrated in Figure 1, a 1-median network with three basic levels: supplier locations, warehouse location, and demand locations. Products are manufactured and sent to a warehouse from which they are distributed to customer home locations. While monthly demand for each product is known and fairly constant, delivery time windows are narrow and thus can produce high transportation costs. Products are shipped via truck from the warehouse to several courier locations that are close to the customers, and couriers then deliver the products from these secondary facilities to patients.

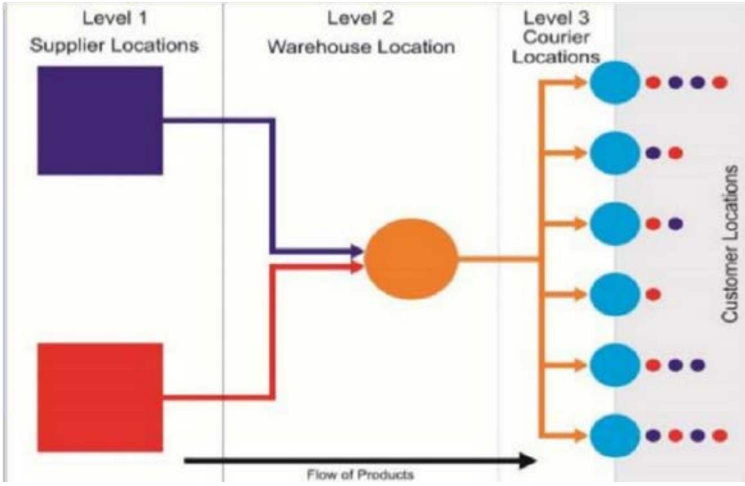

Figure 1: Current supply chain network

3.2 Problem Definition

We consider a crowdsourcing platform that continuously receives new delivery tasks and driver trip announcements over time. Multi-mode distribution network is focused here which is solved by mixed-integer linear programming. The problem is to find the optimal production and distribution levels among a set of factories, warehouses, and sales outlets. The model first generates random locations for factories, warehouses, and sales outlets. One constraint on the model is that the demand is met, meaning the system produces and distributes exactly the quantities in the demand. There are capacity constraints on each factory and each warehouse. Part of the problem is to determine the cheapest mapping of sales outlets to warehouses.

3.3 Mathematical Model

Index Sets:

I Index set of manufacturers
J Index set of candidate warehouse locations
K Index set of demand locations
L Index set of products
S Index set of candidate distribution facility locations

Parameters:

n Number of operating warehouses
r_{kl} Required quantity at demand location k for product l (in lbs.)
$\bar{d}_{ij}$ Distance between manufacturer location i and warehouse location j (in miles)
$\hat{d}_{js}$ Distance between warehouse location j and distribution facility s (in miles)

$ḑ_{sk}$ Distance between distribution facility s and demand locations k (in miles)
d_{jk} Distance between warehouse location j and demand location k (in miles)
c_{ij} Cost per truck from manufacturer i to warehouse j (in \$/mile)
c_{1jk} Cost per truck from warehouse location j to demand location k (in \$/mile)
c_{2jk} Cost of courier shipment from warehouse location j to demand location k (in \$)
m Number of operating distribution facilities
$\hat{c}_{js}$ Cost per truck from warehouse j to distribution facility s (in \$/mile)
$\tilde{c}_{1sk}$ Cost per truck from distribution facility s to demand locations k (in \$/mile)
$\tilde{c}_{2sk}$ Cost of courier shipment from distribution facility s to demand locations k (in \$)
$a_{il}= \{1, if\ manufacturer\ produces\ product\ l 0, otherwise$

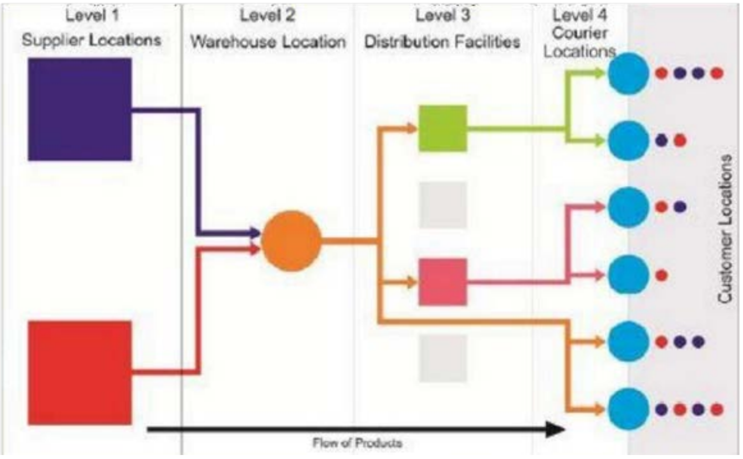

Figure 2: Network Structure; Hub and Spoke Model

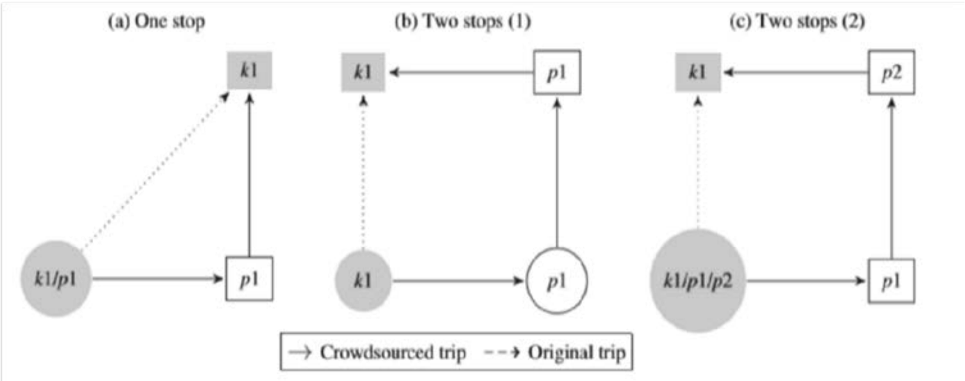

Figure 3: A Driver (Grey) and Tasks (White) Traveling from His Origin (Circle) to Destination (Square) (Arslan, 2018)

Decision variables
$\dot{f}_{ijl}$ Quantity of product l from manufacturer i to warehouse j (in lbs.)
f_{jkl} Quantity of product l from warehouse j to demand location k (in lbs.)
$ţ_{ij}$ Number of trucks from manufacturer to warehouse location j (in trucks)
t_{jk} Number of trucks from warehouse location j to demand location k (in trucks)
$\dot{f}_{jsl}$ Quantity of product l from warehouse j to distribution facility s (in lbs.)
$ꞙ_{skl}$ Quantity of product l from distribution facility s to demand location k (in lbs.)
t_{js} Number of trucks from warehouse location j to distribution facility s (in trucks)
$\hat{\tilde{t}}_{sk}$ Number of trucks from distribution facility s to demand location k (in trucks)

$\dot{x}_s=\{1,$if there is an operating distribution facility at s $0, otherwise$
$\check{z}_{js}=\{1,$if an operating warehouse at j serves an operating distribution facility at s $0, otherwise$
$\tilde{y}_{1sk}=\{1,$if the operating distribution facility at s serves demand location k $0, otherwise$
$x_j=\{1,$if there is an operating warehouse at location j $0, otherwise$
$y_{jk}=\{1,$if the operating warehouse at location j serves demand location k $0, otherwise$
$y_{sk}=\{1,$if the operating distribution facility at location s serves demand location k $0, otherwise$
$x_s=\{1,$if there is an operating distribution facility at location s $0, otherwise$

3.4 Objective Function

$$\text{Min } (\Sigma_{i\in I}\ \Sigma_{j\in J}\ (c_{ij} * \overline{d}_{ij} * \text{ţ}ij) + \Sigma_{j\in J}\ \Sigma_{k\in K}\ (c_{1jk} * \text{ḓ}_{jk} * \text{ṱ}_{jk}) + \Sigma_{j\in J}\ \Sigma_{k\in K}\ (c_{2jk} * y_{jk}) + \Sigma_{j\in J}\ \Sigma_{s\in S}\ (\hat{c}_{js} * d_{js} * t_{js}) + \Sigma_{s\in S}\ \Sigma_{k\in K}(\tilde{c}_{1sk} * \text{ḑ}_{sk} * \tilde{t}_{sk}) + \Sigma_{s\in S}\ \Sigma_{k\in K}(\tilde{c}_{2sk} * y_{sk}))\ (3.1)$$

Constraints:
The objective function is subjected to following constraints:
$\Sigma_j \in J\ x_j=n$ (3.2)
$\Sigma_s \in S\ \dot{x}_s=m$ (3.3)
$\Sigma_s \in S\ \check{z}_{js} \leq m * x_j \quad \forall_j$ (3.4)
$x_s \leq \Sigma_j \in J\ \check{z}_{js} \quad \forall_s$ (3.5)
$\Sigma_k \in K\ (y_{jk}) \geq x_j \quad \forall_j$ (3.6)
$\Sigma_k \in K\ (y_{jk}) \leq x_j * |K| \quad \forall_j$ (3.7)
$\Sigma_k \in K\ (\tilde{y}_{1sk}) \geq \dot{x}_s \quad \forall_s$ (3.8)
$\Sigma_k \in K\ (\tilde{y}_{1sk}) \leq \dot{x}_s * |K| \quad \forall_s$ (3.9)
$y_{jk} \leq x_j \quad \forall_j, \forall_k$ (3.10)
$\check{z}_{js} \leq x_j \quad \forall_j, \forall_s$ (3.11)
$\check{z}_{js} \leq \dot{x}_s \quad \forall_j, \forall_s$ (3.12)
$\Sigma_j \in J_{\check{z}js} \leq \dot{x}_s \quad \forall_s$ (3.13)
$\tilde{y}_{1sk} \leq \dot{x}_s \quad \forall_s, \forall_k$ (3.14)
$\Sigma_j \in J\ y_{jk} + \Sigma_s \in S\ \tilde{y}_{1sk} \leq 1 \quad \forall_k$ (3.15)
$\Sigma_j \in J\ f_{jkl} + \Sigma_s \in S\ \text{ꞙ}_{skl} \geq r_{kl} \quad \forall_k, \forall_l$ (3.16)
$f_{jkl} \leq r_{kl} * y_{jk} \quad \forall_j, \forall_k, \forall_l$ (3.17)
$\text{ꞙ}_{skl} \leq r_{kl} * y_{sk} \quad \forall_s, \forall_k, \forall_l$ (3.18)
$\dot{f}_{ijl} \leq x_j * a_{il} * \Sigma_k \in K\ r_{kl} \quad \forall_i, \forall_j, \forall_l$ (3.19)
$\dot{f}_{jsl} \leq \check{z}_{js} * \Sigma_k \in K\ r_{kl} \quad \forall_j, \forall_s, \forall_l$ (3.20)
$\Sigma_k \in K\ f_{jkl} + \Sigma_s \in S\ \dot{f}_{jsl} \leq \Sigma_i \in I\ \dot{f}_{ijl} \quad \forall_j, \forall_l$ (3.21)
$\Sigma_k \in K\ \text{ꞙ}_{skl} \leq \Sigma_j \in J\ \dot{f}_{jsl} \quad \forall_s, \forall_l$ (3.22)
$x, \dot{x}, y, \tilde{y}, \check{z} \in \{0,1\}$ (3.23)

The objective function 3.1 minimizes the total transportation cost as previously, but now including inbound and outbound costs for distribution facilities. The first four cost terms are the same as the previously, with the additional fifth term being the transportation cost between warehouses and distribution facilities, and the remaining terms being the transportation cost from distribution facilities to demand locations based on number of Full Truck Load (FTL) trucks, courier shipments, respectively. Constraints 3.2 and 3.3 define the number of warehouses and distribution facilities, while constraints 3.4 and 3.5 ensure that only open warehouses serve distribution facilities and that all distribution facilities are served by at least one warehouse.

Constraints 3.6 – 3.9 ensure that only open facilities serve demand locations and that all open facilities serve at least one demand location. Constraints 3.10 and 3.11 ensure possible routes exist only between open warehouse and distribution facilities, while constraint 3.12 allows only one warehouse to supply to each distribution facility. Constraints 3.13 and 3.14 ensure that either a warehouse or a distribution facility serve any particular demand point, constraint 3.15 ensures at most one incoming route to each demand location (either from warehouse or distribution facility), and constraint 3.16 ensures that all customer demand is satisfied. Constraints 3.17 and 3.18 ensure that product ship only across allowed routes.

As previously, constraint 3.19 ensures that shipments to warehouses only come from suppliers who produce that product and constraint 3.20 similarly ensures shipments from warehouses to distribution facilities only through open routes. Constraints 3.21 and 3.22 ensure outbound shipments from warehouses and distribution facilities do not exceed their inbound shipments. Constraint 3.23 defines the decision variables to binary.

4. Result

The general aim in Hub and Spoke warehouse location problems is to locate one or more warehouses that distribute products to a set of demand locations and facility location problems have been investigated in various contexts for decades. In this thesis, the model is used to locate a multiple warehouses to minimize total distance to several customers. The model also used to minimize the cost of transportation. Optimal supply chains can significantly affect transportation costs and profit margins. The network structures for a crowdsourced approach are analyzed in this work to minimize total cost and provide some protection against temporary facility shutdowns. Analysis of the potential network structures with dis-located manufacturers indicate that the manufacturers have greater influence on the distribution network structure than the locations of end-customers, with a noticeable reduction in total transportation cost if two warehouses are used.

5. Conclusion

In this paper, the crowdsourced approach is studied using hub and spoke model. The formulations are made stronger by applying mixed integer linear programming. To investigate the behavior of these formulations, crowdsourced approach were imposed. For the future research, the problem can be extended for congestion consideration over connecting links. In addition, investigating hub capacity planning models with capacity based congestion cost function would be an interesting research direction.

6. Future Work

Arising from this analysis of extant literature, it is possible to identify and suggest future research topics in relation to crowdsourcing and its use within the manufacturing industry. These include:

- Study in more depth the motivational factors which encourage participants to engage in crowdsourcing activities;
- Compare and contrast developed crowdsourcing tools / systems to establish the most suitable methods for specific manufacturing processes;
- How crowdsourcing may be used to capture problems experienced and ideas for improvements by end-users when finished products have entered into service;
- Identify the problems and barriers encountered in successful crowd collaboration.

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