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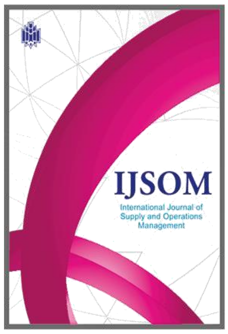

Development of an Integrated Framework for Facility Relocation Problem: A Case Study

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Abstract
The present study has developed an integrated framework for handling a facility relocation problem by combining quantitative modelling methodology with the factor rating technique. It has demonstrated the framework with reference to a real case of a corrugated box manufacturing plant. The first phase of the integrated framework involves evaluation of supply chain cost including inbound logistics cost, in-plant operations cost, and outbound logistics cost of the existing location and two other candidate locations. A mixed integer linear programming model was formulated to reflect the above problem. Sensitivity analyses were also carried out on different parameters in order to test the behavior of the model in respect of total cost. The second phase involves evaluation of both quantitative and qualitative factors across all three locations by a team of experts on a common scale. The outcome of the first phase expressed in terms of quantitative elements of cost enabled the experts to suitably evaluate the candidate locations on cost dimension on the common scale. Finally, the composite score is computed for all three locations which aids location planners in making a realistic comparison among the three locations. Towards the end, managerial implications of the findings are discussed.

Keywords: Facility relocation; Integrated framework; Mixed integer linear programming; Factor rating.

1. Introduction

Facility location and relocation problems have been extensively studied by numerous researchers. Examples include location problems in diverse settings in both private and public sector. The most prominent public facility location problem discussed in the literature pertains to the setting up of healthcare facilities (Gu, et al., 2010; Afsari and peng, 2014; Günes and Nickel, 2015). As regards the facility location problems in private sector, extant literature has dealt with the challenges concerning the location of a manufacturing facility (Melachrinoudis and Min, 2000; Chakraborty, 2005), distribution centre or warehousing facility (Avittathur et al., 2005; Amiri, 2006;), retail store (Erbıyık et al., 2012; Turhan et al., 2013; Müller and Haase, 2014) etc. A wide variety of models including both static and dynamic ones are proposed by the researchers. In all these problems, the location planners attempt to take into consideration the prevailing demand of the products and services in the market, distances the industrial or the retail customers have to travel in order to get the products or the costs incurred in shipping the products to the customers from the manufacturing facility or the distribution centre. In addition, the infrastructural facilities available in the candidate location are also evaluated and finally decision is taken as to whether the facility would be set up or not in that particular location. In case the facility is set up, the distribution of demand of the products also needs to be observed across different demand regions and at different time periods. In addition, the cost of operation at the existing location needs to be monitored with the passage of time in order to find out the possible escalation in the total cost. Increasing cost of operation in the existing location and shifting demand of products to other geographic locations might motivate the location planners to contemplate the relocation of existing facility to some other suitable locations. Findings of several studies (Torres-Soto and Üster, 2011; Sonmez and Lim, 2012; Lim and Sonmez, 2013; Opasanon and Lertsanti, 2013; Eslamipoor and Sepehriar, 2014) bear testimony to this argument.

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Researchers have suggested several sophisticated facility location and relocation models, some of which are mentioned in literature review section. However, in most of the cases, the studies remain confined to two or at most three echelons and thus cannot properly capture the dynamics of sourcing of raw materials and distribution of final products simultaneously. The most sophisticated mathematical model utilized in deciding the facility location/relocation problems includes the application of supply chain network design (SCND) approach to capturing the entire operations across suppliers, manufacturers, distribution centres, and retailers right from upstream to the downstream of a supply chain. The existing literature is replete with many theoretical studies with specific reference to SCND problems (Melo et al., 2005; 2009; Afshari, et al., 2010; Amin and Zhang, 2013; Amin and Baki, 2017; Bilir et al., 2017). The main advantage associated with this approach involves evaluation of the cost of the facilities across the entire operations of a supply chain. However, these models give emphasis merely on cost dimension for selection of a facility or even relocation of an existing facility and can hardly account for other important strategic and qualitative factors of facility location or relocation.

Facility location and relocation decisions, essentially being strategic in nature, need to incorporate both quantitative and qualitative factors. Thus researchers have identified alternative methodologies for evaluating facility location and relocation problems which could account for all relevant factors. These include Factor Rating, Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Fuzzy AHP etc. The above essentially falls under the category of multi-criteria decision-making (MCDM) models. All these models require the experts to evaluate both qualitative and quantitative locational factors on a common scale based on their experience. However, the challenge associated with the above models indicates that different elements of cost cannot be properly captured merely through experts' judgment. Certain estimation of cost needs to be made for all candidate locations based on available data. Once the tentative estimate of cost of operations of all candidate locations is obtained, the same could be translated into suitable rating based on the estimated cost figures. Thus the quantitative estimate of different elements of cost expressed in terms of rating, when integrated with qualitative factors on a common scale, provides a holistic evaluation of all locations on different aspects. However, we have come across very few studies which have attempted to integrate the quantitative modelling methodology with the qualitative approach in evaluating facility location and relocation problems. Thus there exist considerable research gaps in literature in terms of developing integrated framework for evaluating facility location and relocation problems.

With this background, the motivation of the present study has emanated from developing an integrated framework to addressing facility relocation problem with reference to a real-life problem. The study has presented the challenges being faced by the promoters of a corrugated box manufacturing plant in the existing location and also the opportunities available in few other candidate locations. The problems faced by the company include an increase in the price of raw materials and reluctance of the end customers to make additional payment for the increased cost of raw materials. The research question attempted to be addressed in this paper is whether to allow the corrugated box manufacturing plant to continue its operation in the existing facility or to relocate the plant to a new location. All relevant data have been collected from reliable sources and necessary analyses have been carried out.

The remainder of the paper is as follows: Section 2 describes related literature in which research gaps are also highlighted. Section 3 presents the integrated framework of facility relocation encompassing a generic SCND model and factor rating tool. Section 4 deals with the case study wherein a concise description of the supply chain practices adopted by the company, the customized SCND model, its results, sensitivity analyses is provided. It also includes the description of factor rating approach along with its findings. Section 5 deals with the managerial implications of the findings. The paper concludes with a brief summary, its contribution to the existing body of supply chain literature, limitations and future research directions.

2. Literature Review

Researchers view facility location and relocation decision as an important component in strategic planning. The extant literature is replete with many studies pertaining to both facility location and relocation problems. Broadly we observe two streams of works in the domain of facility location and relocation problems: (A) Mathematical programming models and (B) Multi-criteria decision making models.

2.1. Mathematical Programming (MP) Models

A wide variety of MP models relating to facility location problems is found in literature. Different researchers have prescribed different classification schemes for these models. For example, Owen and Daskin (1998) categorized facility location problems under three heads: (1) static and deterministic location problems, (2) dynamic location problems, and (3) stochastic location problems. Daskin (2008) analysed location problems under four heads: (1) Analytic models, (2) continuous models, (3) network models and (4) discrete models. Arabani and Farahani (2012) divided facility location models under two heads: (1) Static models and (2) Dynamic models. Further, the variants of static location models include continuous facility location problems (Azarmand and Neishabouri, 2009; Daneshzand and Shoeleh, 2009), discrete facility location problems (Berman and Drezner, 2006; ReVelle et al., 2008) and network facility location problems (Nickel and Puetro, 2005; Sahin and Süral, 2007) while the types of dynamic location models include dynamic deterministic facility location problem (Wesolowsky, 1973), facility location-relocation problem (Farahani et al., 2009), time-dependent facility location problem (Drezner and Wesolowsky, 1991) and stochastic facility location problem (Snyder, 2006) etc.

The classification schemes of MP models prescribed by the researchers seem to suggest that the same essentially fall into under three categories: (1) Static models, (2) Dynamic models and (3) Stochastic models. Static models consider constant and known quantities as inputs and derive a single solution to be implemented at one point in time. Dynamic models focus on timing issues involved in locating a facility or facilities over an extended horizon. Stochastic models attempt to capture the uncertainty in input parameters such as forecast demand or distance values. The objectives of most of the above-mentioned MP models include minimizing the cost of setting up facilities, minimizing the number of facilities to be set up, minimizing the costs of allocating clients to the facilities, minimizing the distance between customers and facilities, maximizing the amount of demand covered, minimizing the risk of not being able to meet the demand, maximizing profit etc.

Other variants of MP models cover SCND approach to facility location problems. Examples include strategic design of generic supply chain network incorporating dynamic planning horizon (Melo et al., 2005), the integration of location decision with the decision relating to the design of supply chain network (Melo et al., 2009), facility location model for a general closed-loop supply chain network (Amin and Zhang, 2013; Amin and Baki, 2017), inventory decisions in facility location within the framework of distribution network design (Afshari, et al., 2010), the integration of competitive facility location factors into supply chain network optimization model (Bilir et al., 2017) etc. Huang et al. (2013) developed a supply chain configuration model in the form of mixed integer programming model for the purpose of assessing global manufacturing in China. The model suggests relocation of labour-intensive production competing on low cost to mainland China or other Asian countries where labour costs are cheap. However, the qualitative factors reveal that coastal China offers several advantages in respect of industrial clustering and logistics compared to mainland China. Zhang and Atkins (2019) developed several models for designing a network of 'walk-in' medical facilities that provide a homogeneous service in competitive and centralized environments. A somewhat different kind of facility relocation model was proposed by Felice et al. (2015) in which they developed a Project Management Process Reengineering performance model for relocation of an automotive glass production line to low-cost countries in order to make the business process cost-efficient.

2.2. Multi-criteria Decision Making (MCDM) models

The inherent strength of MCDM models lies in its capability to incorporate both qualitative and quantitative factors on a common scale for facility location and relocation problems. Different variants of MCDM models relevant to facility location and relocation problems are found in literature. A brief description of some of these models in terms of their approaches, advantages and limitations are provided in table 1.

Table 1. MCDM Models of facility location

Models	Approach followed	Advantages/Limitations	References
Factor Rating	This method involves four steps in which the relevant factors are identified, their relative importance established, the performance of each location in each factor assessed and finally all this information is combined to rank the locations.	It is simple, easy to understand and also easy to apply in real-life situations. Another advantage of this method is its ability to incorporate any factor into the analyses as long as the decision maker can assess its relative importance. However, when the number of factors is too high, it might become challenging for the experts to assign relative importance to the factors.	Stevenson (2018), Mahadevan (2017)
AHP	It depicts the evaluation criteria of facility location/relocation in a hierarchical fashion. The weights of the criteria and sub-criteria are determined through pair-wise comparison of the same at each level by eliciting opinions from the experts.	It is a simple but robust and powerful MCDM model, which can incorporate both quantitative and qualitative criteria. However, it may give rise to the problem of rank reversal if a new alternative is introduced or an old one is eliminated. Another limitation of AHP is its unidirectional hierarchical relationship among different criteria and sub-criteria.	Min and Melachrinoudis (1999), Farahani et al. (2010), Das and Barman (2010)
ANP	ANP recognises that there exist interrelationships between the elements in different levels of the hierarchy and also between elements in the same level. Thus the decision elements are organized into networks of clusters and nodes.	The problem of rank reversal has been addressed in ANP. However, it may become quite complex when the number of evaluation criteria and interrelationship among the criteria increases.	Farahani et al. (2010), Koc and Burhan (2016)
Fuzzy AHP	The imprecision and the uncertainty associated with the location evaluation problem is addressed by fuzzy set theory while eliciting opinions from the experts. AHP helps in converting the problem into a hierarchy of criteria and sub-criteria.	It takes care of both qualitative and quantitative criteria. However, the process of fuzzy set theory in fuzzy AHP involves time-consuming fuzzification and defuzzification of data.	Farahani et al. (2010), Ozgen and Gulsun (2014), Wichapa and Khokhajaikiat (2017)

Other variants of MCDM models include Fuzzy ANP (Guneri et al., 2009), Fuzzy TOPSIS (Essaadi et al., 2019) etc. It can be inferred from table 1 that no one particular MCDM model is considered superior to other models which could be unequivocally selected for facility location and relocation problems. The selection of the model rather depends on the objectives and the context under which the facility location or relocation decision problem would be analysed.

Even before selecting a particular MCDM model, the factors relevant to facility location and relocation decisions need to be identified from literature. Dijk and Pellenbarg (2000) identified internal factors, external factors and location factors for relocation decision of firm and argued that the decision to relocate is mainly determined by firm internal factors. Kinkel (2012) identified the motives of a firm for relocation of production and also the motives for production backshoring and recommended the revision of production relocation based on pure cost efficiency considerations. Opasanon and Lertsanti (2013) analysed the impact of relocating a company's logistics facility on firm competitiveness in terms of service level, cost efficiency, business operations and accessibility to raw materials and markets. Eslamipoor and Sepehriar (2014) developed a SWOT-AHP hybrid approach incorporating both economic and environmental factors which would aid location planners in taking a judicious relocation decision in respect of a manufacturing facility. Srivastava et al. (2016) applied a combination of qualitative and quantitative analyses to evaluate the relocation decision of a service facility. The factors considered in evaluating service facility relocation decision in this study include proximity to high transaction customers, infrastructure and other input costs, customer service level etc. We present a list of the relevant factors in table 2.

Table 2. Factors relating to relocation decision

Factors	**References**
Inbound logistics cost/Nearness to suppliers (F1)	Min and Melachrinoudis (1999), Dijk and Pellenbarg (2000), Carrincazeaux and Coris, (2015)
Outbound logistics cost/Nearness to markets (F2)	Min and Melachrinoudis (1999), Dijk and Pellenbarg (2000), Kinkel (2012)
Labour cost (F3)	Kinkel (2012), Carrincazeaux and Coris (2015)
Facility establishment cost (F4)	Min and Melachrinoudis (1999)
Connectivity with major places by road/rail/air (F5)	Dijk and Pellenbarg (2000)
Quality of infrastructure (F6)	Dijk and Pellenbarg (2000)
Skill level of workers (F7)	Min and Melachrinoudis (1999), Carrincazeaux and Coris (2015)
Maintenance and repair services (F8)	Min and Melachrinoudis (1999)
Economies of scale in operations (F9)	Bucci et al. (2014), Lu et al. (2014)
Local Government incentives (F10)	Min and Melachrinoudis (1999), Dijk and Pellenbarg (2000), Kinkel (2012)
Presence of competitors (F11)	Min and Melachrinoudis (1999), Farahani et al. (2010)
Overall business climate (F12)	Farahani et al. (2010)

2.3. Research Gaps

The MP models are designed to capture the actual quantitative figures like cost, revenues, profit, demand, time etc. and generate solutions based on these quantitative data. However, most of the times, these models fail to capture the bigger picture which is essentially strategic in nature. On the contrary, MCDM models have the innate capability to include both qualitative and quantitative elements simultaneously on a common time scale. Of course, the entire data utilized in these models are perceptual rather than real and heavily relies upon the experience and judgment of the experts. The experts are not required to have a detailed knowledge on different elements of supply chain cost while evaluating different locations on cost dimension. They simply exercise their judgment on this dimension based on hunches. Thus the decision made through these models has certain elements of subjectivity. We have hardly come across any study which has properly combined the merits of both the approaches. In other words, how the output of the quantitative modelling could be utilized by experts in MCDM models in applying their judgment on quantifiable elements of facility location and relocation problems has not been demonstrated in the existing literature. In addition, hardly any research works are found in literature which have utilized the factor rating approach for evaluating facility location or relocation problem despite many practical applications of the same being available in text books. The most important characteristic feature of factor rating tool is its simple yet practical approach. Thus there exist significant research gaps in respect of the development of an integrated framework of facility location and relocation problems. The present study seeks to bridge this research gap.

3. Integrated Framework

The research gap identified in the preceding section has motivated us to analyse facility relocation problem by integrating quantitative modelling methodology with the qualitative approach. The framework enables the decision-makers to select a suitable location which would minimize the total supply chain cost, meet the demand of goods emanating from its demand centres and also satisfy other qualitative attributes. For this purpose, the entire exercise has been carried out in two sequential stages. The first stage involves modelling the facility relocation problem as a SCND problem in which the aim of the model is to minimize the supply chain cost including inbound logistics cost, in-plant operations cost and outbound logistics cost. The output of the first stage provides an unambiguous result in respect of selection of a location in terms of cost. However, facility location and relocation problems, as mentioned in the beginning, do not solely depend on costs which warrant that other relevant qualitative aspects also need to be taken into consideration for complete evaluation of the same. The second stage of the framework involves identification of all relevant attributes in addition to the elements of supply chain costs for facility location problems and the relative importance of the same depending on the type of manufacturing facilities. This is followed by evaluation of a number of candidate locations on all the attributes identified on a common scale**.** Towards the end, composite scores of all candidate locations are computed which aids locations planners to take a suitable decision with regard to facility location and relocation problems.

3.1. Generic Model

We formulate the model as follows. We consider a set of raw materials R, a set of suppliers S, a set of manufacturers M, a set of distribution centres N and a set of demand centres O. The set of suppliers S includes all kinds of suppliers supplying the set of raw materials R. Each supplier $s \in S$ supplies a set of raw materials $r \in R$ to a manufacturing facility m. The set of manufacturers M includes the existing manufacturing facility along with a few candidate locations. The set of distribution centres N represents distributors and transhipment nodes while the set of demand centres O denotes final customers.

3.1.1. Parameters

D_o : Demand of finished products by final customer 'o'
B_m : Capacity of manufacturing facility 'm'
I_m : In-plant operating cost of manufacturing facility 'm'
P_{rs} : Per unit purchase cost of raw material ‘r’ from supplier 's'
C_{rsm} : Shipping cost per unit of raw material ‘r’ from supplier 's' to manufacturing facility 'm'
$h * P_{rs}$: Inventory carrying cost of raw material ‘r’ corresponding to supplier ‘s’
C_{mo} : Shipping cost per unit from manufacturing facility 'm' to final demand centre 'o'
C_{mn}: Shipping cost per unit from manufacturing facility 'm' to distribution centre 'n'
C_{no} : Shipping cost per unit from distribution centre 'n' to final customer 'o'
h : Percentage inventory holding cost per unit per annum
K_1 : Parameter for cycle inventory
K_2 : Parameter for pipeline inventory

3.1.2. Decision variables

X_{rsm} : Amount of raw material ‘r’ to be purchased from supplier ‘s' by manufacturing facility 'm'
Y_m : 1, if manufacturing facility is open
0, Otherwise
X_{mo} : Amount of finished products to be shipped from manufacturing facility 'm' to final demand centre 'o'
X_{mn} : Amount of finished products to be shipped from manufacturing facility 'm' to distribution centre 'n'
X_{no} : Amount of finished products to be shipped from distribution centre 'n' to final demand centre 'o'

3.1.3. Objective Function

The problem is formulated as a mixed integer linear programming (MILP) model.

Minimize Z =

$$\sum_{r\in R}\sum_{s\in S}\sum_{m\in M} P_{rs}X_{rsm} + \sum_{r\in R}\sum_{s\in S}\sum_{m\in M} C_{rsm}X_{rsm} + \sum_{r\in R}\sum_{s\in S}\sum_{m\in M} (K_1 + K_2) * hP_{rs}X_{rsm} + \sum_{m\in M}\sum_{o\in O} C_{mo}X_{mo} + \sum_{m\in M}\sum_{n\in N} C_{mn}X_{mn} + \sum_{n\in N}\sum_{o\in O} C_{no}X_{no} + \sum_{m\in M} F_mY_m$$

The first term indicates the purchase cost of all raw materials while the second term denotes the shipping cost of all raw materials from the suppliers to the manufacturers. The third term expresses inventory carrying cost of all raw materials including both cycle inventory and pipeline inventory. The fourth, fifth and the sixth term indicate the shipping cost of finished product from manufacturing facilities to final demand centres, from manufacturing facilities to distribution centres and from distribution centres to final demand centres respectively. The last term represents the in-plant operating cost of the manufacturing facilities.

Subject to

Constraint expressing the relationship between the volume of raw materials purchased and the volume of demand

Balanced constraints at manufacturing facility

$$\sum_{s\in S}\sum_{r\in R} X_{rsm} = \sum_{n\in N} X_{mn} + \sum_{o\in O} X_{mo} \qquad \forall m \qquad (1)$$

Capacity constraints of manufacturing facilities

$$\sum_{n\in N} X_{mn} + \sum_{o\in O} X_{mo} \leq B_m Y_m \qquad \forall m \tag{2}$$

Balanced constraints at distribution centres

$$\sum_{m\in M} X_{mn} = \sum_{o\in O} X_{no} \qquad \forall n \tag{3}$$

Demand constraints

$$\sum_{m\in M} X_{mo} + \sum_{n\in N} X_{no} = D_o \qquad \forall o \tag{4}$$

Manufacturing facility constraint

$$\sum_{m\in M} Y_m = 1 \tag{5}$$

Constraint (1) shows that the total amount of raw materials sourced from all the suppliers by a manufacturing facility is equivalent to the amount of finished goods shipped from the same manufacturing facility to the distribution centres and final demand centres. Constraint (2) states that the total amount of finished goods shipped to distribution centres and final demand centres from a manufacturing facility cannot exceed its manufacturing capacity. Constraint (3) represents that the total amount of finished goods shipped from manufacturing facilities to a distribution centre is equal to the total amount of finished goods shipped from the same distribution centre to the final demand centres. Constraint (4) makes sure that the demand at a particular demand centre is satisfied from both the manufacturing facilities and distribution centres. Constraint (5) ensures that there would be exactly one manufacturing facility.

3.2. Factor Rating

As already mentioned, the set of locational factors relevant to a particular manufacturing facility is identified and subsequently the relative importance of the same is ascertained by securing opinions from the experts thoroughly familiar with the research problem. A sound mechanism should be in place to elicit support and engagement of the experts. Different experts might provide different weights to the locational factors. It is important to reach consensus with regard to the weights given to all the factors. The moderator plays a significant role to allow the experts in reaching consensus on finalizing weights of all the factors. Alternatively, the weights provided by individual experts on a particular factor are combined through geometric mean. In the next stage, the same experts are once again requested to evaluate all candidate locations on 1 – 5 scale, or 1 – 10 scale or 1 – 100 scale on all the locational factors. It is again necessary to reach consensus among the experts for evaluation of the factors across all candidate locations. Factor score of a particular factor relevant to a candidate location is computed by multiplying its weight with the corresponding rating provided on that factor. Finally the total factor score of a location is obtained by summing the factor scores across all factors. Mathematically this may be shown as follows:

$$S_j = \sum_{i=1}^{m} F_i L_{ij} \quad \forall\, j \tag{6}$$

$S_j \rightarrow$ Factor score of location j

$F_i \rightarrow$ Relative weight of factor i

$L_{ij} \rightarrow$ Rating assigned to i^{th} factor and j^{th} location

4. Case Study

The present study has been carried out in a corrugated box manufacturing company based in Pune, India. Corrugated box plays a vital role in logistics management as it is primarily used for safe and smooth transportation of goods from the sources of origin to the points of consumption. The Indian corrugated box manufacturing industry is presently worth INR 15,000 crore and has been registering a growth rate of 12-14% in the last five years (http://www.corrupack.com/industry.htm). There are over 10,000 corrugators spread across India, with average production of 45 lakh tonnes per annum. The industry is fragmented and dominated by micro, small and medium enterprises (MSMEs), and employs more than five lakh workers directly and indirectly (http://www.business-standard.com................margin-pressure-114033101193_1.html). XYZ Packaging, falling under the category of MSMEs, was established in 2013 by two young entrepreneurs. It supplies corrugated boxes to the customers located at different places of Maharastra, India. The manufacturing facility of the company is located at Chakan, Pune, which is almost 300 kms away from Mumbai towards south. Chakan is a hub of a number of corrugators. Some of them include Clarasion Enterprises, Kamal Enterprises, Sneh Packaging Solutions etc. Since inception, the company is facing tough competition from these manufacturers. XYZ packaging manufactures mainly three types of corrugated boxes: (1) 3 Ply Corrugated Box, (2) 5 Ply Corrugated Box and (3) 7 Ply Corrugated Box. Raw materials required for manufacturing corrugated box include kraft papers, adhesives, ink, stitching wire etc. out of which kraft paper accounts for around 70-75% of the total input cost.

4.1. Supply Chain of the Company under study

The supply chain of the company under study right from sourcing of inputs to the distribution of final products is discussed under three sub-sections: (1) Sourcing, (2) Internal Operation and (3) Distribution.

4.1.1. Sourcing

The current study has dealt with the sourcing of only major raw material, i.e. kraft paper. Kraft paper is mostly purchased from big suppliers which are situated in Vapi, Gujarat while at the same time a small proportion of kraft paper is also purchased from small suppliers located at Sangli, Aurangabad, and Ichalkaranji in Maharashtra. The quality of kraft paper sourced from Vapi, Gujarat is somewhat superior to the same sourced from Sangli, Aurangabad, and Ichalkaranji. Still XYZ Packaging procures certain percentage of kraft paper from the suppliers of Sangli, Aurangabad. and Ichalkaranji in order to meet occasional spike in demand as these suppliers are located close to the manufacturing facility. On the contrary, Vapi is located quite far-off from Chakan, Pune compared to the above three locations of the suppliers. The location of Vapi, Sangli, Ichalkaranji and Aurangabad is shown in the map of Sourcing and Distribution network of XYZ Packaging (Figure 1).

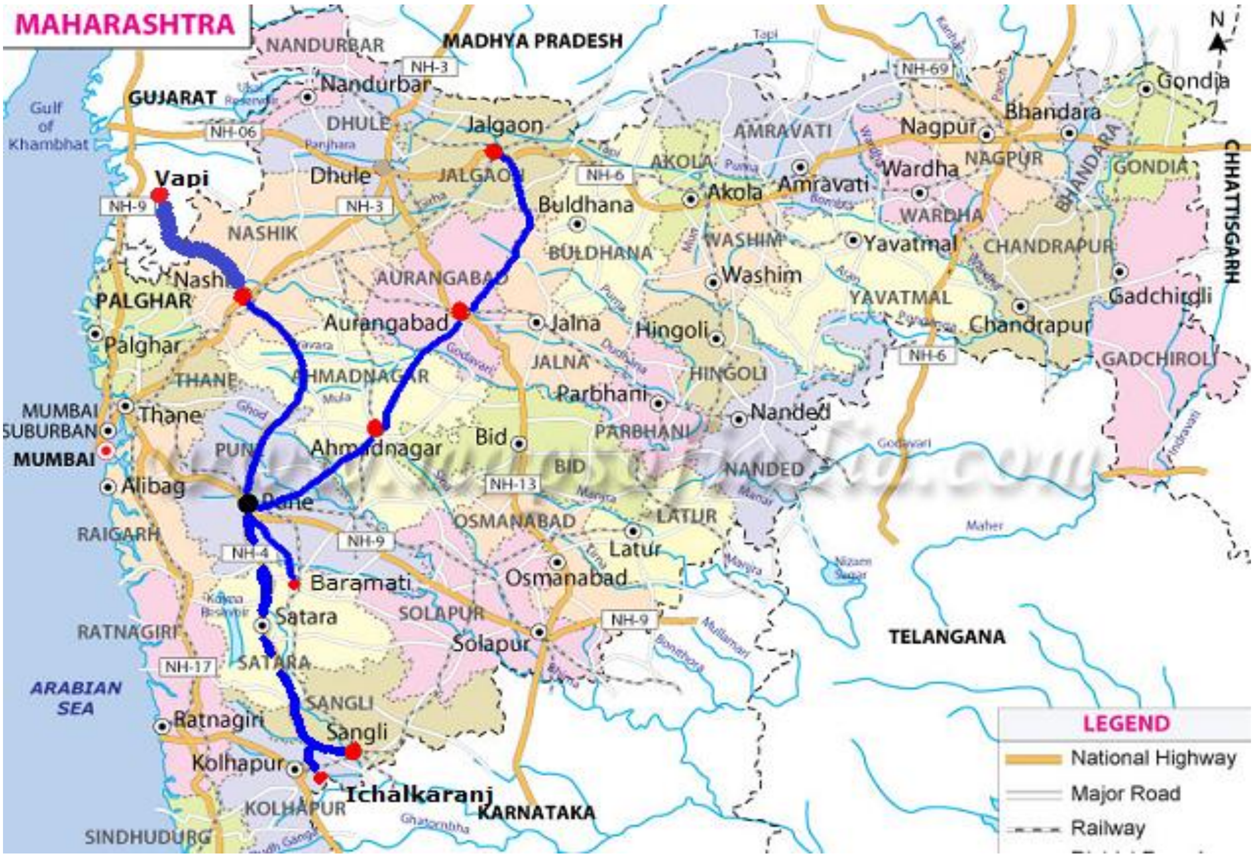

Figure 1. Sourcing and Distribution Network of XYZ Packaging (Source: www.mapsofindia.com)

As regards the purchase cost, the cost of kraft paper sourced from Vapi is slightly lower than the same sourced from the other three locations. Procurement frequency of kraft paper is usually once in a week from the big suppliers of Vapi while the same from small suppliers is almost half the procurement frequency of the big suppliers. Currently as much as 70% of the requirement of kraft paper is met by the big suppliers while the remaining portion is supplied by small suppliers. The lead time of procurement from big suppliers is around 3-4 days while the same is 1-2 days for small suppliers. Thus inventory carrying cost of kraft paper sourced from big suppliers is higher than the same sourced from small suppliers. The conversion factor for transformation of raw material to finished corrugated box is close to 1. Hence, the total amount of kraft paper sourced from the suppliers is assumed to be equal to the total amount of corrugated boxes produced by a manufacturer.

4.1.2. Internal Operation

XYZ packaging produces corrugated boxes weighing 3000 kilogram (kg) per day. The company works in only one shift of 8 hours. Machines take approximately 20 minutes for heating up after which the same gets ready for actual operation. Once machine set up is over, it can produce sheets/boxes continuously for 8 hours. However, the workers are given break for 30 minutes during lunch time and two tea breaks of 15 minutes each in an 8-hour shift. Thus the effective production takes place for almost 7 hours on daily basis, which enables the company to produce 428.57 kg corrugates boxes every hour. Thursday is an official holiday because of unavailability of power. The total weekly production of the company is 18000 Kg. To exploit economies of scale, finished goods are transported only once in a week. Considering 52 weeks in a year, maximum annual production of XYZ Packaging turns out to be 936,000 kg.

4.1.3. Distribution

Corrugated boxes are sold in different SKUs. However, order for any SKU or type is always placed in unit of kg in lieu of unit quantities. For example, no customer places order for an SKU of 3-ply 100 corrugated boxes of a particular dimension. Instead, if a 3-ply corrugated box of certain dimension weighs 2 kg, then the customer places order of 200 kg of that particular SKU. Currently customer base of XYZ Packaging is limited to the state of Maharashtra only. The boxes are sent to different district locations like Aurangabad, Baramati, Jalgaon, Nasik, and Ahmednagar. These district places have direct connectivity with Pune through different highways. Orders also come from several small places. However, all these orders get aggregated at one of the district places. For example, orders from Yawal, Raver, Bhusaval, and Chalisgaon get aggregated at Jalgaon. Orders from Dindori, Nifad, and Chandwar get aggregated at Nasik while orders from Sinnar and Igatpuri get aggregated at Ahmednagar. Company uses this order aggregation model to exploit economies of scale. Thus Jalgaon, Nasik, and Ahmednagar may be considered as transhipment node. The two remaining district places, Aurangabad and Baramati are considered as two other final demand nodes. Figure 1 containing sourcing and distribution network of XYZ Packaging shows three transhipment nodes and the two big demand centres. For the sake of clarity, another schematic diagram of sourcing and distribution network of XYZ Packaging is provided in Figure 2.

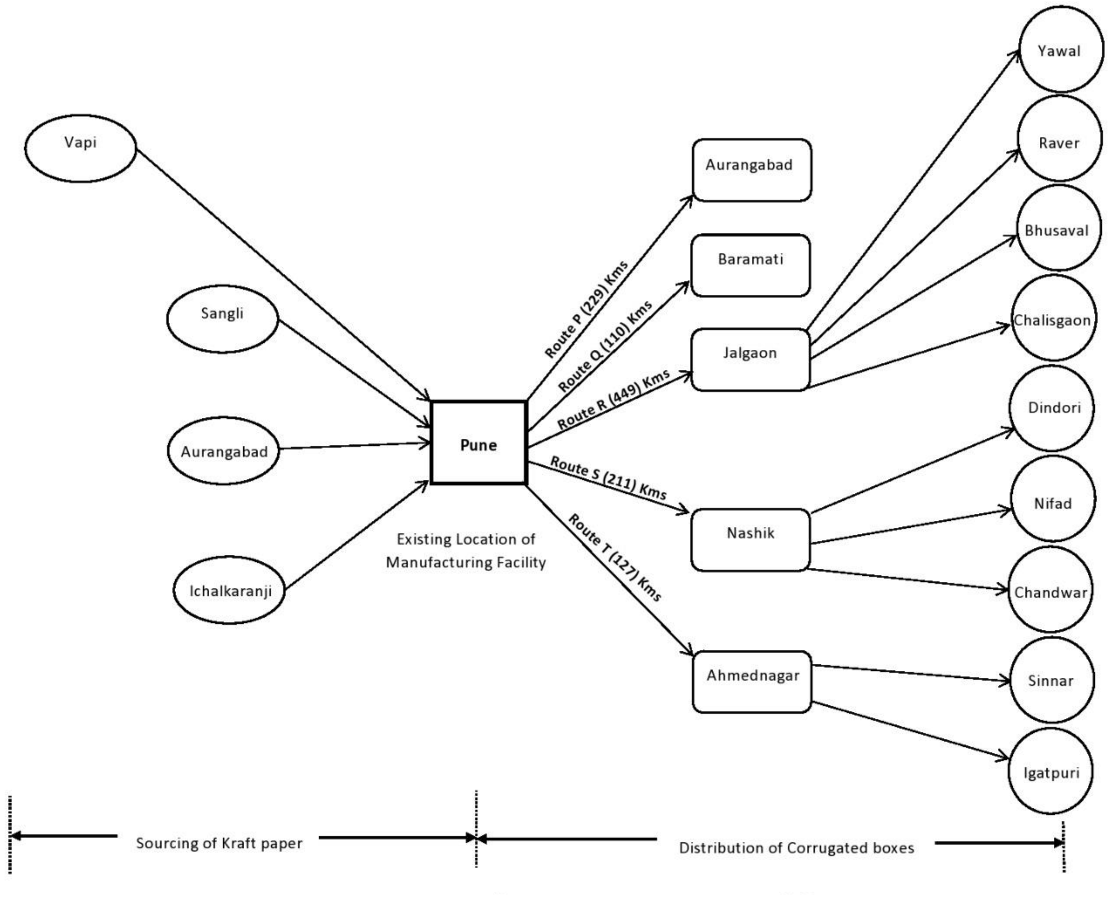

Figure 2. Sourcing and distribution network of XYZ packaging

As shown in Figure 1, all five districts have direct connectivity with Pune through State Highways. Further the details of each route from Pune towards outbound distribution and the corresponding distances are shown in Figure 2.

4.2. Challenges and Opportunities faced by the Company

One of the main challenges being faced by the company is steep hike in the cost of raw materials including the cost of kraft paper. However, customers are very reluctant to pay the company even a moderate increase in the price of corrugated boxes due to increase in the cost of raw materials. Under this circumstances, the margin has become so thin that the survival of the company has been at stake. The option available before the promoters of the company is to identify different elements of costs across the entire supply chain right from sourcing of inputs to the distribution of final products and explore the possibility of reducing the cost of some of these elements. The total supply chain cost includes inbound logistics cost, purchase cost of raw materials, operating cost of the plant, and outbound logistics cost. All elements of the cost considering Pune as the manufacturing facility were carefully evaluated by the company and it was found that there exists little possibility of minimizing any of these elements of inbound logistics cost. The elements of inbound logistics cost include transportation cost from suppliers to the manufacturing facility and inventory carrying cost of raw materials. The promoters also observed that there are certain opportunities available at two prominent locations which are being offered by the Government of Maharastra with a view to improving the economic conditions of the same. In addition, there are certain economic advantages in these locations expected to be available in near future. The issue faced by the promoters is whether to avail the incentives in one of these locations and also to realise the expected future advantages by relocating the plant to one of the new locations. Thus the option available before the company is to consider the above two candidate locations, estimate the elements of inbound logistics cost, operating cost and outbound logistics cost in these locations and evaluate the qualitative attributes of the same. The two new locations identified by the promoters of the company are Baramati and Ahmednagar. We need to investigate the entire cost of operations across all three locations which would give us an idea about the total supply chain cost in all these locations. We have captured this problem in terms of SCND problem and formulated the same in terms of MILP model.

4.3. Customized Model

The MILP model considered in this study has considered the candidate locations as binary variables and the remaining decision variables as linear variables.

4.3.1. Assumptions of the Model

- Kraft paper is considered as the only raw material in the present study as it constitutes 70 – 75% of the finished goods.
- For kraft paper sourced from big suppliers, cycle inventory is computed on the basis of average amount of kraft paper maintained on weekly basis.
- For kraft paper sourced from big suppliers, pipeline inventory is computed on the basis of average lead time of 3.5 days and average consumption on daily basis.
- For kraft paper sourced from small suppliers, cycle inventory is computed on the basis of average amount of kraft paper maintained on bi-weekly basis.
- For kraft paper sourced from small suppliers, pipeline inventory is computed on the basis of average lead time of 1.5 days and average consumption on daily basis.
- Since the demand of corrugated boxes or the lead time of procurement does not vary much, safety inventory has not been considered in the present study.
- Shipping cost from suppliers to manufacturers and also from manufacturers to demand centres has been computed on the basis of transportation cost per unit weight for different routes taking into consideration varying distances in those routes.
- Ordering cost has not separately been considered.

4.3.2. Sets

K: Set of big suppliers $k \in K$
L: Set of small suppliers $l \in L$
M: Set of manufacturers $m \in M$
N: Set of transhipment nodes $n \in N$
O: Set of final customers, $o \in O$

4.3.3. Parameters

D_o : Demand of corrugated boxes by final customer 'o'
B_m : Capacity of manufacturing facility 'm'
F_m : Fixed cost of manufacturing facility 'm'
P_b : Per unit purchase cost of kraft paper from big supplier 'b'
P_s : Per unit purchase cost of kraft paper from small supplier 's'
C_{bm} : Shipping cost per unit from big supplier 'b' to manufacturing facility 'm'
C_{sm} : Shipping cost per unit from small supplier 's' to manufacturing facility 'm'
$h * P_b$: Inventory carrying cost of kraft paper sourced from big supplier ‘b’
$h * P_s$: Inventory carrying cost of kraft paper sourced from small supplier ‘s’
C_{mo} : Shipping cost per unit from manufacturing facility 'm' to final demand centre 'o'
C_{mn}: Shipping cost per unit from manufacturing facility 'm' to transhipment node 'n'
C_{no} : Shipping cost per unit from transhipment node 'n' to final customer 'o'
ά : Allocation of total customer demand in terms of percentage to big suppliers
h : Percentage inventory holding cost per unit per annum

4.3.4. Decision variables

X_{bm} : Amount of kraft paper to be purchased from big supplier ‘b' by manufacturing facility 'm'
X_{sm} : Amount of kraft paper to be purchased from small supplier 's' by manufacturing facility 'm'
Y_m : 1, if manufacturing facility is open
0, Otherwise
X_{mo} : Amount of corrugated boxes to be shipped from manufacturing facility 'm' to final demand centre 'o'
X_{mn} : Amount of corrugated boxes to be shipped from manufacturing facility 'm' to transhipment node 'n'
X_{no} : Amount of corrugated boxes to be shipped from transhipment node 'n' to final demand centre 'o'

4.3.5. Formulation

The problem can be formulated as a mixed integer linear programming (MILP) model. The objective function and the constraints are mentioned below.

Minimize Z =

$$\sum_{b\in B}\sum_{m\in M} P_b X_{bm} + \sum_{s\in S}\sum_{m\in M} P_s X_{sm} + \sum_{b\in B}\sum_{m\in M} C_{bm} X_{bm} + \sum_{s\in S}\sum_{m\in M} C_{sm} X_{sm} +$$
$$\sum_{b\in B}\sum_{m\in M}\left(0.5*\frac{1}{52}+3.5*\frac{1}{52}*\frac{1}{7}\right)*hP_b X_{bm} + \sum_{s\in S}\sum_{m\in M}\left(0.5*\frac{1}{104}+1.5*\frac{1}{52}*\frac{1}{7}\right)*hP_s X_{sm} +$$
$$\sum_{m\in M}\sum_{o\in O} C_{mo} X_{mo} + \sum_{m\in M}\sum_{n\in N} C_{mn} X_{mn} + \sum_{n\in N}\sum_{o\in O} C_{no} X_{no} + \sum_{m\in M} F_m Y_m$$

The objective function attempts to minimize the cost of operation which includes both variable cost and fixed cost of operation. The first nine elements indicate variable costs while the last element represents the fixed cost. The first and the second element of the above expression indicate total purchase cost of kraft materials sourced from big suppliers and small suppliers respectively. The third and the fourth element include the shipping cost incurred in transporting the kraft materials from big suppliers and small suppliers respectively to the manufacturing facility. The fifth and the sixth element denote the inventory carrying cost incurred in connection with sourcing kraft materials from big suppliers and small suppliers respectively. Both cycle inventory and pipeline inventory have been incorporated in the fifth and the sixth element while computing inventory carrying cost. Kraft materials are sourced from big suppliers once every week while the same is sourced from small suppliers once every two weeks. Thus the cycle inventory for big and small suppliers has been computed as half the amount purchased every week $(0.5 * X_{bm}/52)$ and half the amount purchased every two weeks $(0.5 * X_{sm}/104)$ respectively. Further it takes an average of 3.5 days and 1.5 days to source kraft materials from big suppliers and small suppliers respectively. Thus the pipeline inventory from big suppliers and small suppliers is computed as the amount required in 3.5 days $(3.5 * X_{bm} * 1/52 * 1/7)$ and the amount required in 1.5 days $(1.5 * X_{sm} * 1/52 * 1/7)$ respectively. The seventh, eighth and the ninth element indicate the respective shipping cost of corrugated box from manufacturing facility to final demand centre, from manufacturing facility to transhipment node and from transhipment node to final demand centre. Finally the last element of the above expression indicates the fixed cost of operation.

Subject to

Allocation of final total customer demand to small and big suppliers

$$\sum_{b\in B} X_{bm} = \alpha \sum_{o\in O} D_o \qquad \forall m \tag{7}$$

$$\sum_{s\in S} X_{sm} = (1-\alpha) \sum_{o\in O} D_o \qquad \forall m \tag{8}$$

Balanced constraints at manufacturing facility

$$\sum_{b\in B} X_{bm} + \sum_{s\in S} X_{sm} = \sum_{n\in N} X_{mn} + \sum_{o\in O} X_{mo} \qquad \forall m \tag{9}$$

Capacity constraints of manufacturing facility

$$\sum_{n\in N} X_{mn} + \sum_{o\in O} X_{mo} \le B_m Y_m \qquad \forall m \tag{10}$$

Balanced constraints at transhipment nodes

$$\sum_{m\in M} X_{mn} = \sum_{o\in O} X_{no} \qquad \forall n \tag{11}$$

Demand constraints

$$\sum_{m\in M} X_{mo} + \sum_{n\in N} X_{no} = D_o \qquad \forall o \tag{12}$$

Manufacturing facility constraint

$$\sum_{m\in M} Y_m = 1 \tag{13}$$

Equation (7) states that a fraction of total demand is assigned to big suppliers while equation (8) states that the remaining fraction of total demand is assigned to small suppliers. Equation (9) makes sure that the total amount of kraft materials sourced from big suppliers and small suppliers to a manufacturing facility is equal to the total amount of corrugated boxes shipped from the manufacturing facility to the transhipment nodes and final demand centres. Equation (10) states that the total amount of corrugated boxes shipped to transhipment nodes and final demand centres from a manufacturing facility cannot exceed its manufacturing capacity. Equation (11) states that the total amount of corrugated boxes shipped from manufacturing facilities to a transhipment node is equal to the total amount of corrugated boxes shipped from a transhipment node to the final demand centres. Equation (12) makes sure that the demand at a particular demand centre is satisfied from both the manufacturing facilities and transhipment nodes. Equation (13) ensures that there would be exactly one manufacturing facility.

4.4. Data

The data pertaining to the purchase cost of kraft paper, shipping cost and inventory carrying cost of kraft paper from both big and small suppliers to Pune is provided in Appendix A. Annual demand of corrugated boxes emanating from the final demand centres is shown in Appendix B. Appendix C captures shipping cost per unit from all three locations to the two final demand centres and three transhipment nodes. Transportation of finished corrugated boxes from Pune to the final demand centres takes place with the help of both single axle and multi axle trucks. Appendix D shows the basis of per unit transportation cost of corrugated boxes from Pune to the two final demand centres and three transhipment nodes. Transportation cost includes fuel charges and expenses on several other heads. The expenditure on other heads is categorized under two heads: (1) packaging & handling charges, and (2) miscellaneous charges. Packaging and handling charges include the expenditure incurred in connection with the covering of cargo with tarpaulin to protect it from rain and abnormal atmospheric conditions, loading and unloading of boxes etc. Miscellaneous charges include the expenses incurred in the context of documentation, insurance, weighing of truck etc. Appendix E includes the data on transportation cost per unit from three transhipment nodes to the remaining nine (final) demand centres. The estimates of different elements of operating costs of all three locations are provided in Appendix F. This estimate is based on annual production run of 936,000 kg of corrugated box. For the sake of comparison, maximum annual production capacity of all three locations is assumed to be the same, i.e. 936,000 kg. The estimate of in-plant operations cost shown in Appendix F reveals that the cost of operations at Pune is quite high compared to both Ahmednagar and Baramati.

4.5. Numerical results

The mathematical model formulated above indicates a four echelon network consisting of one big supplier and three small suppliers at the first echelon, one manufacturer each at three locations at second echelon, three transhipment nodes and two demand centres at third echelon and finally nine demand centres at the fourth echelon. The model consists of 39 decision variables and 23 constraints. Out of 39 decision variables, 36 are linear variables and the remaining three are binary variables. The model was run in Excel solver based on the data collected in the model parameters as shown in Appendix A through G. The output of this model gives rise to an optimal solution which selects Ahmednagar as the new destination of the manufacturing facility. In addition, it also shows the amount of kraft material sourced from big supplier and small suppliers on yearly basis. The amount of corrugated boxes shipped directly from Ahmednagar to two demand centres is computed by the model. Further, the amount of corrugated boxes shipped from the manufacturing facility to three transhipment nodes and finally from the transhipment nodes to the remaining demand centres are also revealed by the model. All values have been computed on annual basis. The total cost including both variable and fixed cost of this allocation turns out to be INR 431,86,044/-. Table 3 provides the details of the values of decision variables, which have assumed non-negative values.

Table 3. Values of the decision variables

Variable	Value
Amount of kraft material sourced from big supplier located at Vapi	655,200 kg
Amount of kraft material sourced from small supplier located at Aurangabad	280,800 kg
Amount corrugated boxes shipped from Ahmednagar to Aurangabad (final demand node)	104,000 kg
Amount corrugated boxes shipped from Ahmednagar to Baramati (final demand node)	52,000 kg
Amount corrugated boxes shipped from Ahmednagar to Jalgaon (Transhipment node)	312,000 kg
Amount corrugated boxes shipped from Ahmednagar to Nashik (Transhipment node)	364,000 kg
Amount corrugated boxes shipped from Ahmednagar to Ahmednagar (Transhipment node)	104,000 kg
Amount corrugated boxes shipped from Jalgaon (Transhipment node) to Yawal (final demand centre)	52,000 kg
Amount corrugated boxes shipped from Jalgaon (Transhipment node) to Raver (final demand centre)	156,000 kg
Amount corrugated boxes shipped from Jalgaon (Transhipment node) to Bhusaval (final demand centre)	52,000 kg
Amount corrugated boxes shipped from Jalgaon (Transhipment node) to Chaligaon (final demand centre)	52,000 kg
Amount corrugated boxes shipped from Nashik (Transhipment node) to Dindori (final demand centre)	260,000 kg
Amount corrugated boxes shipped from Nashik (Transhipment node) to Nifad (final demand centre)	52,000 kg
Amount corrugated boxes shipped from Nashik (Transhipment node) to Chandwar (final demand centre)	52,000 kg
Amount corrugated boxes shipped from Ahmednagar (Transhipment node) to Sinnar (final demand centre)	52,000 kg
Amount corrugated boxes shipped from Ahmednagar (Transhipment node) to Igatpuri (final demand centre)	52,000 kg

The above table reveals that 16 linear decision variables assume positive values. In addition, one binary integer variable takes on the value of 1. The remaining 20 linear variables and two binary variables assume the value of zero. The overall result gives rise to an optimum solution in terms of minimum total cost. However, the robustness of the model needs to be checked in order to evaluate its performance on different parameters. This is carried out through sensitivity analysis and shown in the following section.

4.5.1. Sensitivity analyses

The parameters that were considered to investigate the impact on total cost include demand, amount of kraft material sourced from big and small suppliers, operating cost of all three locations, and finally the material cost. Accordingly, we have investigated the impact of the variation in demand, variation in the amount of kraft material sourced from big and small suppliers, variation in operating cost of all three locations, and finally variation in the material cost on the total cost.

4.5.1.1 Impact of variation in demand

We vary the demand of corrugated boxes by 10%, 20% and 30% for all three locations: Ahmednagar, Baramati and Pune individually and find out its impact on the total cost of operations. It is found that the location Ahmednagar turns out to be the best in terms of the total cost of operation for all the above scenarios. The cost of operations at Pune is slightly higher compared to the same at Ahmednagar. The cost of operations at Baramati is the highest amongst all three locations for all scenarios. The phenomenon is elucidated with the help of Figure 3 as shown below. The horizontal axis indicates variation in demand while the vertical axis denotes the total cost of operations.

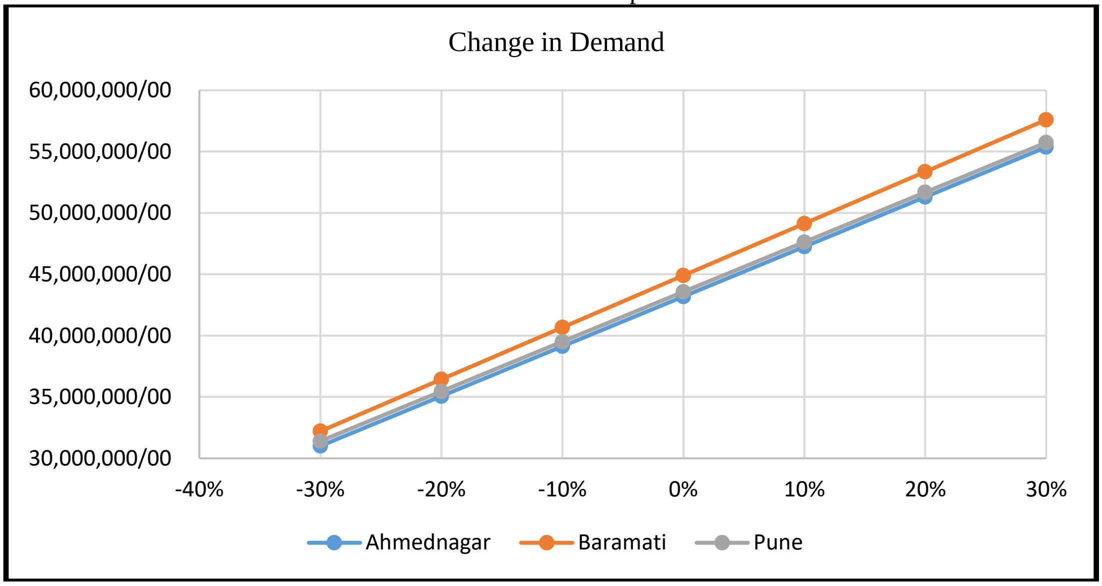

Figure 3. Impact of variation in demand on total cost

4.5.1.2. Impact of variation in the amount of kraft material sourced from big and small suppliers

We have elaborately described the sourcing practices of XYZ Packaging with specific reference to kraft material in Section 3.1.1. It is mentioned that the company sources 70% of kraft material from the big suppliers while the remaining 30% is sourced from the small suppliers. In this analysis, we have varied the proportion of kraft material sourced from big and small suppliers and determined its impact on the total cost of operations. The analysis reveals that when the percentage of kraft material sourced from big supplier is gradually increased from 70% to 100%, the total cost of operations reduces for all three locations, when each location is considered separately. Ahmednagar turns out to be the location with the least total cost of operations with Pune and Baramati coming out to be second and third respectively. Further when the proportion of kraft material sourced from big suppliers is gradually decreased from 70% to 40%, the total cost of operations demonstrates an increasing trend for all three locations in the same order. The phenomenon is explained with the help of Figure 4. The horizontal axis indicates the percentage of kraft material sourced from big and small suppliers. For example, 40% shown in Figure 4 implies that 40% of kraft material is sourced from a big supplier while the remaining 60% is sourced from small suppliers. The vertical axis captures the total cost of operations.

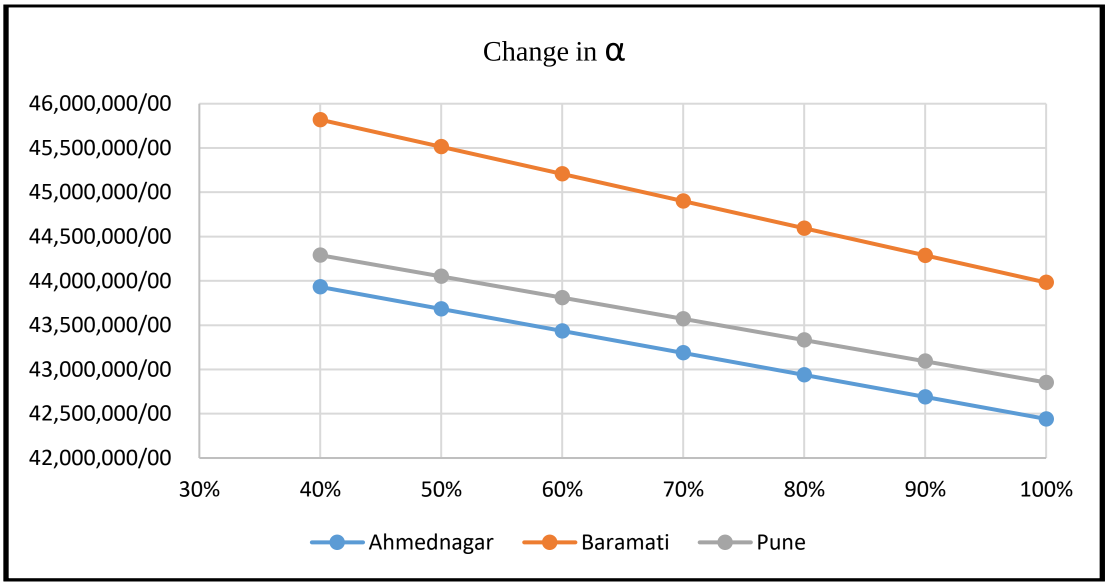

Figure 4. Impact of variation in the amount of kraft paper sourced from big and small suppliers on total cost

4.5.1.3. Impact of variation in operating cost

We vary the operating cost of all three locations separately by 5%, 10%, 15%, 20%, 25% and 30% and demonstrate its impact on the total cost of operations. Ahmednagar turns out to be the location with the least cost of operations followed by Pune and Baramati under all scenarios. This is evident from Figure 5 as shown below. The horizontal axis shows the variation in operating cost while the vertical axis indicates the total cost of operations.

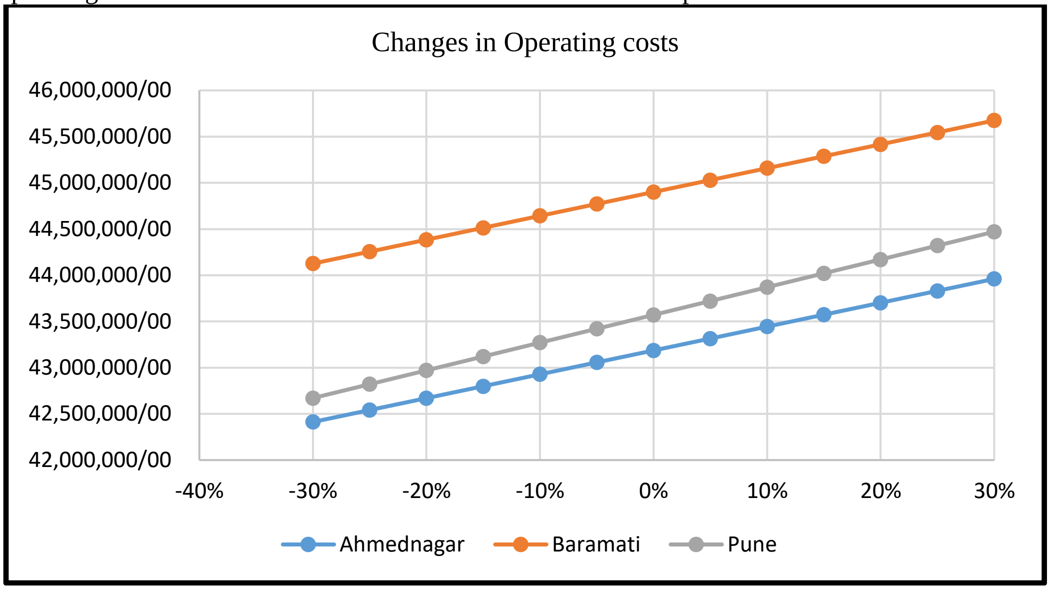

Figure 5. Impact of variation in operating cost on total cost

4.5.1.4. Impact of variation in materials cost

We vary the material cost in all three locations separately by 5%, 10% and 15% and find out its impact on the total cost of operations. It is again found that Ahmednagar turns out to be the location with the least total cost of operations followed by Pune and Baramati under all scenarios. This is explained with the help of Figure 6 as shown below. The horizontal axis indicates variation in material costs while the vertical axis represents the total cost of operations.

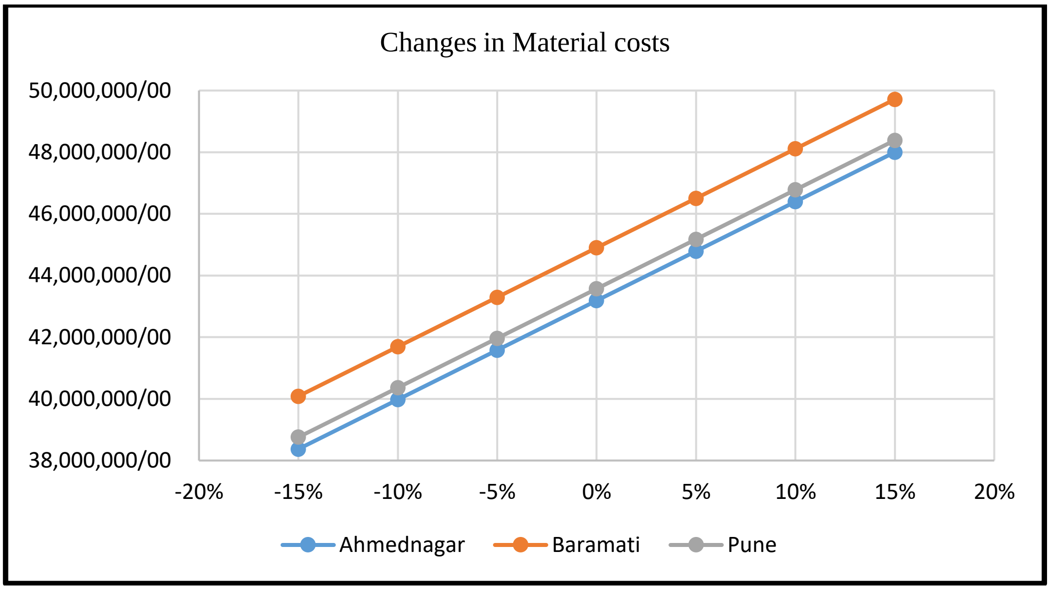

Figure 6. Impact of variation in material costs on total cost

The results of sensitivity analyses demonstrate that under all possible scenarios, Ahmednagar turns out to be the destination with the least total cost of operations. This revelation would definitely motivate the location planners to relocate the existing corrugated box manufacturing facility currently situated at Pune to Ahmednagar. However, the decision to relocate should not be merely based on cost dimension. There are other important strategic and qualitative factors which are unique to all three locations and should not evade the attention of the location planners. These factors should be properly accounted for in facility relocation decision. This is demonstrated in the following section.

4.6. Factor Rating

The factors relevant to facility location/relocation problem have been extracted from the extant literature as shown in table 2. The suitability of these factors with specific reference to facility relocation problem of a packaging plant was ascertained by consulting several experts. The experts include two promoters of the company and two external professionals from packaging industry who were well-versed with the market scenario, supply chain, industry dynamics and the locational attributes of all three locations. They observed that all these factors are relevant to facility relocation problem of a packaging plant. The above factors ratified by the experts served as the basis for both quantitative and qualitative evaluation of the existing location and two more candidate locations. The methodology proceeds through several steps as discussed below.

Step 1 involves determination of the relative importance of all factors. For this purpose, all four experts were explained the purpose of the study and requested to take active participation in the same due to their rich experience. One of the authors visited them in person by taking prior appointment for the above purpose. All of them were invited on a convenient date and time at a designated place. The experts were very kind to give their consent. The purpose of the meeting was to capitalize on their collective wisdom and allow them to reach consensus in respect of the relative importance of the factors. The relative importance of the factors was to be determined in such a manner that the sum of the weights of all factors turned out to be one. At the start of the meeting, all the experts were given the list of factors and requested to engage themselves in discussion with a view to determining the weight of each factor and finally reaching consensus with regard to its weight. The author present in the meeting moderated the discussion.

Step 2 involves evaluation of three locations individually on all 12 factors. A 5-point Likert scale with the values ranging from 1 = very poor to 5 = very good was considered as an instrument for evaluating the three locations on the above factors. The elemental cost of supply chain of all three locations along with the sensitivity report was presented to the experts in order to enable them to make realistic assessment of cost factors of these locations in terms of Likert scale. The experts were requested to reach consensus in evaluating the locations on all factors in lieu of giving individual rating on the same. This approach encouraged the experts to engage themselves in lively discussion which, in turn, brought out all nuances associated with a particular factor for a particular location. This finally helped them reach consensus in evaluating the locations on all factors.

Step 3 involves determination of factor scores of all factors across three locations and finally the composite score of three locations. The factor score of a factor of a particular location is computed by multiplying the score obtained on the factor with the corresponding score obtained on its relative importance. Thus factor scores of all factors across all three locations are obtained. Finally composite score of each individual location is determined by summing the factor scores of all factors. This is shown in table 4.

Table 4. Evaluation of locations

Factors	**Importance Weight**	**Performance rating of locations**			**Factor Scores of locations**		
		Pune	**Ahmednagar**	**Baramati**	**Pune**	**Ahmednagar**	**Baramati**
F1	0.1	5	4	3	0.5	0.4	0.3
F2	0.1	4	5	5	0.4	0.5	0.5
F3	0.1	3	4	5	0.3	0.4	0.5
F4	0.1	3	4	4	0.3	0.4	0.4
F5	0.05	5	4	3	0.25	0.20	0.15
F6	0.1	5	4	3	0.5	0.4	0.3
F7	0.05	5	4	3	0.25	0.20	0.15
F8	0.05	5	4	3	0.25	0.20	0.15
F9	0.2	3	5	5	0.6	1.0	1.0
F10	0.05	3	4	4	0.15	0.20	0.20
F11	0.05	5	4	3	0.25	0.20	0.15
F12	0.05	5	4	3	0.25	0.20	0.15
Composite score of the three locations					**4.00**	**4.30**	**3.95**

5. Managerial Implications

The results of factor rating reveal that Ahmednagar turns out to be the most attractive location. This is somewhat consistent with the results obtained through quantitative modelling approach. If we consider the locational attributes associated with Baramati, we find that the people in and around Baramati are primarily dependent on agriculture and farming for their livelihood. Of late, many industries have flourished in Baramati owing to the favourable conditions for growth. The advantages associated with setting up a corrugated packaging plant include low rental rate of shed and the reduced cost of labour. However, Baramati, being a small city, is not properly connected to the major cities of India. Even it does not have direct connectivity with Mumbai. Further the distance of Baramati from the major suppliers of raw materials of corrugated box is more than the same between Pune and its major suppliers of raw materials. The labour available at Baramati is mostly unskilled. As regards the locational traits of Ahmednagar, it seems to have immense economic potential and is expected to be an economic powerhouse in Maharastra in the coming decade like Nagpur and Pune. The other locational advantages in favour of Ahmednagar include low rental rate of shed and the low cost of labour. However, compared to Pune, the connectivity of Ahmednagar with other cities of India is relatively poor. Major suppliers of raw materials including kraft material are mostly located at moderate distances from Ahmednagar. The labour available at Ahmednagar is not as skilled as the same available at Pune. Finally Pune is considered to be one of India's major industrial hubs. Connectivity of Pune with other major cities including Mumbai is well developed. It possesses sound infrastructure and has abundant supply of skilled labour. Maintenance and repair services are easily available at Pune. Major suppliers of raw materials are mostly located at nearby places. However, the rental rate of shed and the cost of labour at Pune is the highest amongst all three locations.

Considering the pros and cons of all three locations in respect of qualitative features, the total annual cost of operations and also the results of sensitivity analyses, it seems that the location planners are left with the option to choose between Ahmednagar and Pune. As already mentioned, Ahmednagar is a fast growing industrial city while Pune is a well-developed industrial hub with the city already reaching the saturation limit in terms of its carrying capacity. If the future volume of demand continues to increase significantly, in that case relocating the manufacturing facility of corrugated box to Ahmednagar would enable the company to derive higher economies of scale in its operations. The management can devise suitable strategy for improving the skill base of labour at Ahmednagar keeping in mind the growth in the volume of demand of corrugated boxes. However, if the increase in demand in corrugated boxes is not very significant, relocation of manufacturing facility to Ahmednagar from Pune will result in marginal decrease in the total cost of operations. Thus managers need to incorporate all pertinent factors in a holistic manner while taking decision in respect of relocation of corrugated box manufacturing facility.

6. Conclusion

The present study has attempted to evaluate a facility relocation problem of a packaging plant by demonstrating an integrated framework through integration of quantitative modelling methodology with the factor rating technique. In the first phase, the elements of supply chain cost including inbound logistics cost, in-plant operations cost and outbound logistics cost were considered for all three locations and evaluated with the help of MILP model and the subsequent sensitivity analyses. The second phase attempts to capture all quantitative and qualitative elements and evaluate them on a common scale. The outcome of the first phase enabled the experts to realistically translate the elements of cost into suitable scale in the second phase. The rich experience of experts further facilitated the evaluation of qualitative attributes through healthy discussion. Finally the composite score obtained on three locations helped the promoters make a comparison among these locations. The quantitative analysis coupled with qualitative investigation would definitely aid the managers in taking a judicious decision in respect of relocation of corrugated box manufacturing facility. The facility location or relocation problem itself is nothing new in operations and supply chain literature. However, developing an integrated framework combining quantitative modelling with a qualitative tool and subsequently demonstrating the framework with reference to a real case on facility relocation problem is somewhat unique. This framework allows the synthesis of quantitative modelling with the rich experience of experts and finally helps decision makers arrive at a decision. The framework could also be applied to other related problems. Thus it has made a significant contribution to the existing body of supply chain literature.The study suffers from few limitations. The model considered in the study is a deterministic one. It has not incorporated safety stock into the total volume of inventory. The framework suggested in this study has not considered the actions or strategies being contemplated by other corrugated box manufacturers in view of the challenges faced by them and also the opportunities offered in other locations. Future studies should attempt to incorporate these aspects into facility relocation problem. The model developed in the present study has not explicitly incorporated time dimension. Future researchers may consider introducing multi-period dimension into the model.

References

Afshari, H., Amin-Nayeri, M. and Ardestanijaafari, A. (2010). Optimizing inventory decisions in facility location within distributed network design. *Proceedings of the Int. Multi-Conference of Engineers and Computer Scientists,* Vol. 3, March 17 – 19, 2010, Hong Kong.

Afshari, H. and Peng, Q. (2014). Challenges and solution for location of healthcare facilities. *Industrial Engineering & Management,* Vol. 3 (2), pp. 1 – 12.

Amin, S.H. and Baki, F. (2017). A facility location model for global closed –loop supply chain network design. *Applied Mathematical Modelling,* Vol. 41, pp. 316 – 330.

Amin, S.H. and Zhang, G. (2013). A multi-objective facility location model for closed-loop supply chain network under uncertain demand and return. *Applied Mathematical Modelling,* Vol. 37, pp. 4165 – 4176.

Amiri, A. (2006). Designing a distribution network in a supply chain system: formulation and efficient solution procedure. *European Journal of Operational Research,* Vol. 171, pp. 567 – 576.

Arabani, A.B. and Farahani, R.Z. (2012). Facility location dynamics: an overview of classifications and applications. *Computers & Industrial Engineering,* Vol. 62, pp. 408 – 420.

Avittathur, B., Shah, J., Gupta, O.K. (2005). Distribution centre location modelling for differential sales tax structure. *European Journal of Operational Research,* Vol. 162, pp. 191 – 205.

Azarmand, Z. and Neishabouri Jami, E. (2009). Location allocation problem. In *R.Z. Farahani & M. Hekmatfar (Eds.) Facility location: Concepts, models, algorithms and case studies*. *Contributions to management science*. Heidelberg: Physica-Verlag. pp. 93 – 109.

Berman, O. and Drezner, Z. (2006). Location of congested capacitated facilities with distance-sensitive demand. *IIE Transactions*, Vol. 38, pp. 213 – 221.

Bilir, C., Ekici, S.O. and Ulengin, F. (2017). An integrated multi-objective supply chain network and competitive facility location model. *Computers & Industrial Engineering*, Vol. 108, pp. 136 – 148.

Bucci, M.J., Woolard, R., Joines, J., Thoney, K., King, R.E. (2014) Incorporating economies of scale into facility location problems in carpet recycling. *The Journal of the Textile* Institute, Vol. 105 (12), pp. 1300 – 1311.

Carrincazeaux, C. and Coris, M. (2015) why do firms relocate? Lessons from a regional analysis. *European Planning Studies*, Vol. 23(9), pp. 1695 – 1721.

Chakraborty, A.K. (2005). Global plant capacity and product allocation with pricing decisions. *European Journal of Operational Research*, Vol. 165, pp. 157–181.

Daneshzand, F. and Shoeleh, R. (2009) Multi-facility location problem. In *R.Z. Farahani & M. Hekmatfar (Eds.) Facility location: Concepts, models, algorithms and case studies. Contributions to management science*. Heidelberg: Physica-Verlag. pp. 69–92.

Das, D. and Barman, D. (2010) An AHP framework of supplier evaluation with reference to high-value and critical items: a case study. *International Journal of Services and Operations Management*, Vol. 7 (4), pp. 465–482.

Daskin, M.S. (2008). What you should know about location modelling. *Naval Research Logistics,* Vol. 55, pp. 283–294.

Drezner, Z. and Wesolowsky, G.O. (1991). Facility location when demand is time dependent. *Naval Research Logistics*, Vol. 38 (5), pp. 763–777.

Dijk, J.V. and Pellenbarg, P.H. (2000) Firm relocation in decisions in The Netherlands: An ordered logit approach. *Papers in Regional Science*, Vol. 79, pp. 191–219.

Erbıyık, H., Özcan, S. and Karaboğa, K. (2012). Retail store location selection problem with multiple analytical hierarchy process of decision making an application in Turkey. *Procedia Social and Behavioural Sciences*, Vol. 58, pp. 1405–1414.

Eslamipoor, R. and Sepehriar, A. (2014). Firm relocation as a potential solution for environment improvement using a SWOT-AHP hybrid method. *Process Safety and Environmental Protection*, Vol. 92, pp. 269 –276.

Essaadi, I., Grabot, B., Féniès, P. (2019). Location of global logistic hubs within Africa based on a fuzzy multi-criteria approach. *Computers & Industrial Engineering*, Vol. 132, pp. 1–22.

Farahani, R.Z., Abedin, M. and Sharahi, S. (2009). Dynamic facility location problem. In *R.Z. Farahani & M. Hekmatfar (Eds.) Facility location: Concepts, models, algorithms and case studies. Contributions to management science.* Heidelberg: Physica-Verlag. pp. 347–372.

Farahani, R.Z., SteadieSeifi, M. and Asgari, N. (2010) multiple criteria facility location problems: A survey. *Applied Mathematical Modelling*, Vol. 34, pp. 1689–1709.

Felice, F.D., Petrillo, A., Silvestre, A. (2015) Offshoring: Relocation of production processes towards low-cost countries through the project management & process reengineering performance model. *Business Process Management Journal*, Vol. 21(2), pp. 379-402.

Gu, W., Wang, X. and McGregor, S.E. (2010). Optimization of preventive healthcare facility locations. *International Journal of Health Geographics*, Vol. 9(17), pp. 1–16.

Guneri, A.F. Cengiz, M., Seker, S. (2009) A fuzzy ANP approach to shipyard location selection. *Expert Systems with Applications*, Vol. 36 (4), pp. 7992–7999.

Günes, E.D. and Nickel, S. (2015). Location problems in healthcare. *Location Science*. Chapter 21, pp. 555–579.

Huang, G. Q., Zhang, A., Liu, X. (2013) "A supply chain configuration model for reassessing global manufacturing in China", *Journal of Manufacturing Technology Management*, Vol. 24(5), pp. 669-687.

Kinkel, S. (2012) Trends in production relocation and backshoring activities: Changing patterns in the course of the global economic crisis. *International Journal of Operations & Production Management*, Vol. 32 (6), pp. 696–720.

Koc, E., Burhan, H.A. (2016) Analytic network process in location selection and its application to a real-life problem. *International Scholarly and Scientific Research & Innovation*, Vol. 10 (3), pp. 507–512.

Lim, G.J. and Sonmez, A.D. (2013). γ-Robust facility relocation problem. *European Journal of Operational Research*, Vol. 229, pp. 67–74.

Lu, D., Gzara, F., Elhedhli, S. (2014) Facility location with economies and diseconomies of scale: models and column generation heuristics. *IIE Transactions*, Vol. 46, pp.585–600.

Mahadevan, B. (2017) *Operations Management: Theory and Practice*. Pearson Education, 3rd edition, Noida, India.

Min, H. and Melachrinoudis, E. (1999) the relocation of a hybrid manufacturing/distribution facility from supply chain perspectives: a case study. *Omega*, Vol. 27, pp. 75–85.

Melachrinoudis, E. and Min, H. (2000). The dynamic relocation and phase-out of a hybrid, two- echelon plant/warehousing facility: a multiple objective approach. *European Journal of Operational Research*, Vol. 123(1), pp. 1–15.

Melo, M.T., Nickel, S. and da Gama, F. S. (2005). Dynamic multi-commodity capacitated facility location: a mathematical modelling framework for strategic supply chain planning. *Computers & Operations Research*, Vol. 33, pp. 181–208.

Melo, M.T., Nickel, S. and da Gama, F. S. (2009). Facility location and supply chain management – A review. *European Journal of Operational Research*, Vol. 196, pp.401–412.

Müller, S. and Haase, K. (2014). Customer segmentation in retail facility location planning. *Business Research*, Vol. 7(2), pp. 235–261.

Nickel, S. and Puetro, J. (2005). *Location theory: A unified approach*. Berlin Heidelberg: Springer-Verlag.

Opasanon, S. and Lertsanti, P. (2013). Impact analysis of logistics facility relocation using the analytic hierarchy process (AHP). *International Transactions in Operations Research*, 20, 325 – 339.

Ozgen, D., Gulsun, B. (2014) Combining possibilistic linear programming and fuzzy AHP for solving the multi-objective capacitated multi-facility location problem. Information Sciences, Vol. 268, pp. 185–201.

Owen, S.H. and Daskin, M.S. (1998). Strategic facility location: a review. *European Journal of Operational Research*, Vol. 111, pp. 423–447.

ReVelle, C.S., Eiselt, H.A. and Daskin, M.S. (2008). A bibliography for some fundamental problem categories in discrete location science. *European Journal of Operational Research*, Vol. 184 (3), pp. 817–848.

Sahin, G and Süral, H. (2007). A review of hierarchical facility location models. *Computers & Operations Research*, Vol. 34 (8), pp. 2310–2331.

Snyder, L.V. (2006). Facility location under uncertainty: A review. *IIE Transactions*, Vol. 38 (7), pp. 547–564.

Sonmez, A.D. and Lim, S.G. (2012). A decomposition approach for facility location and relocation problem with uncertain number of future facilities. *European Journal of Operational Research*, Vol. 218, pp. 327 – 338.

Srivastava, S.K., Amula, A., Ghagare, P. (2016) Service facility relocation decision. *Facilities*, Vol. 34(9/10), pp. 595–610.

Stevenson, W.J. (2018). *Operations Management.* Tata McGraw Hill, 12th edition, New Delhi.

Torres-Soto, J.E. and Üster, H. (2011). Dynamic-demand capacitated facility location problems with and without relocation. *International Journal of Production Research,* Vol. 49(13), pp. 3979 – 4005.

Turhan, G., Akalın, M. and Zehir, C. (2013). Literature review on selection criteria of store location based on performance measures. *Procedia Social and Behavioural Sciences,* Vol. 99, pp. 391 – 402.

Wesolowsky, G.O. (1973). Dynamic facility location. *Management Science*, Vol. 19(11), pp. 1241 – 1248.

Wichapa, N., Khokhajaikiat, P. (2017) Solving multi-objective facility location problems using the fuzzy analytical hierarchy process and goal programming: a case study on infectious waste disposal centres. *Operations Research Perspectives*, Vol. 4, pp. 39 – 48.

Zhang, Y., Atkins, D. (2019). Medical facility network design: User-choice and system-optimal models. European Journal of Operational Research, Vol. 273 (1), 305-319.

http://www.corrupack.com/industry.htm accessed June 15, 2016.

http://www.business-standard.com/article/sme/corrugated-box-industry-reeling-under-margin-pressure-114033101193_1.html accessed June 25, 2016.

Appendix

A: Purchase cost of kraft paper from big and small suppliers, shipping cost from suppliers to manufacturing facility at Pune and two other candidate locations and inventory carrying cost of kraft paper

Particulars	**Symbol**	**Value(Rs)**
Per unit purchase cost of kraft paper sourced from big supplier 'b' located at Vapi	P_b	33
Per unit purchase cost of kraft paper sourced from small supplier 's' located at Sangli, Aurangabad and Ichalkaranji	P_s	
Per unit purchase cost of kraft paper from a small supplier located at Sangli	P_{s1}	37
Per unit purchase cost of kraft paper from a small supplier located at Aurangabad	P_{s2}	37
Per unit purchase cost of kraft paper from a small supplier located at Ichalkaranji	P_{s3}	37
Per unit shipping cost from big supplier 'b' to manufacturing facility 'm'	C_{bm}	
Per unit shipping cost from a big supplier located at Vapi to a manufacturing facility located at Pune	C_{bm1}	3.863
Per unit shipping cost from a big supplier located at Vapi to a manufacturing facility located at Baramati	C_{bm2}	5.349
Per unit shipping cost from a big supplier located at Vapi to a manufacturing facility located at Ahmednagar	C_{bm3}	3.969
Per unit shipping cost from small supplier 's' to manufacturing facility 'm'	C_{sm}	
Per unit shipping cost from a small supplier located at Sangli to a manufacturing facility located at Pune	C_{s1m1}	3.39
Per unit shipping cost from a small supplier located at Sangli to a manufacturing facility located at Baramati	C_{s1m2}	6.18
Per unit shipping cost from a small supplier located at Sangli to a manufacturing facility located at Ahmednagar	C_{s1m3}	4.99
Per unit shipping cost from a small supplier located at Aurangabad to a manufacturing facility located at Pune	C_{s2m1}	2.44
Per unit shipping cost from a small supplier located at Aurangabad to a manufacturing facility located at Baramati	C_{s2m2}	4.64
Per unit shipping cost from a small supplier located at Aurangabad to a manufacturing facility located at Ahmednagar	C_{s2m3}	2.64
Per unit shipping cost from a small supplier located at Ichalkaranji to a manufacturing facility located at Pune	C_{s3m1}	3.39
Per unit shipping cost from a small supplier located at Ichalkaranji to a manufacturing facility located at Baramati	C_{s3m2}	6.18
Per unit shipping cost from a small supplier located at Ichalkaranji to a manufacturing facility located at Ahmednagar	C_{s3m3}	4.99
Inventory carrying cost of kraft paper sourced from big supplier 'b'	$h^* P_b$	0.0952
Inventory carrying cost of kraft paper sourced from small supplier 's' located at Sangli, Aurangabad and Ichalkaranji	h^*P_s	
Inventory carrying cost of kraft paper purchased from small supplier located at Sangli	h^*P_{s1}	0.08
Inventory carrying cost of kraft paper purchased from small supplier located at Aurangabad	h^*P_{s2}	0.08
Inventory carrying cost of kraft paper purchased from small supplier located at Ichalkaranji	h^*P_{s3}	0.08

B: Annual Demand data of the final demand centres

Demand centre	Symbol (D_o)	Amount (kg)
Aurangabad	D_{o1}	104000
Baramati	D_{o2}	52000
Yawal	D_{o3}	52000
Raver	D_{o4}	156000
Bhusaval	D_{o5}	52000
Chalisgaon	D_{o6}	52000
Dindori	D_{o7}	260000
Nifad	D_{o8}	52000
Chandwad	D_{o9}	52000
Sinnar	D_{o10}	52000
Igatpuri	D_{o11}	52000

C: Shipping cost from three manufacturing facilities to two final demand centers and three transshipment nodes

Per unit shipping cost from manufacturing facility 'm' to final demand centre 'o'	C_{mo}	
Per unit shipping cost from manufacturing facility at Pune to final demand centre at Aurangabad	C_{m1o1}	4.228
Per unit shipping cost from manufacturing facility at Pune to final demand centre at Baramati	C_{m1o2}	5.549
Per unit shipping cost from manufacturing facility at Baramati to final demand centre at Aurangabad	C_{m2o1}	4.588
Per unit shipping cost from manufacturing facility at Baramati to final demand centre at Baramati	C_{m2o2}	2.690
Per unit shipping cost from manufacturing facility at Ahmednagar to final demand centre at Aurangabad	C_{m3o1}	4.275
Per unit shipping cost from manufacturing facility at Ahmednagar to final demand centre at Baramati	C_{m3o2}	5.638
Per unit shipping cost from manufacturing facility 'm' to transhipment node 'n'	C_{mn}	
Per unit shipping cost from manufacturing facility at Pune to transhipment node at Jalgaon	C_{m1n1}	6.525
Per unit shipping cost from manufacturing facility at Pune to transhipment node at Nashik	C_{m1n2}	3.348
Per unit shipping cost from manufacturing facility at Pune to transhipment node at Ahmednagar	C_{m1n3}	3.125
Per unit shipping cost from manufacturing facility at Baramati to transhipment node at Jalgaon	C_{m2n1}	6.919
Per unit shipping cost from manufacturing facility at Baramati to transhipment node at Nashik	C_{m2n2}	3.664
Per unit shipping cost from manufacturing facility at Baramati to transhipment node at Ahmednagar	C_{m2n3}	3.429
Per unit shipping cost from manufacturing facility at Ahmednagar to transhipment node at Jalgaon	C_{m3n1}	6.668
Per unit shipping cost from manufacturing facility at Ahmednagar to transhipment node at Nashik	C_{m3n2}	3.411
Per unit shipping cost from manufacturing facility at Ahmednagar to transhipment node at Ahmednagar	C_{m3n3}	1.518

D: Freight Charges on Different Routes

Route	Weekly Demand in Kg	Fuel Charges (INR)	Miscellaneous Charges (INR)	Handling Charges (INR)	Total Charges (INR)	Transportation Cost (INR/kg)
P	2000	6495	1461	500	8456	4.228
Q	1000	4285	964	300	5549	5.549
R	6000	30495	6858	1800	39153	6.525
S	7000	17500	3935	2000	23435	3.348
T	2000	4695	1056	500	6251	3.125

E: Shipping cost from three transshipment nodes to nine final demand centers

Per unit shipping cost from transhipment node 'n' to final demand centre 'o'	C_{no}	
Per unit shipping cost from transhipment node Jalgaon to Yawal	C_{n1o3}	1.40
Per unit shipping cost from transhipment node Jalgaon to Raver	C_{n1o4}	1.233
Per unit shipping cost from transhipment node Jalgaon to Bhusaval	C_{n1o5}	0.80
Per unit shipping cost from transhipment node Jalgaon to Chalisgaon	C_{n1o6}	1.30
Per unit shipping cost from transhipment node Nashik to Dindori	C_{n2o7}	1.20
Per unit shipping cost from transhipment node Nashik to Nifad	C_{n2o8}	1.30
Per unit shipping cost from transhipment node Nashik to Chandwar	C_{n2o9}	1.60
Per unit shipping cost from transhipment node Ahmednagar to Sinnar	C_{n3o10}	1.20
Per unit shipping cost from transhipment node Ahmednagar to Igatpuri	C_{n3o11}	1.00

F: Elements of operating costs

Elements	Pune	Baramati	Ahmednagar
Rent of Shed per month (~4500 Sq. Ft)	60,000.00	35,000.00	40,000.00
Labour cost per month	150,000.00	140,000.00	135,000.00
Maintenance cost per month	10,000.00	10,000.00	10,000.00
Electricity bill per month	30,000.00	30,000.00	30,000.00
Total operating cost per month	250,000.00	215,000.00	215,000.00
Total operating cost per year	3,000,000.00	2,580,000.00	2,580,000.00