Optimization of Supply Chain Network Design for Multiple-Channel Distribution

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Abstract

Modern day customers wish to receive product and services as per their choice of channel, reach and convenience. For meeting such needs, supply chain managers have always looked for newer approaches and philosophy. One of such philosophy is emergence of Omnichannel for providing seamless shopping experience to its customers. To implement omnichannel strategies in real practices need structuring and reconfiguring the practices of traditional supply chain network (SCN). Also due to easy and rich availability of information on dot com, customers tend to shift to the channel where prices are low. Thus demand fulfillment is affected by uncertainty in demand. For this, in this work a mathematical MILP model of multiple-channel distribution SCN (MCDSCN) has been proposed in which customers will be able access to product and services as per their choice of channels. So, the objectives of this model is not only minimizing total supply chain cost but also maximizing service level under uncertain environment. For showing the applicability of proposed model a numerical is illustrated which compares proposed model with traditional SCN. Significant saving is being achieved in proposed model over traditional SCN which justifies its applicability.

Keywords
Flexible Distribution Network, Omnichannel, Optimization, Supply Chain, Uncertainty.

1. Introduction

Today’s customers have become more powerful than ever. They expect flexible and fast delivery and moreover wish to choose the channel as per their wish, reach and convenience. This idea of providing the customer shopping experience as seamless has given birth to the concept of Omnichannel retailing (Rigby 2011). In simple terms omnichannel (OC) is the integration of all available channels for making customer shopping experience seamless (Rigby 2011; Brynjolfsson et al. 2013). The different channels in omnichannel could be physical stores, websites, kiosks, direct mail and catalogs, social media, call centers, mobile devices, gaming consoles, televisions, home services, networked appliances and more (Rigby 2011). Broadly these channels can be categorized as shown in Figure 1. To provide omnichannel experience the traditional supply chains need to be altered which would result in structuring and reconfiguring the practices of designing traditional distribution network (Yadav et al. (2017)). These changes possess lots of challenges. Some of these challenges include providing flexible distribution, providing real time information to all stakeholders of supply chain, faster and on-time delivery etc. For handling such challenges, organizations look for various operations and activities, among them an efficient and effective supply chain network (SCN) is most preferred option (Sachan & Dutta 2005).

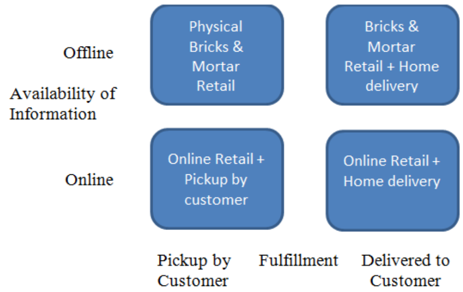

Figure 1 Different retailing channel (Yadav et al. (2017))

A good supply chain network is mandatory for the organizations to excel in business. Since well-designed SCN is most suitable for introducing flexibility and can be scaled to measure performances. The traditional SCN possess many restrictions for operational process. For e.g. market could be served only from regional distribution centers (DCs). Regional DCs receives their inventory from central DCs which in turn receives theirs from manufacturer. Further, this traditional SCN require more time and resources to supply products to end user. Thus there is scope of reconfiguring the practices of traditional supply chain. In this work, we propose a multiple channel distribution SCN (MCDSCN) which is more flexible in distribution especially for end user. Through the proposed model customers can be served as per their choice of channel i.e. through directly from manufacturer, central DCs or regional DCs. The determination of facilities serving customer in MCDSCN depend on many factors such as transportation cost, fixed cost, tariff and duties etc. However service level is of utmost important since customer expect to enjoy higher service.

The deigned of MCDSCN include determining number of facilities to be operated, optimal flow of product between different facilities, capacities of facilities and allocation to customer etc. Further this is very complex problem to solve due to presence of many variable and multiple echelons settings. Further real world scenarios like uncertainty increase the complexity of problem. This paper also handles uncertainty in demand side. The proposed is subjected different uncertainty levels and the results are compared with traditional SCN which justifies our model. Further this paper is organized as follows: Next section talks about relevant literature while section three deals with development of mathematical model. A numerical is illustrated with purpose of showing the applicability of proposed model in section four. Finally, section five gives the concluding remarks of this paper.

2. Literature Review

Rigby (2011) gave the concept of Omnichannel and stated that it would be future of retailing. The author created an imaginary character “Amy” and imagined a situation after five years in 2016. The author made her shop like anything as she wished as per her desired channel and convenience. This emotionally engaging experience where shopping was made seamless termed as Omnichannel. Ericsson et al. (2012) from Cisco ISBG applied philosophy of omnichannel in banking sector and found win-win situation for both bank as well as customer since customer wish to use the desired channel according to their wish. They stated it to be future of banking too which is clear indication that the world is moving to virtual banking soon.

Brynjolfsson et al. (2013) talked about the competitive strategies for OC retailing. According to their views, one of important aspects in OC retailing is use of Information Technology (IT) which makes integration of all channels possible through providing access to real time information for all stakeholder of distribution network. They also claimed that demand for new product is higher on online channel whereas offline channel is more popular for common and daily use type of products among consumer. Chopra (2016) gave the procedures to make OC as future of retailing in Indian perspective. The author also discussed about the weakness and strength of different channel involved in SC and found that integration of brick and mortar physical stores through local retailers and online giant will have dominance in future market.

Bell et al. (2013) conducted a research on different omnichannel issues using econometric models. They collected many data regarding customer activities through Crate & Barrel, Bonobos.com, WarbyParker.com and public sources and analyzed econometric calculations to find the major impacts of interventions from management to one of the omnichannel features i.e. “buy online and pick up in store” (BOPS) which is gaining much of sales now-a-days. BOPS is becoming win-win scenarios for both customer as well as organization since SC cost is reduced due reduced transportation cost i.e. it’s not necessary to deliver product at home rather customer picks up as per their convenience from the store which leads to reduced cost of product, ultimately benefitting the customer.

Lazaris (2014) reviewed the transformation of multi-channel to OC and discussed research gap to be analyzed in OC for its improvement. Neslin et al. (2014) came up with a framework for consumer decision for what and where to buy based on channel brand and channel choice. This framework would be helpful in developing omnichannel strategy for OC retailing.

Rikhy (2015) listed some of the unique and major challenges when an enterprise is being transferred from traditional retailing to OC retailing and gave some of the practical approaches to the implementation of OC retailing through a responsive and agile OC. Hübner et al. (2016) studied the last mile fulfilment and developed distribution framework for grocery retailing.

Verhoef et al. (2015) in a special issue on omnichannel reviewed 55 papers and concluded that the market is moving from multichannel to omnichannel. They also have put research question regarding difficulties in implementing the omnichannel in practice. Kuźmicz (2015) talked benchmarking in omnichannel logistics. Flexible delivery was used as a proxy for benchmarking.

Xie et al.(2014) developed a distribution network in which manufacturer was sell product directly to the customers as well as with the help of a third party service provider. For this purpose a two stage mathematical model for allocation and capacity planning for manufacture in SC was developed.

Peltola, Vainio, & Nieminen (2015) conducted a research to develop an OC experience for customer in Finland. They recognized that transforming organization to Omnichannel way lies where there is unity in retailer's organizational culture, operations, communications and pricing for all the products and services of the organizations.

Moreno and Molina (2016) studied the current case of e-government development of public services in Spain. They claimed that use of omnichannel strategies could enhance the citizen's rate for better use of public services through e-government in Spain. This suggests that the philosophy of omnichannel is practical and is applicable to various fields and hence has got great scope in today's world. Moreover, omnichannel is more customer-oriented and customer-focused (Peltola, Vainio, & Nieminen, 2015).

Yadav et al. (2017) developed a bi-objective sustainable supply chain network design for omnichannel environment for cost minimization and reducing carbon content through minimizing travel distance. They solved this bi-objective MILP model using GAMS software using CPLEX solver. Many researches have been carried out in the area of network design to get rid different supply chain issues (Farahani, Rezapour, Drezner, & Fallah 2014; Melo, Nickel, & Saldanha-da-Gama 2009). Application of network design could be found to handle different supply chain issues like risk mitigation (see Singh, Mishra, Jain, & Khurana, 2012), uncertainty in supply chain (see Pishvaee, Rabbani, & Torabi, 2011; Singh, Jain, & Mishra, 2013) etc.

In spite of having so much benefit through implementation of omnichannel for all stakeholder of supply chain, very less work has been done in the field of designing distribution network for omni-environment. This is due to the fact that network design problem for omni-environment is very complex. This is because of dealing with many stochastics variables which are very difficult to tackle and also need huge computations. This paper attempts to design a multi-channel distribution supply chain network with the aim of minimizing total supply chain cost and maximizing service level since service level is of utmost important in omnichannel scenarios. Also due to easy and rich availability of information about product on dot com, the customer's nature for choice of channel is very volatile. They tend to shift to the channel where price is low. This creates uncertainty in demand. The proposed model is also well capable of handling such uncertain scenarios. For this purpose, the proposed model is developed under uncertain demand. Different uncertainties level considered are ±5%, ±10%, ±15% & ±20%, which is very much practical for omnichannel scenarios.

3. Mathematical Formulation

The notations and symbols used in designing MCDSCN are mentioned in the appendix.

3.1 Assumption for Proposed MCDSCN Model

The design of MCDSCN is based on following assumptions:

1. Each customer can get their product and services from any facility.
2. The capacity and location of suppliers, manufacturers, central & regional DC is known well in advance.
3. The capacities of different facilities are arranged in descending order from supplier to customer to maintain product flow.
4. There is no intra-echelons flow of products between facilities.
5. The model is developed for a single product and single period.

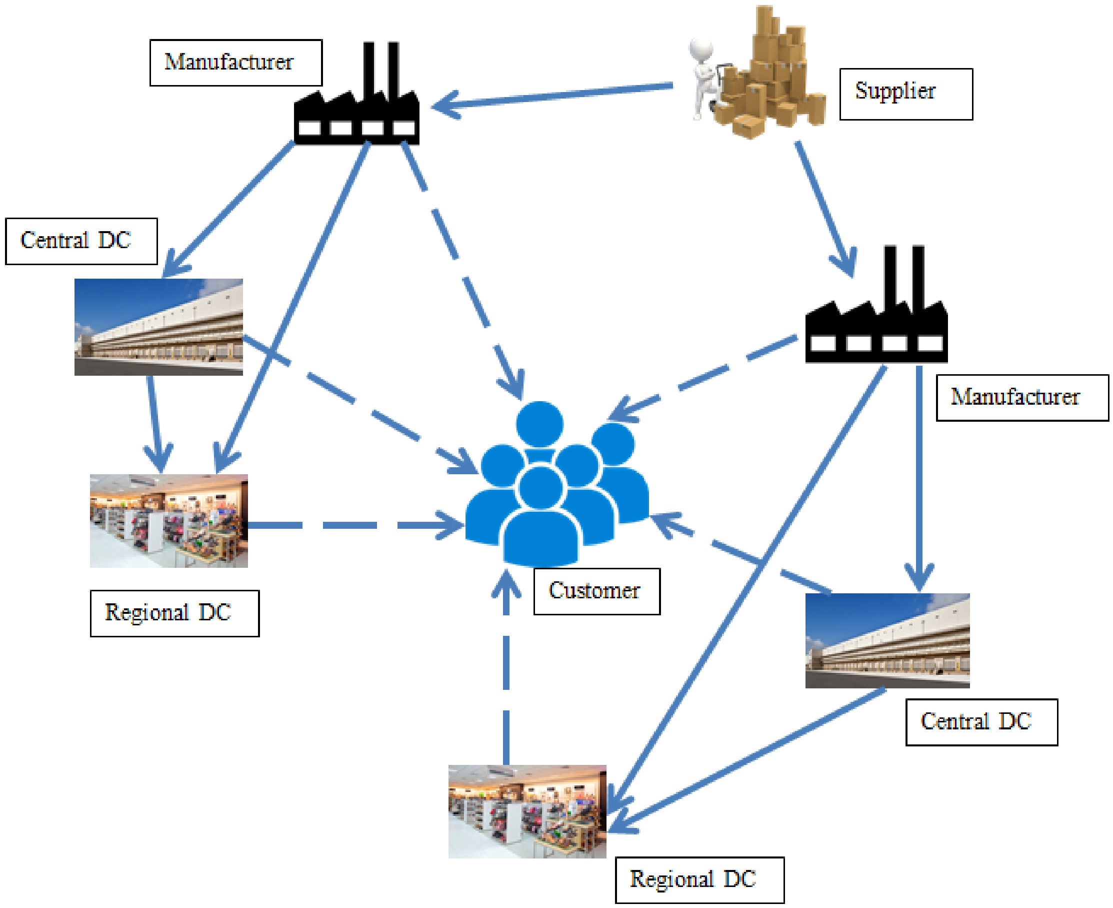

Figure 2 The illustrations of the proposed MCDSCN

3.2 Formulation of the Objective Function

In this research work a multi-objective consisting of minimizing total supply chain cost and subsequently maximizing service level under uncertain environment is introduced through this proposed MCDSCN model. Figure 2 shows the schematic of proposed MCDSCN model. The first objective is minimizing supply chain cost which comprises of fixed cost of the facility and transportation cost between the concerned facilities in addition to inventory and stock out cost. All the other related cost like production cost, procurement cost etc. has been not considered here since they are more or somewhat are constant. Mathematically supply chain cost can be written as follows:

$$Min\ f_1 = \sum_{m\in M} m_f y_m + \sum_{c\in C} c_f y_c + \sum_{r\in R} r_f y_r + \sum_{s\in S}\sum_{m\in M} c_{sm}\, z_{sm} + \sum_{m\in M}\sum_{c\in C} c_{mc}\, z_{mc} + \sum_{c\in C}\sum_{r\in R} c_{cr}\, z_{cr} + \sum_{r\in R}\sum_{k\in K} c_{rk}\, z_{rk} + \sum_{m\in M}\sum_{r\in R} c_{mr}\, z_{mr} + \sum_{m\in M}\sum_{k\in K} c_{mk}\, z_{mk} + \sum_{c\in C}\sum_{k\in K} c_{ck}\, z_{ck} + (\mathrm{v}+\mathrm{u}) * (\mathrm{V}+\mathrm{U})$$

The second objective is to maximize service level for customer since it is of utmost important consideration in omnichannel.

$$Min\ f_2 = \left(\sum_{m\in M} z_{mk} + \sum_{c\in C} z_{mk} + \sum_{r\in R} z_{mk}\right) / \ k_d$$

For solving this multi-objective problem, ε constraint method is suggested. Using the concept of ε constraint method objective function f_2 is added to constraint by bounding the minimum acceptation level of service. Finally the objective function could be rephrased as:

$$Min\ f_1 = \sum_{m\in M} m_f y_m + \sum_{c\in C} c_f y_c + \sum_{r\in R} r_f y_r + \sum_{s\in S}\sum_{m\in M} c_{sm}\, z_{sm} + \sum_{m\in M}\sum_{c\in C} c_{mc}\, z_{mc} + \sum_{c\in C}\sum_{r\in R} c_{cr}\, z_{cr} + \sum_{r\in R}\sum_{k\in K} c_{rk}\, z_{rk} + \sum_{m\in M}\sum_{r\in R} c_{mr}\, z_{mr} + \sum_{m\in M}\sum_{k\in K} c_{mk}\, z_{mk} + \sum_{c\in C}\sum_{k\in K} c_{ck}\, z_{ck} + (\mathrm{v}+\mathrm{u}) * (\mathrm{V}+\mathrm{U})$$

Subjected to
$(\sum_{m\in M} z_{mk} + \sum_{c\in C} z_{mk} + \sum_{r\in R} z_{mk})/\ k_d \geq \varepsilon$

Now this model could be represented in the form:

$$Min\ f_1 = \sum_{m\in M} m_f y_m + \sum_{c\in C} c_f y_c + \sum_{r\in R} r_f y_r + \sum_{s\in S}\sum_{m\in M} c_{sm}\, z_{sm} + \sum_{m\in M}\sum_{c\in C} c_{mc}\, z_{mc} + \sum_{c\in C}\sum_{r\in R} c_{cr}\, z_{cr} + \sum_{r\in R}\sum_{k\in K} c_{rk}\, z_{rk} + \sum_{m\in M}\sum_{r\in R} c_{mr}\, z_{mr} + \sum_{m\in M}\sum_{k\in K} c_{mk}\, z_{mk} + \sum_{c\in C}\sum_{k\in K} c_{ck}\, z_{ck} + (\mathrm{v}+\mathrm{u}) * (\mathrm{V}+\mathrm{U}) \quad \ldots (1)$$

The constraint associated with this are as follows:

$\sum_{m\in M} z_{mk} + \sum_{c\in C} z_{mk} + \sum_{r\in R} z_{mk} = \mathrm{k_d} \quad \forall\ \mathrm{k} \in \mathrm{K}\ \&\ \ \mathrm{k_d} \in \mathrm{K_{box}}\ \ \mathrm{L} < \mathrm{k_{box}} < \mathrm{U}$ … (2)

$\sum_{k\in K} z_{rk} *\ y_r < \mathrm{r_c}$ … (3)

$\sum_{k\in K} z_{ck} *\ y_c + \sum_{r\in R} z_{cr} *\ y_c < \mathrm{c_c}$ … (4)

$\sum_{k\in K} z_{mk} *\ y_m + \sum_{c\in C} z_{mc} *\ y_m + \sum_{r\in R} z_{mr} *\ y_m < \mathrm{m_c}$ … (5)

$\sum_{m\in M} z_{sm} < \mathrm{s_c}$ … (6)

$(\sum_{m\in M} z_{mk} + \sum_{c\in C} z_{mk} + \sum_{r\in R} z_{mk})/\ k_d \geq \varepsilon$ … (7)

Constraint (2) ensures that customer demands are met. Constraints (4)-(7) are capacity constraint. They make sure that product flow from any facility i.e. suppliers, manufacturer, central DCs and regional DCs do not exceed their respective capacities. Further, theses constraint also establishes the linking/flow constraint between these facilities. From above it is quite clear that this turns out to be MILP model. For solving such type of problem, commercial package like GAMS using CPLEX solver or Microsoft Excel can be used.

4. Numerical Illustrations

In this section a numerical illustration is given for proposed MCDSCN model and its applicability is shown by considering different real world scenarios. The proposed MCDSCN model is also compared with traditional supply chain network and corresponding remarks are made. The location of different facilities is considered within a 100 X 100 coordinate system. For our problem, we have considered four suppliers, three manufacturer, four regional DCs, four central DCs and six customer zones. The distance between the facilities were considered using Euclidian distance formula. Based on these distances the different transportation costs were considered. Further the transportation cost between different facilities, operating cost i.e. fixed cost and capacities of facilities are mentioned in Table 1 to Table 6. The demand of customer follows a uniform distribution U(50,150), which is divided in ratio of 2:1:1 from regional DCs, central DCs and manufacturers respectively. The capacities of different facilities are arranged in descending order from supplier to customer demands as mention in inequality 8. This constraint is maintained in order to have proper product flow between these facilities. Traditional SCN is being shown in Figure 2.

$\sum_{\mathrm{s}\in\mathrm{S}} \mathrm{s_c} > \sum_{\mathrm{m}\in\mathrm{M}} \mathrm{m_c} * \mathrm{y_m} > \sum_{\mathrm{c}\in\mathrm{C}} \mathrm{c_c} *\ \mathrm{y_c} > \sum_{\mathrm{r}\in\mathrm{R}} \mathrm{r_c} *\ \mathrm{y_r} > \sum_{\mathrm{k}\in\mathrm{K}} \mathrm{k_d}$ … (8)

Table 1 Unit transportation cost (TC) from Supplier (S) to Manufacturer (M) and capacity of supplier

	M1	M2	M3	Capacity
S1	7.42	10.11	6.49	400
S2	2.84	8.16	7.74	500
S3	5.40	1.92	5.60	450
S4	2.91	8.22	6.98	600

Table 2 Unit transportation cost (TC) from Manufacturer to central DC (CDC) and capacity of manufacture

	CDC 1	CDC 2	CDC 3	CDC 4	Capacity	FC
M1	1.34	6.62	3.33	8.65	500	540
M2	4.58	10.31	8.71	7.12	400	500
M3	3.74	7.14	7.56	3.79	600	580

FC- Fixed Cost or Operating Cost

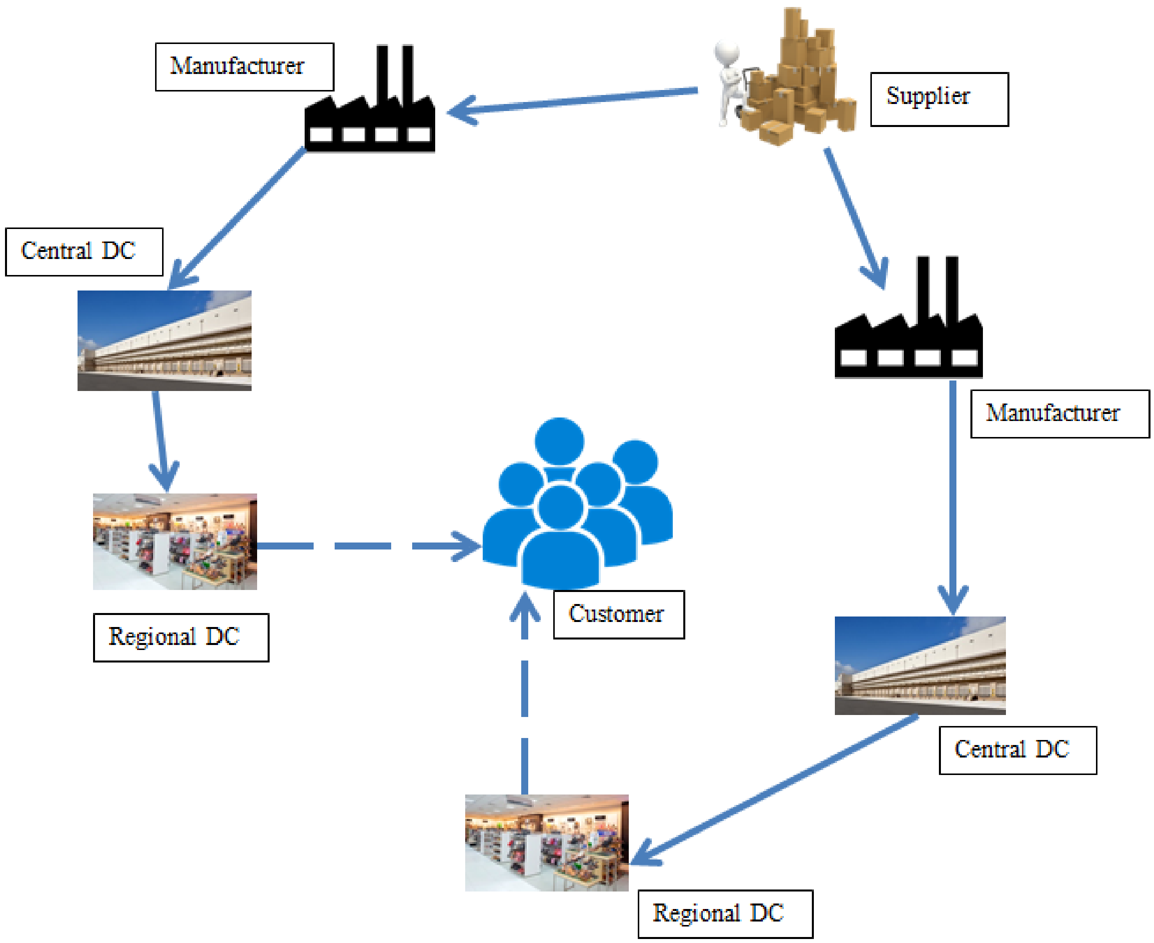

Figure 3 A Schematic of Conventional Supply Chain Network

Table 3 Unit transportation cost (TC) from central DC to regional DC (RDC) and capacity of central DC

	RDC 1	RDC 2	RDC 3	RDC 4	Capacity	FC
CDC 1	5.73	7.34	5.63	3.10	400	400
CDC 2	1.02	1.30	4.76	6.67	300	350
CDC 3	4.30	6.60	7.76	2	350	375
CDC 4	8.54	8	3.35	10.23	350	375

Table 4 Unit transportation cost (TC) from regional DC to demand points (K) and capacity of regional DC

	K1	K2	K3	K4	K5	K6	Capacity	FC
RDC 1	9.30	5.51	6.82	3	1.61	3.38	400	350
RDC 2	10.38	5.94	9.10	1.60	3.9	4.53	300	320
RDC 3	6.89	2.28	9.61	3.15	5.80	3.36	300	320
RDC 4	6.72	6.36	1.70	7.90	4.17	4.64	250	250

Table 5 Unit transportation cost from manufacturer to regional DC

	RDC1	RDC2	RDC3	RDC4
M1	5.88	7.78	6.76	1.83
M2	9.97	11.08	7.58	7.14
M3	7.10	7.64	3.66	6.82

Table 6 Unit transportation cost from manufacturer to demand points

	K1	K2	K3	K4	K5	K6
M1	4.93	4.87	3.44	7.37	4.52	3.70
M2	0.71	5.42	8.46	9.97	9.14	6.65
M3	3.26	1.7	8.50	6.32	6.81	3.80

Table 7 Unit transportation cost from central DC to demand points

	K1	K2	K3	K4	K5	K6
CDC 1	4.02	3.60	4.76	6.68	4.65	2.91
CDC 2	9.62	5.48	7.81	2.12	2.6	3.66
CDC 3	8.20	6.66	2.54	6.91	2.70	4.45
CDC 4	6.60	3.88	11.93	6.4	8.94	6.10

For omnichannel scenarios due rich availability of information, the customer's nature in choice of channel is volatile. They tend to shift to the channel where prices are lower. For such situations, uncertainty is bound to happen. With this view in mind the proposed MCDSCN model was designed for different uncertainty levels. The different uncertainties level considered are ±5%, ±10%, ±15% & ±20%. Also the same set of uncertainty level was incorporated in both the proposed MCDSCN model (as shown in Figure 2) and traditional SCN (as shown in Figure 3). The proposed model was coded in MS-Excel and results were tabulated below and it was found that MCDSCN possess superiority over traditional SCN in terms of both objectives i.e. minimizing total supply chain cost and maximizing service level.

Table 7 Summary of results and comparison of saving between MCDSCN and traditional SCN

Uncertainty Level	**MCDSCN**		**Traditional SCN**		**Saving**	
	Total SC Cost (in Dollars)	**Service Level (%)**	**Total SC Cost (in Dollars)**	**Service Level (%)**	**Total Cost (%)**	**Increase in Service (%)**
0%	5701.33	100	10460.41	100	45.49	0
±5%	5720.53	98.18	10481.11	97.87	45.42	0.31
±10%	5736.03	97.5	10490.01	96.61	45.31	0.92
±15%	5752.73	97.4	10509.31	96.51	45.26	0.92
±20%	5756.03	95.81	10521.71	95.26	45.29	0.58

Some of the notable difference between proposed MCDSCN model and traditional SCN can be stated in the terms average SC cost incurred, range of SC cost incurred, average saving in SC cost and increase in service level. The average SC cost for all five period in proposed MCDSCN is found to be \$5733.33 while in the case of traditional SCN it was \$10492.51 which is much higher. The SC cost in proposed MCDSCN ranges from \$5701.33 to \$5756.03 whereas in the case of traditional SCN it ranges from \$10460.41 to \$10521.71. Also a significant average saving in SC cost is seen i.e. 45.35% in proposed MCDSCN over traditional SCN. The increase in service level in proposed MCDSCN model over traditional SCN varies from 0% to 0.92%.

As shown in Table 7 it is clear that the proposed MCDSCN model has achieved significant saving than traditional SCN for both objectives. The capacity of Central DCs and Regional DCs could be reduced with maintaining same level of service since DCs need to carry lesser inventory in Central and Regional DCs. This is due to the fact manufacturer and central DCs both are directly serving the customer which means all products need to flow through these facilities. Further it could also be concluded that now these facilities need to carry lesser inventory so the size of DCs could also be reduced. This will results in better utilization of space and also provide an opportunities for organization to expand their business.

5. Conclusion

In this work a mathematical MILP model for multi-channel distribution supply chain network (MCDSCN) is proposed for flexible distribution in omnichannel environment. Through this model customers have access to product and services according to their choice of channels i.e. either from manufacturers, central DCs or regional DCs. The proposed model is also beneficial for online giants as it is well integrated distribution network due to proper integration of different channel. Further it would help online giants to attract more customers and gain market share thus increasing the profit of the organizations.

Two objectives i.e. minimizing SC cost, and maximizing service level has been considered in this MCDSCN model. A similar situation is considered for traditional SCN and results obtained are compared with the proposed MCDSCN. Our MCDSCN has superiority over traditional SCN in terms of cost saving and maximizing service level along with better customer service i.e. customer convenience by flexible distribution. Due to flexibility in distribution and easy access to different channel in the proposed model, uncertainty in demand may arise. Uncertainty at any point in MCDSCN model has lesser overall effect since it is being divided into different channel. The proposed model is also tested for uncertainty level up to 20% in discrete sets i.e. at ±5%, ±10%, ±15% & ±20%. Our MCDSCN model has better capability to handle uncertainty than traditional SCN. One of the prominent benefits of MCDSCN model is that in this model the capacity of central DC and regional DC could be reduced since they don't need to carry full inventory which lead lesser requirement of space. Further this space could be used for expansion of other business activities.

The proposed model could be further improved by capturing real-time information to the stakeholder of the supply chain. This would make the model more complex and could be solved using non-traditional optimization techniques like Multi-objective Particle Swarm Optimization (MOPSO), Multi-objective Genetic Algorithm (MOGA), Ant Colony Optimization (ACO), Ant Bee Colony (ABC) and simulated annealing (SA) etc. Further different type of risk could also be embedded to make model more realistic. Testing the proposed model on actual field data would provide more appropriate conclusion, which is the limitation of this work. Though the numerical illustration resembles the real world scenarios and can be considered as good move in this regard.

Appendix

Notations used in the mathematical model

Notations	Description
$s \in S$, $m \in M$, $c \in C$, $r \in R$, $k \in K$	Set corresponding suppliers, set of manufacturers, set of central & regional DCs and set of customers
s, s_c	The indexing of supplier and their capacity
m, m_c, m_f	Manufacturer's index, capacity and fixed cost
c, c_c, c_f	Central DC's index, capacity and fixed cost
r, r_c, r_f	Regional DC's index, capacity and fixed cost
k, k_d, v, u, V, U	Customer index, demands, unit inventory cost, unit shortage cost, No. of quantity stored and no. of quantity short
c_{ij}, $i,j \in S \cup^m \cup^c \cup^r \cup^k$ $i \neq j$	Unit cost of transportation between two facilities

Decision Variables used in the mathematical model

Decision Variables	Their description
y_m, y_c, y_r	Binary variables used for showing open/close status of manufacturer, central and regional DCs
z_{sm}, z_{mc}, z_{cr}, z_{mr}, z_{rk}	Integer variables used for showing quantity of product flow from supplier to manufacturer, manufacturer to central DC, central to regional DC, manufacture to regional DC and finally from regional DC to customer
z_{mk}, z_{ck}	Integer Variables showing quantity of product flow to customer directly from manufacturers and central DCs respectively

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