Innovative supply chain optimization models with multiple uncertainty factors

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Abstract

Uncertainty is one of those factors that impact the supply chain and all of its processes. There are many different types of uncertainties micro, meso and macro level uncertainty. Each uncertainty is a different scenario and may bring a different difficulty to the business. The competition and coordination of the supply chain are affected by it. This paper discusses different basic and innovative supply chain models. With light on different research papers to understand innovative optimization models and novel methods.

Introduction

With each passing day the vulnerability and risk factors increase that cause disruption in the business world and mostly so on the operations of the company. For a business to become successful and out do their competition their supply chain process must be the strongest and it must know the type of strategies they must adopt in order to avoid and disruption in the process. Supply chain includes everything from transforming of the needs of the customer into their desired products to cater them back to the customer.

Over the years it has been reported that the natural and human disasters are increasing in number by each passing year and are having grave effects on the supply chain process of the product, causing either disruption in the process or faults in the end product as a result of the disruption caused by the uncertainty. The event of lightning strike on the Philips factory in New Mexico that led to the disruption in the supply chain process and eventually the whole generation of cell phones (Sheffi, 2005). Nokia was the one to deploy the right kind of innovative strategies that helped them overcome the disruption while Ericsson lost the race.

Some of the risk and uncertainty factors include external factor that happen on a national, international and environmental level that might cause disruption these factors may be, earthquakes, wars, terrorist attacks, novel virus (such as covid), strikes, recession and economic crisis etc. however it is also true that uncertainty factors also come from within the supply chain, such as fluctuating price, stochastic demand, lead time variation etc. multiple factors combine and overlap one another and present at the same time causing excessive damage to the supply chain. This is the reason why many of the researcher have been looking into the topic and trying to study the uncertainty factors and the amount of impact they leave on the supply chain, alongside that the industry and academia are also trying to look for new solution and innovative ways in which the risk of uncertainty can be tackled.

This report will look into the multiple uncertainty factors and the different levels of supply chain they impact. The report will also look into the different strategies that are proposed by several authors and the focus of their study summarizing the studies and presenting a core idea of the data. The main purpose of this study is took look into the data already present for supply chain risk management and strategies to bring innovative solutions that optimize the supply chain so it can be of more value. This paper will also provide some recommendations that the future researches must carry on and provide a better more

evolved version of the models that cater to the changing uncertain situations that supply chain will face in the upcoming years.

Uncertainty in supply chain

Supply chain uncertainty can be viewed as a multi-level phenomenon. The physical types of uncertainty come from the complexity of the supply chain and the certain dynamics of the supply chain. These can be modified by the right kind of estimation and decision making according to the perceptions and social expectation that are associated with the supply chain roles in its multiple processes. is translated into a cognitive map, which is the basis for a behavioral response repertoire. Flynn et al (2016) defined the supply chain uncertainty in three levels where it acts on different processes.

Micro-Level Uncertainty

Micro-Level Uncertainty in the supply chain occurs in those process that are repetitive in the task environment and characterized by low complexities hence the failure to focus may result in the uncertain situation. According to (Sivadasan, et al., 2002), "uncertainty of material flows and information flows in the deviation from a scheduled or planned state, in terms of both times and quantity". This kind of uncertainty has serious impacts on the demand amplification and bracing behavior of the process. By demand amplification it is meant by the compilation of small turbulences into a big disruption as they transfer along the supply chain. The bullwhip effect is the result of the bracing behavior of the decision making who anticipates that their might be loss in a certain activity and overcompensates for that loss. "The bullwhip effect is especially potent due to its cumulative nature, as micro-level uncertainty is amplified by bracing as it moves through interdependent supply chain members" (Tokar, et al., 2014).

Meso-level uncertainty

This level of uncertainty occurs when the supply chain members are differentiated and they withhold the information which causes disruption in the process and end product (Rabinovich, et al., 2007). The interdependence is the main reason of uncertainty and cause of disruption because if one part is effect automatically the whole chain is impacted. Which is why it is defined as the gap between the amount of information which is needed to complete the process and amount of information that is already in the possession of the supply chain based on the based on information processing theory. In formation that is acquired in the right time is able to prevent various losses and uncertain situations such as prevent lost sales, speed up payment cycles, prevent overproduction and reduce inventories (Stevenson & Spring, 2007). Accurate information such as demand forecast, sales forecast, order status and additional information about the customer specific requirements, inventory level, delivery status and customer support. Wu and Pagel (2011) describe the prominence of complete information in evaluating the environmental impact of a supply chain. Solutions and models must clearly depict that information is being fully disseminated and that the distortions should be taken care of. Once the information needed about the demand is present then the Meso-level uncertainties can be controlled and taken care of. Information must also be transferred free of any opinion of bias related to it, it should be totally based on facts and evidence rather one's opinion and perception.

Macro-level uncertainty

Macro-level uncertainty is related to the ambiguous situations that are relating to the ill structure for example the sudden shifts in the demand of the product that the supply chain is not prepared for or when

and organization became a target in a natural calamity such as the earthquake or lightening. It is when the kind of information needed is unknown. This kind of uncertainty is high when the frame of reference of a certain manager in the supply chain is different than the other. According to Germain, et al (2008), apart from environmental issues the primary reasons for this kind of uncertainty are economic conditions, market turbulence, competitive intensity and technological turbulence. The information present about these factors is difficult to understand or even anticipate but they have the most profound impact on the supply chain and its processes.

Basic models

There are multiple models in the studies previously done that are have focused on the uncertainties that are faced by the supply chain as well as the disruption that are caused by those uncertainties. Based on the information these models tend to come up with scenario specific solutions for the optimization of the supply chain.

The first ever model that was created in regards to disruption in the supply chain was by Drezner (1987), the focus of the study was facility location model. He stated that there are two classic problems "The first, a reliability version of the classical p-median problem, assumes that nodes fail with a given probability. In the second model, called the (p, q)-center problem, p facilities must be located to minimize the maximum cost that may occur when."

Snyder and Daskin (2006), went on to study further that same model and created fixed-charge location problem (RFLP) and the reliability p-median problem (RPMP). These two models are based on the bi objective formulation where one does not consider the disruptions caused (nominal cost) and the other consider these disruptions (failure cost). The model assumes that the customers are being served from the nearest facility that is non disrupted. With this model that author suggest a Lagrangian relaxation algorithm, to solve the problem at hand. The one shortcoming of this particular model is the assumption that all facilities have the same kind of disruption and nothing is different, however it is not the case, each location might have a different impact of the uncertainty and the hence a different level of disruption.

Berman et al. (2007), further goes on to discuss the same kind of problem as the Snyder and Daskin's (2005) which is RPMP. The model that resulted from their study of the problem is the median problem with unreliable facilities (MPUF). The travel distance is calculated based on the highly nonlinear term. Structural results suggest that optimal solutions for the MPUF tend to be more centralized than those for the classical UFLP, and may even involve the co-location of two or more facilities at a single location.

These are an overview of the initial models that were created to tackle with the uncertainty and disruption related to location facility, the following section will focus on the literature and data from various authors that are specific to each process of the supply chain.

Supply chain processes

Uncertainty can impact supply chain in its various processes which will result in disruption of that certain process causing the whole process to suffer. The process involves network designing, procurement, logistics, and customer support. Uncertainty can be faced by anyone of these process and sometimes multiple uncertainties at different stages making the supply chain operation complex. This section will go on to discover different work that has been done on the uncertainties that each phase face and how to optimize it.

Multiple researches have been conducted on the topic of uncertainty in supply chain and its process. These uncertainties are defined and distinguished from one another. Patil et al (2012), discussed how any of the uncertainty be it natural or manmade creates a bottleneck effect and hamper the performance of the supply chain performance and in return the final output. The paper goes on to define the meaning of uncertainty and impact of customer needs on implied demand uncertainty. It goes on to explain the different process that are impacted and how the uncertainty can be dealt with.

Heckman et al (2015), went on to use a different approach which defined the supply chain risk, terminologies associated with the risk and the specific measuring of the risk. It also goes on to include the models of the same field.

Wang and Jie (2019), in their conceptual paper presented a framework keeping in mind the pharmaceutical industry and the supply chain risk and uncertainties they face. Based on their work they conclude that the capability of a supply chain to create integration within its processes can be used as a tool for risk management which is effective and efficient way to mitigate the risk and uncertainty factors attached with the supply chain. the proposed framework can be validated with an empirical work in different sectors.

Network design planning phase

This phase is the most initially phase of the supply chain as it involves the strategic planning which is crucial and essential for the other process to follow. In this process the infrastructure and the physical structure of the supply chain is determined. Revelle, Eiselt, and Daskin (2008), have categorized facility location model in 4 parts out of which one part is network design. they all include a set of customers with known locations and a set of facilities whose locations should be specified. Most SCND models belong to the category of discrete location models.

Govindan, Fattahi and Keyvanshokooh (2017), presented the comprehensive review of studies in the area of supply chain network design problems that come under uncertainty. The uncertainties were divided into the existing uncertainty such as supply, demand, and costs and the man made uncertainties.

Snyder et al (2014), represented a view where they accepted the presence and impact of disruptions caused by the uncertainties in network phase of supply chain and presented a broad range of models that can be used to create a supply chain that can be resilient to the disruption that are the most common. They concluded that a network may designed from scratch or modified on the basis on the models and the gaps identified. divided each category based on the underlying optimization model (facility location or network design) and the risk measure (expected cost or worst-case cost).

Klibi, Martel, and Guitouni (2010), provided a critical review and understanding of the optimization model for the purpose of robust design supply chain networks, while doing so they also categorized the existing uncertainties in the supply chain network design problems and reviewed their impacts on the network and planning phase of the supply chain.

Procurement

Supply and demand side uncertainties have a grave and direct impact on the procurement process of the supply chain. Examples of how these uncertainties have impacted businesses can be seen through real life scenarios such as the success of Nokia even after the plant fire or the Cisco systems excess inventory

write off while there was an economic turndown (Lakenan, Boyd, and Frey, 2001). These events are a small depiction of what happens when uncertainties strike the procurement department of a supply chain. While the challenges are greater the opportunities are also endless. Hewlett-Packard is a real life example of how the to realize money in cost saving as they did realize $ 425 million because of the effective procurement strategies they implemented (Nagali et al, 2008).

Hong et al (2018), provided an overview about the uncertainties that are found in the procurement process of the supply chain also the approaches that are applicable for analyzing these different uncertain situations. They used a systematic approach by creating a database of the researches based on the keywords that ranged from1995 to 2017, which were further streamlined out of which 156 paper were selected. The final findings of the paper concluded that there are five main risk relate to procurement, strategies and suggestion were provided based on those risk and how to tackle them.

Zhen (2016), discusses in their paper the integrated optimization problem of the procurement process and how they face stochastic demands of multiple products made by multiple components. The authors propose the use of a deterministic model for the problem of unknown demand. He also proposes the use of stochastic programming model and a robust optimization model for handling the right kind of production and procurement decision that are difficult to make under uncertainty. The efficiency of the proposed models in the given scenario is investigated through the numerical experiments.

Logistics

Logistic is vast process that involves several other processes such as transportation, inventory and storage. In recent times it has been seen that the logistics departments of many of the organizations are outsourced entirely or partially to the third party where they keep track of all or partial functions of this process.

According to Liu et al (2017), owing to the concept of functional logistics service providers the authors looks into influences uncertainty has on them and their operations, customer requirements scheduling decision of optimal level within the logistic service of supply chain. A programming model is created by which is multi objective for the scheduling problem that occurs in the logistic service of the supply chain. The total operation cost tends to reduce in the logistic service supply chain through this optimization model. The gap between the operation time and the customer requirement was reduced, which increased the satisfaction level of the functional logistics service provider's (FLSP's). through a genetic algorithm approach towards the problem the programming model that is multi objective is then made into a single objective programming approach.

Choy et al (2017), took the example of the third party logistics providers in china which are small and medium companies and are most effected by the uncertainties because of their lack of information for decision making. The main aim of this department is to fulfill the order and make sure of the inventory and storage so that the material for order is enough. The authors advised the Integrated Logistics Information Management System (ILIMS), the man made uncertainties that interrupted the flow of information between the third part logistic and the actual company. The advised system increases transparency so to make the uncertainties clear.

Maihami, Karimi, and Ghomi (2017), the authors focus on the deteriorating process and its problems that arise from the joint inventory system and the policy of price. This model advises a trade credit policy

between a vendor and a supplier which is known as the two echelon trade credit policy. The problem of randomness lies in product demand and deteriorating process. The trade policy advised is the solution that the authors have suggested. Through an algorithm the optimal solution is advised, for selling price and inventory decisions. The numerical approach is taken for the sensitivity test of the variables that impact the system decision and its performance such as cost of order, time taken for trade credit, the interest that is payable.

Pricing in supply chain

Pricing is a significant part of the supply chain function and falls under the category of process because it also faces many uncertainties and must be addressed by an innovative model for a solution.

Salehi et al (2020), addresses the location-allocation-pricing issues that comes with uncertainties of three levels in designing the supply chain network with stochastic demands. With the help of the problems that occur in the market segmentations a network is created for supply chain with two distribution channels in it consisting of Brick & Mortar and online market in the scenario of demand leakages occurring from the market in high prices. A return poly is being used because of the lack of physical observation of product in the online market. In this case the demand behavior of a product is being analyzed through the pricing policy and the return policy. t is formulated as a mixed-integer non-linear programming (MINLP) model and solved by a Lagrangian relaxation algorithm.

Wu (2017), according to this author the pricing strategy is dependent on the consumer behavior and the marginal willingness to pay that certain amount for the product since there might be a perception difference in the pass through concept of the supply chain channel. Monopoly with a single product, monopoly with multiple products, duopoly that has a direct and indirect channel are the four major market strictures that are studied in the research. The author has chosen to use the discrete choice model, where the demand is created based on the consumer purchasing behavior. the consumer marginal willingness to pay will lead to a different pass through price behavior. the price implications are deeply and thoroughly researched under cost certainties in the supply chain.

Zhang and Liu (2017), based their research on a firm that focuses on profit maximization and also sells products that live a short life-cycle. The aim of their study was to explore the decisions that are jointly made on pricing and the situation of group buying when the unknown or stochastic demand is met by providing urgent procumbent. For their study they explored the monopoly and duopoly market structures. The factors that were mostly focused in the research where the prices of joint buying and the quantity allowed for group buying online so that the equilibrium focused solutions can be derived for the retailers. The results showed the retailers prefer a single channel for the purpose of group buying and prefer dual channels for competing retailers for emergency procurement activities.

Competition as a problem of disruption

Heavy competition and interaction between the firms can be a challenged and uncertainty that firms face in the supply chain the presence of other uncertain factors increases the problem making it more complex than other. The problems can be seen in the heavy competition that occurs vertically or horizontally. Vertically competition occurs between the supplier and the reseller. Horizontally it occurs between the same layer of suppliers.

Li, Li, Chen, and Hou (2017), based their research on the scenario of a Supply chain that has dual or multiple channels where the manufacturers are either indifferent about the risk factors known as risk neutrals or are cautious about the risk attached such as the risk averse. The producers sells their product to the retailer who then sells it to the customer. On the other hand, the manufacturer is also using a direct channel to provide the same product directly to the customer. Here it is assumed that the retailer has more information about the demand of the product than the manufacturer. manufacturer's per-unit selling cost and the degree of risk aversion of the retailer have the most impact on decided the equilibrium.

Hafezalkotob and Makui (2012), researched how two main uncertainties are faced by the decision makers in supply one is the purchasing behavior which has been covered and the other is the rival strategies. It suggests that fuzzy strategies can help the decision makers perceive an estimation of the rival strategies. competition model is advised by the author and that can help achieve a Nash equilibrium. Since price cutting and increasing service level are main responses to rival supply chain, after calculating optimal strategies, we show that more efficient responses depend on customer preferences.

According to Zhu (2017), Stackelberg game to model can be used to depict the outsourcing scenario between the supplier and the buyer. According to her research and the model she suggested the information of both supplier and buyer demand is private information and not available for sharing with one another making it. Equilibrium is derived by investigation of non-information sharing, information sharing, and buyer forecasting cases. No difference was found between the buyers are suppliers that share information as compare to those who do not share information.

Contracting in supply chain

Contracting and collaborating can be a beneficial aspect for the supply chain at it provides ease to the functions but the following section is dedicated to provide literature that world. The concept of double marginalization is such that it is known for increase the amount of challenges already present for the supply chain with the numerous uncertainties already attached to them.

Yang and Ma (2017), examined the scenario where there are two unreliable competing retailers and one retailer. The model focuses in a scenario where the supplier is leading the game buy announcing the two part-tariff contract in the initial stage of to the retailer. According to the author all the uncertainties are realized in the later stages of production, where the retailer sets the price according their own profit maximization and this is how the author defines the optimal decision of the supplier and retailer in the contract design. With the help of numerical evidence, it is shown in the research that information rent tends to increase with the degree of substitution. Their final revelation was that larger and more intensified competition is a disadvantage to the supplier.

Cheng, Yang, and Tsay (2017), in their study they created an integrated model for understanding and designing of contracts that are made from supplier's point of view, buyer and the whole system as one unit when both parties are accompanied by alternative parties. Wide range of contracts types were considered and with them their fixed and flexible components too. To help the managers and decision makers with the creation of contracts, multiple contract structures are taken into consideration to understand how a structure of contract is created that focuses on one goal that is maximization of the profits of the supply chain also the way the fair game is done between both parties while the profit is allocated.

He and Zhao (2016), they studied that when a supplier which is subject to yield uncertainty who is selling to a retailer facing the stochastic demand, classic coordination contracts tends to be a failure in this scenario hence the efficient performance on both parties is not achieved. They first studied the vendor managed inventory (VMI) partnership. They advised that the vendor managed inventory (VMI) partnership merged with the production cost subsidy provides for a win-win situation for both parties. The production cost subsidy is also subject to the bargaining power that supplier and retailer have. advance-purchase discount (APD) contract alongside the revenue sharing contract tends to work well in the supply chain coordination. The discussion on the application of these contracts with further recommendations have been made.

Conclusion

in the above section we have successful managed to define uncertainty at different levels, introduce the basic models that were initially used and then divided that into the supply chain process. The section of supply chain process includes the major processes that can face uncertainty and disruption. Literature suggest models for optimization in those scenarios further extends to the disruption in competition and contracting. This research has led us to believe that there are promising avenues that should be used for further research since disruption will keep on growing in one form or the other and the models must keep innovating to match the new uncertainties. These models and papers that have been discussed have created a foundation under the topic which can be further explored through the future researches to make the models that are near to perfection and cater for all the flaws that the previosu studies have shown.

Recommendation

It is seen that most of the models discussed in the literature above are based on risk neutral decision rather than being risk averse. The risk neutral decision makers want to optimize the expected value of the objective. However, it must be understood that there are some certainties so rare that risk aversion become a need, in this way the other measures re also optimized for example worst-case objectives, p-robustness, and conditional value-at-risk (CVaR).

Disruptions are a part of multi-echelon events, when the upstream disruption propagating downstream in a way stock outs do. The literature on the specific topic is not found in vast amounts which is why there is a need for new models on the topic to understand that how the disruptions take place and what are the main strategies to overcome these disruption multi-echelon systems.

It is a fact that the disruptions are not normal events but abnormal events that happen in uncertain situations and the manager that make decision might tend to deviate from the solution that are provided by these models. Behavior studies must also be made part of the studies so that the manager and their behaviors towards decision making is accounted for and the irrational behavior can also be modeled. The description of manager's behavior under the uncertain situation and tackling of the disruption must also be made part of the studies. The models must discuss how in a multi-player supply chain the rational behavior of the manager is expected while solving the optimization problem presented in their unique scenario.

Although models do discuss the endogenous disruptions, but in most of the literature it is found that the disruptions that are discussed are exogenous. In real time the disruptions that occur are affected by the

firm's own actions. Labor strikes occur when the demand tends to be high or when the inventory is low so that is makes an impact. Mitigation strategies in this regard should be advised with the models so that the recovery time is decreased.

Demand may tend to fluctuate based on the disruption that is being caused in the supply chain process. An example of this may be the bottled water or fuel. Demand is fluctuating before, during and after the disruptions happening. This is why there is a need for models and strategies that account for the non-stationary demand depending on the state of disruption. Such models will be related to the literature on disaster relief and public-sector supply chains.

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