A Simulation-based Analytical Approach to Enhance Distribution Networks in Pharmaceutical Supply Chains

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Abstract

This paper focuses on the most efficient factors to be considered when designing a distribution network for pharmaceutical supply chains (PSC). When considering the impact on the consumers, distributing pharmaceutical products has become a crucial process than distributing other commercial goods. The study has a two-fold approach. Where in the first phase, the paper represents a comprehensive systematic review of literature based on PSC in terms of simulation and modelling techniques and the distribution networks. In the second phase, it designs distribution network models to simulate pre-identified clusters of the pharmaceutical based on the inherent characteristics. Finally, the most efficient distribution network designs are identified for each cluster. Here, four different distribution network designs were modelled using SupplychainGuru® simulation and modelling platform. These models help make strategic decisions such as designing and operating different distribution networks to better suit the product characteristics of a given PSC by contributing to reduce overall supply chain cost, reduce overall supply chain time, increase product availability and to increase product quality in order to deliver better quality products to the patients in need.

Keywords: *Distribution networks, Pharmaceutical supply chain, Simulation and modelling*

1. Introduction

Distribution of medicine has always been a vital part of the history of human civilization. Be it a war or an outbreak of an epidemic, the pinpoint accuracy of the pharmaceutical supply chain will decide the fate of thousands of lives. It is not just delivering medicine, it needs to be efficient, safe, in addition to being time sensitive. It is found out that the pharmaceutical supply chains have a highly dynamic and uncertain behaviour. Because of this reason, it is difficult to maintain an efficient distribution network for pharmaceutical supply chains. Proposed here is a solution to this in the form of four clusters of pharmaceuticals.

2. Literature Review

Pharmaceutical Supply chains preserve higher importance than the other commercial goods and services, since it costs a significant amount of money and time to produce and distribute pharmaceutical products. Not only that, when it comes to pharmaceutical product supply chains, all the contributors have to go through strict rules and regulations laid by the governments [13]. As the distribution networks of PSC are not well-managed, thousands of patients have to suffer and significant amount of investments are wasted [3]. The displacement of pharmaceutical products from the manufacturer to its consumer involves multiple parties such as suppliers, manufacturers, distributors, pharmaceutical benefit managers, health insurance companies, hospitals and pharmacies [1]. Therefore, pharmaceutical distribution process has become highly complex and fragmented. According to the literature, researchers are yet to address the role of complex and dynamic relationships that exist between individual members of PSC [8]. When considered about all the processes in PSC, distribution networks become more important since it bears a higher cost portion among all PSC functions [11] and [7]. Since different pharmaceutical products require different distribution networks, standard logistic strategy models that have been useful to guide managerial policy in other distribution industries cannot be easily applied to PSC [5] and [6]. The importance of having an efficient distribution network design is to determine the least cost system design such that the consumer demand is satisfied with their expected level. As literature emphasis, there are two factors to be considered when designing a distribution network [2].

1.) Will the product be delivered to the consumer location or picked up from a pre-ordained site?
2.) Will the distribution network have any intermediaries?

Based on these two factors, the decision makers can decide on the various types of distribution network designs to deliver products from the manufacturers to the consumers. In this paper, the authors intend to develop the most effective distribution network design for the distribution of pharmaceutical from the manufacturer to the consumer. Here the authors consider about pharmaceutical distribution network with manufacturers, warehouses and consumers. For this study, a two-echelon network is considered. The main perspective of this study is to determine the number and locations of manufacturing plants, warehouses related to the pharmaceutical supply chains.

When considered about the PSC, it shows a very dynamic behaviour than other commercial goods. When we compare different pharmaceutical products, they tend to show a large deviation from one to another and when considered about the prominent characteristics of the pharmaceuticals, it is difficult to have one distribution network design to distribute all the pharmaceuticals. Therefore, the products need to be categorized and distributed according to their special characteristics. The literature clearly emphasizes that the traditional distribution network designs cannot be used to distribute pharmaceuticals and there should be special network design for them [14]. Inherently PSC is dynamic and risky. In order to run multiple interactive scenarios, simulation methods can be used. In the literature review, the importance of the use of simulation and modelling techniques to enhance distribution networks in PSC has been clearly laid out. Out of all approaches for network optimization, simulation and modelling techniques have been identified as one of the best means to analyze and deal with stochastic facets existing in the supply chain [7]. Since the simulation methods have the capability of capturing uncertainty and complex system dynamics make it well suited for supply chain studies, this approach has the ability to help the optimization process by evaluating the impact of alternative policies [4]. Since it is a dynamic and a risky environment, decision makers tend to use simulation and modelling approach when designing models for the PSC.

PSC is composed of multiple firms interacting to produce and distribute drugs in an uncertainty environment. Even after a successful drug development, demand is highly variable and at the end of it, patent life demand all but vanishes due to competition from the generics. To counter this uncertainty, drug-specific contracts exist between suppliers, manufacturers, and distributors those results in complex, competitive, and dynamic relationships in the PSC.

The movement of pharmaceutical products from manufacturer to its consumer involves multiple players such as suppliers, manufacturers, distributers, pharmaceutical benefit managers, health insurance companies, hospitals and pharmacies. Therefore, pharmaceutical distribution process becomes highly complex and fragmented [3]. According to the past literature, around 6% of sales is sold directly by manufacturers. Hence, it shows that the distribution networks of the pharmaceutical industry is quite complex than the other commercial goods.

There are many models developed to determine logistic strategies. These standard logistic strategic models have been useful to guide managerial policies in other distribution industries and are not easily applicable to PSC. Researchers have yet to address the role of complex and dynamic relationships that exist between individual members of PSC [3]. In a PSC, the number of consumption points, the role and number of intermediaries, and the long lead times and highly unpredictable nature of bio-pharma manufacturing have created a web of contingencies, interdependencies, and uncertainties. Because existing research does not address the realities of PSC, there is an acute need for supply chain researchers to begin investigating these phenomena.

3. Methodology

Overview of the methodology is as follows and are presented in four main phrases:

1) Systematic Review

Literature review is the first step of the research that will be conducted to identify the studies that have been already done related to PSC. In this phase, current studies are thoroughly examined to identify the fundamental characteristics in PSC. Then the

case studies are identified in order to gather data for the study.

2) Classification

Pharmaceutical products can be classified into several clusters based on their prominent characteristics. There can be different pharmaceutical such as tablets, hazard drugs, liquids and etc. There are different policies and strategies to distribute pharmaceuticals. Therefore these several types of products can be distributed in various different ways. In this phase it is decided to identify the classifications of the drugs and follow up with relevent clustering for PSC.

3) Simulation and Modelling

Simulation and modelling techniques are used since there is a significant need of using these technologies to enhance distribution networks in PSC. Simulation and modelling techniques are highly applicable for uncertain environments. In this phase, simulation and modelling techniques are used for the following purposes,

1.) Distribution network models are developed to simulate the pre-identified clusters.
2.) Use data from the previous literature to simulate the developed models.
3.) Change policies and strategies for these models and simulate them in different scenarios.
4.) Identify and analyse the behaviours of distribution networks in pre-defined clusters.
5.) Compare the behaviours of the distribution networks.
6.) Develop most capable distribution network which can be apply to enhance the distribution networks in PSC.

4) Validation and verification

- The model will be verified by testing the data using the model and testing the data under normal conditions without the model.
- The model will also be validated in this stage using appropriate validating techniques.

A. Clustering Process

As per the literature emphasis, it is ineffectual to use the same distribution network for all the pharmaceutical products, since one product is highly deviated from the other product [4]. Different types of pharmaceutical product categories require specialized distribution networks and there are different policies and strategic levels to distribute pharmaceuticals. Therefore, it is difficult to use same distribution network design for all the pharmaceutical products. Therefore, at the second stage of the study, pharmaceutical products are clustered based on their prominent characteristics. In this phase of the study, it is decided to identify the classifications of the drugs and do relevant clustering for PSC. Pharmaceutical products are clustered based on their prominent characteristics. According to the literature, four main pharmaceutical clusters were identified [11] and [12]. These identified pharmaceutical clusters are described in the Table 1.

Table 1. Description of Pharmaceutical Product Clusters

Cluster Name	Description
Time Sensitive Pharmaceutical Product Cluster	These products are highly sensitive to the time. They have a minimum lifetime. Products should be distributed within minimum time period
Hazardous Pharmaceuticals Product Cluster	Hazardous pharmaceutical products are, which has the potential to cause harm to the other products. Therefore, these pharmaceuticals should be transported individually, without having any interaction with the others.
Hybrid Pharmaceutical Product Cluster	These products are highly sensitive to the time and they have the potential to cause harm to the other products. Therefore, these products should be transported individually within minimum time period.
General Pharmaceutical Product Cluster	Products can be distributed as the commercial goods.

As described, each and every cluster consists of different characteristics. These clusters have different Key Performance Indicators (KPI). In order to identify, analyze and compare the behaviours of each and every cluster, the relevant KPI's were identified first. These identified KPI's are described in the Table 2. When simulation techniques are used on the distribution networks of each and every pharmaceutical cluster, these KPI's are used to identify the necessary requirements related to each and every pharmaceutical cluster [14].

Table 2. Considered In The Pharmaceutical Clusters

Cluster Name	KPI's
Time Sensitive Pharmaceutical Product Cluster	Distribute products using minimum time Distribute Products before the due date Minimize the product exchanging rate among distribution centers. Actual adjusted on-time delivery compared to the customer service level target established
Hazardous Pharmaceuticals Product Cluster	Maximize the usage of possible warehouses. Monthly tracking of slow moving inventory Actual cycle count of finished goods inventory
Hybrid Pharmaceutical Product Cluster	Distribute products using minimum time Distribute Products before the due date Minimize the product exchanging rate among distribution centers. Maximize the usage of possible warehouses.
General Pharmaceutical Product Cluster	Minimize the total cost (Inventory cost, Distribution cost, Operational cost)

B. Simulation And Modelling Procedure

In order to identify the most efficient distribution network design for each and every pharmaceutical cluster, the simulation techniques are used. Since the authors consider the problem from the process side, discrete event simulation method is used. As described earlier, simulation and modelling techniques are highly applicable in uncertain environments [10]. For the model development process, the authors derived the test cases from the literature and used them as the input data of the model development process [8]. These derived test cases different from one to another based on the prominent characteristics align with each pharmaceutical cluster. This network design is used to distribute all the types of pharmaceutical products in the industry. All the four pharmaceutical product clusters use the same distribution network design, which is shown in Figure 1.

This is a multi-sourcing distribution network and all the plants and distribution centers connect to each other. Then the distributed network design is modelled using modelling and simulation tool. State-of-the-art supply chain modelling and simulation software, Supply Chain Guru ® was used for the simulations. The modelled design of the baseline scenario is shown in Figure 1. Then the interactive scenarios were run related to each and every cluster to identify best distribution network design for them. Here, scenarios were selected based on the KPI's which are mentioned in Table 2 and the constraints related to the clusters. Then the different scenarios were run to identify the most suitable distribution network design for each and every cluster. Then different distribution networks for different clusters were derived. The relevant scenarios for the pharmaceutical clusters are as mentioned in Table 3. As the final stage, the new distribution network design and the previous network design were compared.

C. Results

When distribution network design changes from the baseline design to another, the cost of the distribution network is reduced. The results of the simulation process are as follows.

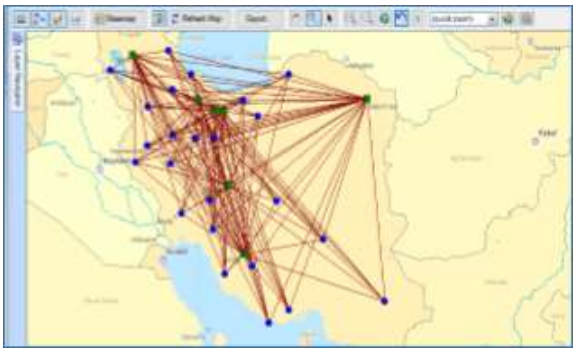

Figure 1. Baseline scenario of PSC

Table 3. Scenarios Considered For the Simulation Process

Cluster Name	Scenarios
Time Sensitive Pharmaceutical Product Cluster	Here time constraints such as expiry dates and minimum travelling time is considered to ensure that the products are distributed within minimum time throughout the distribution network.
Hazardous Pharmaceuticals Product Cluster	Here it is a must to assign one product time to one warehouse. Therefore, all the possible warehouses need to be considered in the distribution network.
Hybrid Pharmaceutical Product Cluster	All the scenarios, which were considered for both Time Sensitive Pharmaceutical Product Cluster and Hazardous Pharmaceuticals Product Cluster, were considered.
General Pharmaceutical Product Cluster	Consider as a general distribution network. Instead of creating transportation policies for every source/destination/product, author use groups to apply the same policy across a number of products, sources, or destinations.

Figure 2. Optimized Distribution Network Design for Hybrid Pharmaceutical Cluster

When time sensitive pharmaceutical products are distributed using the network design mention in Figure 3, rather than using the baseline scenario, the distribution cost can be reduced by 5.88 percent

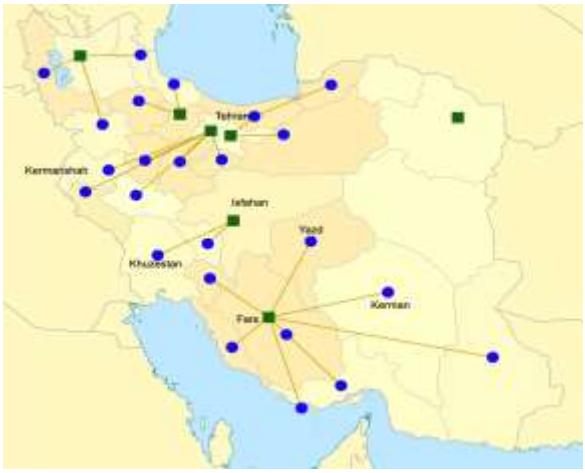

Figure 3. Optimized Distribution Network Design for Time Sensitive Pharmaceutical Cluster

When hybrid pharmaceutical products are distributed using the network design mention in Figure 2, rather than using the baseline scenario, the distribution cost can be reduced by 6.34 percent. When hazardous pharmaceutical products are distributed using the network design mention in Figure 4, rather than using the baseline scenario, the distribution cost can be reduced by 10.82 percent. When general pharmaceutical products are distributed using the network design mention in Figure 5, rather than using the baseline scenario, the distribution cost can be reduced by 72.1 percent.

Figure 4. Optimized Distribution Network Design for Hazardous Pharmaceutical Cluster

Figure 5. Optimized Distribution Network Design for General Pharmaceutical Cluster

4. Conclusions

The simulation model developed in this paper addresses the PSC distribution network design problems. The aim of this study is to design most effective distribution network design considering different clusters of pharmaceuticals. Through the application of the modelling and simulation techniques, the most efficient distribution network designs were developed for all the four main pharmaceutical clusters. The cost differences of the distribution network designs are summarized in the Table 4 and Figure 6.

Table 4. Percentage of Cost Changes

Cluster Name	Percentage
Time Sensitive Pharmaceutical Product Cluster	5.88%
Hazardous Pharmaceuticals Product Cluster	10.82%
Hybrid Pharmaceutical Product Cluster	6.34%
General Pharmaceutical Product Cluster	72.1%

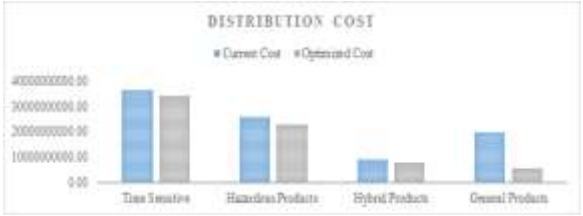

Figure 6. Cost Differences

Since PSC deals with higher degree of uncertainty in input parameters, simulation-based analytical approach is applied to cope with the dynamic relationships. This study emphasis that, as a result of highly dynamic behaviours and the prominent characteristics of the PSC it is difficult to distribute pharmaceuticals by using general distribution network designs. Hence, through this study four main pharmaceutical distribution clusters were identified. Then, simulation-based analytical approach is used to identify the most efficient distribution network design for PSC clusters. Through the results of the study, it is clear that distributing products with in the relevant cluster makes a significant cost difference. The literature emphasized that due to the highly dynamic behaviours of the PSC it is difficult to find solutions to the problems in PSC. This study suggests clustering approach to categorize products with equal characteristics. This study introduces four main pharmaceutical distribution clusters with the relevant KPI's.

The clustering approach can be used to reduce the influence of the dynamic behaviours of PSC. Furthermore, this study suggests the scenarios for all the clusters to simulate and find the most efficient distribution network designs. This study proposes new avenues in designing and operating different distribution networks to better suit the product characteristics of a given PSC in order to deliver better quality products to the patients in need.

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