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A Single Mathematical Model Considering the Cost of Poor Quality for Green Pharmaceutical Supply Chain Management

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Abstract

This study proposes a single mathematical model in a green supply chain network consisting of suppliers, manufacturers and distribution centers for pharmaceutical products. The main objectives are: minimizing operational cost considering total purchasing cost of materials, production costs (including cost of poor quality), transportation cost of materials, and social cost of carbon dioxide emissions. We solved the proposed mathematical model by the LINGO 16.0 Software .The results illustrate by increasing the social cost rate of carbon dioxide emissions, the amount of the emission of carbon dioxide will decrease.

Keywords: Mathematical Model, Green Pharmaceutical Supply Chain, Cost of Poor Quality, Social Cost.

I. INTRODUCTION AND LITERATURE REVIEW

Unlike many industries, there are numbers of fundamental differences between pharmacy and other consumer products supply chain management. Almarsdóttir and Traulsen[1] stated that medicines are developed, manufactured, and distributed according to strict regulatory requirements. The one of the challenging part is the products must be clinically safe before they are sent to the market, and provide assurance regimes that products are not contaminated or altered from the accepted form at any point in the supply chain [2] and, there is an important trade-off between minimizing health care costs and saving life of patients. The pharmaceutical company products and its supply chain have major influences on the lasting and profitability of the company. Thus, there has been extensive research on the different stage of the pharmaceutical supply chain (PSC).

The first supply chain model of the pharmaceutical industry is developed by Rotstein et al [3]. Their chain started from the drug development stage until final manufacture stage and they focused on the production issues and capacity investment together. Later, Papageorgiou et al. [4] developed new model with a multi-site, multi-period and multi- pharmaceutical product. Their model is formulated as a deterministic with a higher degree of detail in the production part. Aptel and Pourjalali [5] argued that during the PSC, the management and the control of perishable pharmaceutical supplies is one of the most important managerial problems in health care industries. Different from the others, Pitta and Laric [6] developed a supply chain of healthcare system which follows the flow of information through the system. But their healthcare value chain is not linear in nature. Tsang et al. [7] focused on the risk metrics of the PSC. Sinha and Kohnke [8] proposed a conceptual framework for the design of healthcare supply chains. Abdelkafi et al. [9] selected the best supply chain plan balancing costs in health care. Nagurney et al. [10] developed a model may be utilized for the determination of the optimal allocation of resources for multiple vaccine and pharmaceutical production, storage, and distribution to points of need in the case of disasters, epidemics, or pandemics. Laínez et al. [11] developed particular attention to three key stages in the life cycle of an innovative pharmaceutical product, namely the product development pipeline management, capacity planning and supply chain network. Chen et al. [12] suggested a HSC research model based on a relational view, delineating the factors that improve hospital supply chain performance: trust, knowledge exchange, IT integration between the hospital and its suppliers, and hospital–supplier integration. Kumar and Kumar [13] used system dynamics technique to model the rural PSC of one of the important drug of folic acid. In their study, causal loop diagram and stock flow diagram have been developed. Yadav et al. [14] integrated the vaccine supply chains with other healthcare supply chain (HCSC) to improved economies of both scale and scope. Azadeh et al. [15] presented an integrated approach for analyzing the impact of macro-ergonomics factors in HCSC by data envelopment analysis. Levis and Papageorgiou [16] introduce an uncertainty factor, where the demand forecasts are dependent on the results of the clinical trials for each product. The healthcare supply chain is very complicated and carries high responsibilities that drug reaches the right people at the right time with a right amount [17]. In addition to uncertainty environmental conditions, inventory management is the one of the most important issue during the HCSC. Michelon et al. [18] applied a heuristic method to optimize distribution of supplies and to control the inventory in a healthcare. Dellaert and Van de Poel [19] presented an inventory rule for joint ordering in a hospital but they ignored the capacity constraints. Gatica et al. [20] developed models for capacity expansion and production for pharmaceutical enterprises. Kim [21] designed and developed a model to optimize inventory control and to reduce material handling costs of pharmaceutical products in healthcare sector. Tetteh [22] claimed that drug inventory management in the supply chains should receive a high priority condition in that they affect the availability and the affordability dimensions of access to medicine.

despite of all advances and improvements in the manufacturing, storage, and distribution methods, several pharmaceutical companies are still mainly far from effectively satisfying market demands in a consistent manner[23].So, PSC is quite ready for receiving help from efficient optimization techniques[24].Timpe and Kallrath [25] developed a mixed integer linear programming model (MILP) model for optimizing a multi-site network with production, distribution, and marketing constraints. Jayaraman and Pirkul [26] developed a Capacitated Plant Location Problem (CPLP) type model for planning and coordination of production and distribution facilities for multiple commodities, including raw materials suppliers, production sites, warehouses and customer areas. Oh and Karimi [27] proposed a deterministic MILP model that introduce of two important regulatory factors, corporate tax and import duty in PSC. Amaro and Barbosa-Póvoa [28] developed two MILP models and solved them sequentially for the integration of planning and scheduling models in pharmaceutical supply chains. Cetin and Sarul [29] proposed a multi-objective goal programming model for the blood supply chain to determine location of blood banks among hospitals or clinics. Their proposed model tries to minimize the total fixed cost of locating blood banks and the total distance traveled between the blood banks and hospitals. Griffin [30] addressed the allocation problem in both public and private hospitals. He modeled health care delivery systems utilizing a MILP which accounts for financial and personnel constraints as well as infrastructure quality.

Recently, a few studies have offered decision support tools that to make better health policy, public health and patient safety in the pharmaceutical supply chain. Sundaramoorthy, et al. [31] developed a simple LP model as a decision support tool for medium term integrated making decisions in the pharmaceutical industry. Kelle et al. [32] focused on to improve pharmacy inventory management strategy in the healthcare industry. They developed decision support tool that control the ordering system at a local storage unit within an individual Care Unit. Turgay and Taskın [33] proposed a fuzzy mixed goal-programming model referring health care organization’s resource allocation problem in a fuzzy environment.

Yet, most producers of carbon dioxide emissions do not emphasize to these social costs while communities pay for them. To mitigate the damages caused by carbon dioxide emissions, we need to take the social costs of carbon dioxide emissions account for all economic activities. On the other hand, quality concepts such as cost of poor quality play key role for pharmaceutical products. So, in this study, a single mathematical model considering the cost of poor quality and social costs of CO_2 for pharmaceutical Supply Chain Management The paper is structured as follows: Section II describes the problem definition and the proposed mathematical model. Finally, the paper ends with Section III includes results and conclusions.

II. PROBLEM DEFINITION AND MATHEMATICAL MODEL

In this study, we assumed that the materials suppliers and decision center locations are determined in advance, and the potential plants such as their capacities, are also specified. In addition, the authors assumed that the production of one unit of a pharmaceutical product needs one unit of production capacity, regardless of type of pharmaceutical product. For each supplier, plant and distribution center, decisions must be made on the amount of materials purchased from each supplier for each plant, the total units of pharmaceutical products that need to be produced in each plant, and the amounts of pharmaceutical products shipping from each plant to each decision center. An operational cost includes materials purchasing cost, Production cost, considering appraisal cost and failure cost (cost of poor quality) and transportation cost. Carbon Dioxide emissions include the emissions resulting from the production process and transportation. The decisions to be determined include the demand requirement of every decision center (DC).

The objective is to minimize the total costs by including both operational costs and social costs of carbon dioxide emissions. Schema of pharmaceutical supply chain network can be seen at Figure 1.

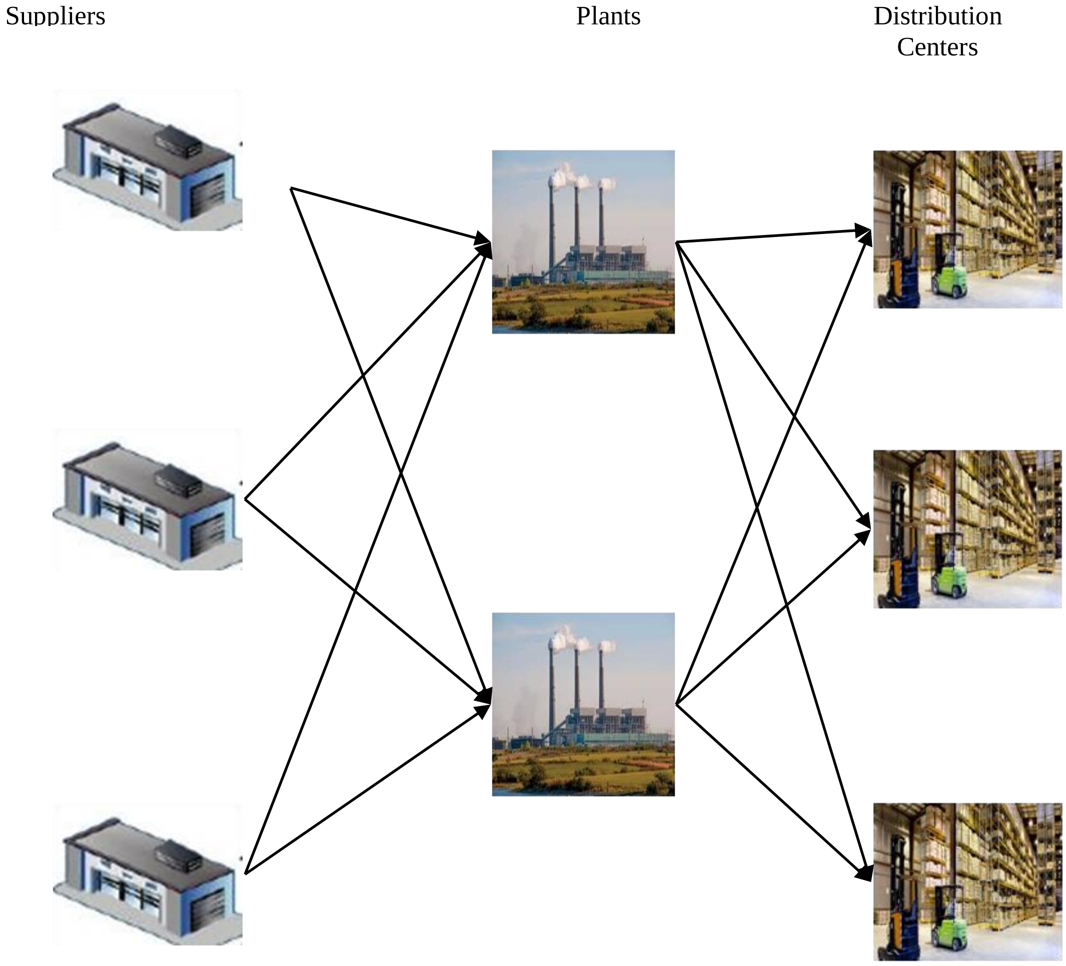

Fig.1 Schema of pharmaceutical supply chain network

A. Indices and parameter notations

In this paper, the following indices have been used:
s ∈ S, a set of candidate suppliers;
p ∈ P, a set of possible plants;
d ∈ D, a set of candidate distribution centers;
m ∈ M, a set of raw materials;
i ∈ I, a set of products

The parameters and variables can be seen as follows:

1) Parameters

$RMCmsp$	The unit cost of raw material m from supplier s to plant p (including appraisal cost)
$SCms$	The capacity limit of raw material m of supplier s
CPp	The capacity limit of plant p
$PCip$	The unit production cost of product I in plant p, (including failure cost)
$TCipd$	The unit transportation cost of product i

$RMmi$	The unit of raw material m required to produce one unit of product i
$LCip, UCip$	The lower and upper production capacity limits of product I in plant p
$CO2v$	The CO_2 emissions of unit weight, unit distance using transportation mode v
Wm	The unit weight of raw material m
Wi	The unit weight of product i

2) *Variables*

TRMmsp	The total units of raw material purchased from supplier s to plant m
TPipd	The total units of product I transported from plant m to distribution center d
$TDmv$	The raw material m transportation distance of mode v
$TDiv$	The product I transportation distance of mode v
SCR_{CO2}	The social cost rate of CO_2 emission

B. *The mathematical Model*

$$\text{Minz} = \text{Min}\ [\ \sum_{m,s,p} \text{RMCmsp TRMmsp} + \sum_{i,p,d} \text{PC ip TPipd} + \sum_{i,p,d} \text{TCipd TPipd} +$$
$$(\ \sum_{i,p,d} \text{CO2ip TPipd} + \qquad (1)$$
$$\sum_{m,s,p,v} \text{CO2v Wm TRMmsp TPmv} + \sum_{i,p,d,v} \text{CO2v Wi TPipd TDiv})\ \text{SCRco2}]$$

St:

$$\sum_{i,d} TPipd\ RMmi \leq \sum_{s} TRMmsp \qquad (2)$$
$$\sum_{p} TRMmsp \leq SC_{ms} \qquad (3)$$
$$LCip \leq \sum_{d} TPipd \leq UCip \qquad (4)$$
$$\sum TPipd \leq CPp \qquad (5)$$
$$TRMmsp \geq 0, TPipd \geq 0,\ TDmv \geq 0,\ TDiv \geq 0, SCR_{CO2} \geq 0 \qquad (6)$$

The first term in the objective function is the total purchasing cost of materials from all suppliers (including transportation cost of materials). The second term is the total production cost (including appraisal cost and failure costs) in all plants. The third one is the total transportation cost of all products, and the last term defines the total social cost of carbon dioxide emissions (including emissions caused by production process, material transportation and products transportation). Constraint 2 ensures materials balance. Constraint 3 and 5 ensure the capacity limit of raw material m of supplier s. Constraint 4 ensures lower and upper production capacity limits of product i in plant p. Constraint 6 determines non-negativity for variables.

III. CONCLUSION AND RESULTS

This study proposes a single mathematical model for optimizing pharmaceutical supply chain costs with respect to social cost of carbon dioxide impact. The aim of the model is to optimize total costs, considering cost of poor quality as well as minimizing carbon emission in the supply chain system. Furthermore, this model can be applied as a decision support system for determining the green economic production quantity (GEPQ). We solved the proposed mathematical model by the LINGO 16.0 Software. The results can be seen in Table 1. Nine tests were given and used to analyze the results. In test one; the authors take only the operational costs into consideration. From test two to test nine, eight different social cost rates were considered: 25dollar per tonCO2, 50 dollar per ton CO2, 75 dollar per ton CO2, 100 dollar per ton CO2, 125 dollar per ton CO2, 150 dollar per ton CO2, 175 dollar per ton CO2, and 200 Dollar per ton CO2 of carbon dioxide emissions, respectively, to determine the optimal material purchasing lot size from each supplier, the optimal production size in each plant, and the optimal amount of products transporting from each plant to each decision center (DC). The results illustrate by increasing the social cost rate of carbon dioxide emissions, the amount of the emission of carbon dioxide will decrease. The coverage of social costs in supply chain management could allow decision-makers of enterprises to anticipate more feasible costs in the operations of supply chain networks. The proposed model has the potential to become an effective tool that simplifies the understanding of optimal supply chain policies with consideration for social costs of carbon dioxide and other wastes emissions resulting from operating such a supply chain network. In addition, the proposed model could employ useful reference for legislators in estimating the monetary loss resulting from carbon dioxide emissions in the operations of supply chain networks. In addition, the legislators could use the model to propose legislations to force the enterprises to pay for the social costs of carbon dioxide emissions. Therefore, the enterprises must finance in reducing carbon dioxide emissions from the operations of such supply chain networks. For future studies, some parameters such as $RMCmsp$ (The unit cost of raw material m from supplier s to plant p), $RMmi$ (The unit of raw material m required to produce one unit of product i) , $PCip$ (unit production cost of product I in plant p) and $TCipd$(unit transportation cost of product i from plant m to distribution center d) can be considered at uncertainty environment. Also, social costs of other wastes emissions caused by the operations of supply chain network could be considered for future researches.

Table 1
Result of tests

Test	CO2 emissions Unit cost ($/ton)	CO2 emissions Amount (tons)	CO2 emissions Social costs ($)	Operational costs ($)	Objective function(Total cost $)
1	0	3049.687	0	1,368,687	1,368,687
2	25	3049.687	76242.2	1,368,687	1,444,929
3	50	3049.284	152464.2	1,368,997	1,521,461
4	75	3047.632	228572.4	1,366,547	1,595,119
5	100	3021.430	302143.0	1,368,814	1,670,957
6	125	2984.351	373043.9	1,372,294	1,745,338
7	150	2969.646	445446.9	1,366,414	1,811,861
8	175	2919.165	510853.9	1,374,518	1,885,372
9	200	2882.374	576474.8	1,400,056	1,976,531

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