Multi-Objective Optimization of Green Supply Chains considering Nitrogen Emissions

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ABSTRACT

The total costs of the supply chain have always focused on generic costs such as fixed and variable costs of the factory and the transportation costs and sometimes the inventory holding costs. In the real world, there are high nitrogen oxides emissions during factory operation which are known to cause both health and environmental issues. These gases are released during production activities at the factory and also during transportation activities. A multi-objective optimization problem is used to minimize the total cost of the supply chain and the nitrogen oxides emissions. The paper attempts to model a supply chain problem for cost minimization while also considering the nitrogen oxides emissions from the facilities and transportation. The total costs of the supply chain are initially modelled as a MILP (Mixed Integer Linear Program). The full proposed linear program consisting of the two objective functions is finally solved with 11 different sets of randomly-generated data. The two objective functions were solved with a particle swarm optimization technique.

Keywords: Nitrogen oxides, Particle Swarm Optimization (PSO), Total Costs, MILP

1.Introduction

When an environmental constraint is added into a normal supply chain, the costs are impacted. Nitrogen oxides can affect both the environment and human health. These gases can be harmful to vegetation which in turn reduce crop yields These gases also impact the environment by reducing visibility due to smog. In greening the supply chain, there must be proper minimization of costs due to the facilities, transportation and the also the environmental impacts of these facilities and transportation.

The green operations cover topics such as reverse logistics and network designs. Liu *et al.* (2019) conducted an exploratory case study that found out that different green operations strategies require the support of different supply chain flexibility dimensions Each flexibility dimension's role varies s depending on the degree of innovativeness in the green design initiatives and the types of green purchasing initiatives. Chawla et al. evaluated green operations management practices and also highlighted the benefits of green operations management over conventional management they used fuzzy analytical hierarchy process to justify the adoption of green operations management practices.

Decision making is critical in supply chains whereby precautions are being taken against environmental decay. Alzaman *et al*. (2018) stated that normally production costs are lumped as just one cost. The authors believe that this prevents one from seeing the hidden opportunities in shortening the production duration. Shortening is well known for increasing the direct production costs. Jeon et. al. (2019) stated that sustainable manufacturing is one of important areas in smart production strategies and operations, this is because more production energy data can be collected from the smart manufacturing environment. Reduction of greenhouse gases and excessive energy consumption is a necessary condition.

A lot of previous studies have shown that companies and governments should implement efficient environmental policies for better supply chains. Scavarda *et al* (2019) proposed a recycling activity implementation policy which aimed at emphasizing the corporate social responsibility I the philosophy of the healthcare institution. It was found that the healthcare supply chain management is capable of improving the population's quality of life. It is also advisable for the implementation of the educational program and the development the corporate social responsibility through the Triple Bottom Line.
A lot of models for total cost of the supply chain minimization have been derived in recent years. Sun *et al.* (2019) stated that in the context of global slowdown, most studies do not consider transaction costs. Tshivhase and Kainuma (2019) designed and solved a mathematical model with the help of a software package to optimize the costs. The problem was solved using a mixed integer linear program (MILP) which required a binary which was applied between the customer bases and the warehouses to capture economies of scale that are common in transportation. The methods were also investigated for sensitivity to key factors such as demand structure. Zhang *et al.* (2013) optimized terminal networks taking into consideration the costs of carbon dioxide emissions They optimized the problem through bi-level programming where upper level searches for the optimal terminal network. They found out that a reduction in total system costs appears feasible when carbon dioxide emission prices are raised. Tshivhase (2018) studied the airport industry which is a well-known contributor to carbon emissions. Tshivhase and Vilakazi 2018) focused on the mining industry which is also a strong contributor of carbon emissions. Tshivhase and Kainuma (2019) addressed the emissions of carbon into the atmosphere by proposing a single period, multi-supplier low carbon mixed integer model. This model was proven to reduce carbon emissions in the supply chain and also find the optimum distribution levels among different facilities including factories. Tshivhase and Kainuma (2018) identified the existing literature gaps and possible future research focus with respect to carbon emission reduction by looking at literature done between 1995 1nd 2018. In the 1990s due to improved computer models a

consensus was formed that stated that greenhouses gases were deeply involved in most climate changes and emissions were bringing discernable global warming. During the same decade, scientific research in emissions has included multiple disciplines.

Tshivhase and Kainuma (2019) reviewed the literature of what has been studied with respect to carbon emissions and also identify the gaps in the literature using a systematic literature review approach. Content analysis was used to categorize existing literature on the various topics and methods over time in the area of carbon emissions in the supply chain.

This paper attempts to study the impact of nitrogen emissions in the supply chain. A lot of studies about optimization while also taking into account overall carbon emissions have been done. It is also beneficial for the full impact of nitrogen emission to be studied as this can be useful for smaller firms that are interested in focusing in reducing one type of emission at a time. In recent months the study of the full impact of nitrogen oxides has been gaining in momentum. Ozgen et al. (2021) reviewed the literature regarding nitrogen oxides emissions from the emission source while also discussing the main formation mechanisms techniques. The review managed to crosslink several aspects that are usually treated separately in scientific papers such as laboratory tests with basic theory or only field tests. Most nitrogen emission studies normally deal with pure chemistry without employing other areas of engineering and sciences.
In this paper we study a supply chain that delivers products from the suppliers to the customers. All the facilities and transportations have capacity constraints. There is an objective that minimizes the total cost of the supply chain which includes transportation, raw material, holding, fixed and variable costs. The second objective is to minimize the amount of nitrogen oxides produced by the facilities. The supply chain is initially modelled mathematically and then algorithms are used to produce a feasible solution.
The rest of the paper is organized as follows. Section 2 is the model development which basically shows the mathematical formulation. Section 3 describes the results with some example problems Section 4 is the conclusion.

2. Model Development

2.1. Description of the model

. A simple supply chain is considered and it consists of the plant, warehouses and the customer outlets. Only one type of transportation option is considered. In this study we are looking at the environmental impacts of nitrogen oxides produced by the transportation option. We will only consider two objective functions. The first one will minimize the total costs of this supply chain and the second objective function will minimize the environmental impact of nitrogen oxides (NO_x). This second objective function will be represented in terms of litres.

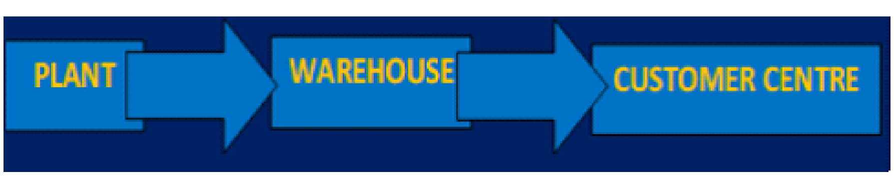


Figure 1: The flow of products between the facilities diagrammatically

Products are produced at the plant. There is also a certain amount of demand at the at the customer centres. The objective is to minimize the total costs of this supply chain and the environmental impact of nitrogen oxides. The plan is to optimize the model such that the total costs including transportation costs are minimized.

Some assumptions of this mathematical problem

- All the facilities have capacity constraints
- Only one warehouse can fulfill the demands of each customer outlet
- The transportation options used between the facilities is identical
- These transportation options emit nitrogen monoxides
- The facilities also do emit nitrogen oxides
- Demand is met
- Only one type of product is produced

2.2. Environmental Impact of nitrogen oxides (NO_x).

Emission of nitrogen oxides contribute to environmental decay. Industrial operations are also high emitters of these dangerous gases. Hence the reason that researches on minimization of carbon emissions including nitrogen oxides are really important. The amount of nitrogen oxides depends on the number of products being transported and the distance between the facilities.

2.3. Mathematical model

The two objectives are each divided into several components. Table 1 shows the components of these objective functions.

Table 1: The cost and environmental function

Cost	CP (CF) (CV) CT CH CPur	Plant Costs - Fixed Costs, Variable Costs Transportation Costs Inventory Holding Costs Cost of Purchasing Raw Materials from Suppliers
Environmental Function	EN	Amount of Nitrogen oxides

Table 2 : Notations for facilities

p	Plant
w	Warehouses
s	Customer outlet
t	Transportation option

Table 3: Parameters

dem_s	Demand at the customer outlet
dem_x	Demand of facility x϶{p,w}
rc_p	Unit raw material costs from supplier to the plant
tc_{pw}	Unit transportation cost from the plant to the warehouse
tc_{ws}	Unit transportation cost from warehouse to the customer outlet
dis_{xy}	Distance between facility x϶{p,w} and facility y ϵ{w,s}
fc_x	Fixed cost of opening facility x϶{p,w}
vc_x	Unit variable cost per unit at facility x϶{p,w}
in_w	Expected inventory at the warehouse w
r_{num}	Number of units of raw material a required for one product
cap_x	Capacity of facility x
cap_y	Capacity of transportation option
NR^x	Rate of nitrogen oxides released to produce a unit of product in facility x
NR^y	Rate of nitrogen oxides released per a unit transportation distance
$h_p \in \begin{cases}1\\0\end{cases}$	Binary, 1 if plant p is open otherwise its 0
$h_w \in \begin{cases}1\\0\end{cases}$	Binary, 1 if warehouse w is open otherwise its 0
pr_q_{pw}	Quantity of products transported between the plant and the warehouse
pr_q_{ws}	Quantity of products transported between the warehouse and the customer outlet
µ	Mean of data
xx_i	Individual data points
N	Number of data points
σ	Population standard deviation

The objective model is formulated in the next steps:

$$Obj_1 = CP + CT + CH \tag{1}$$

$$CP = CF + CV \tag{2}$$

$$Obj_2 = EN \tag{3}$$

$$CF = \sum_p fc_p h_p + \sum_w fc_w h_w \tag{4}$$

$$CV = \sum_p vc_p dem_p + \sum_w vc_w dem_w \tag{5}$$

$$CT = \sum_{p}\sum_{w} pr\_q_{pw}tc_{pw}dis_{pw} + \sum_{w}\sum_{s} pr\_q_{ws}tc_{ws}dis_{ws} \tag{6}$$

$$CH = \sum_{w.} h_w in_w \tag{7}$$

$$EN = \left(\sum_{w} dem_w\, NR^w\right) + \left(\sum_{s} dem_s\, NR^s\right) + \left(\sum_{p}\sum_{w} pr\_q_{pw}NR^y\, dis_{pw} + \sum_{w}\sum_{s} pr\_q_{ws}NR^y\, dis_{ws}\right) \tag{8}$$

$$dem_p = \sum_{w} pr\_q_{pw} \qquad \forall\, p \tag{9}$$

$$dem_w = \sum_{w} pr\_q_{ws} \qquad \forall\, w \tag{10}$$

$$in_w = \frac{dem_w}{2} + \sigma_w\left(\frac{\sum_w pr\_q_{pw}}{dem_w}\right) \tag{11}$$

$$\sigma_w = \frac{\sum_w \sum_s \sigma_s pr\_q_{ws}}{dem_w} \tag{12}$$

$$\sum_{w} pr\_q_{pw} \leq cap_p h_p \qquad \forall\, p \tag{13}$$

$$\sum_{s} pr\_q_{ws} \leq cap_w h_w \qquad \forall\, w \tag{14}$$

$$\sum_{m} pr\_q_{pw} = dem_w \forall\, w \tag{15}$$

$$\sum_{m} pr\_q_{ws} = dem_s \forall\, s \tag{16}$$

$$\sum_{p}\sum_{w} pr\_q_{pw} \leq cap_y \tag{17}$$

$$\sum_{w}\sum_{s} pr\_q_{ws} \leq cap_y \tag{18}$$

Objective function 1 (1) minimizes the total costs that we are looking at in a typical supply chain. The plant costs (2) comprises of the variable and fixed costs. Objective function 2 (3) minimizes the nitrogen oxides. Equation (4) determines the fixed costs of this supply chain when the facilities are in operation. Equation (5) calculates the amount of variable costs according to the facilities' demands. Equation (6) Computes the transportation cost according to the distance and amount of transported product Equation (7) Determines the inventory holding cost at the warehouses. Equation (8) calculates the amount of produced nitrogen oxides taking into account that the released amount by the facilities is calculated based on the release rate and the demand. Equation (9) and (10) determines the demand at each facility. Equation (11) calculates the inventory level at the warehouse and ensures that demand is always lower than the facility's capacity. The standard deviation of demand (12) is defined as the weighted average of the standard deviation of other facilities' demand. The capacity of a facility is always higher (13) and (14) than the demand in the next facility Equation (15) and (16) ensures that the amount of products from facility A to facility B must be equal to facility B' s demand Equation (17) and (18) ensures that transportation is not overloaded.

3.Results and Discussions

3.1. Results analysis

The algorithms were coded in MATLAB. It is a requirement for repeated simulations to find suitable parameter values. Eleven test instances of different customer sizes were evaluated to examine the proposed particle swarm optimization (PSO) algorithm method. The parameters for these instances are generated randomly using uniform distribution. The objective functions were tested on data sets of various number of customers.

Figure 2: Association of warehouses during optimal operation

The association of warehouses to customer outlets are plotted as shown in Figure 2. Only for of the 11 data sets are shown. These data sets consist of 13,14,20 and 24 warehouses. Initially, the values of these facilities is chosen with the condition that these facilities in the above mentioned

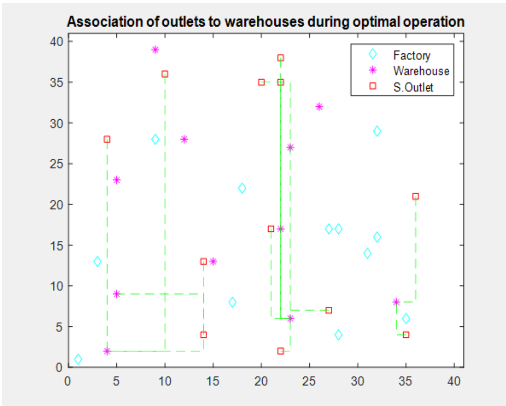


Figure 2(a)

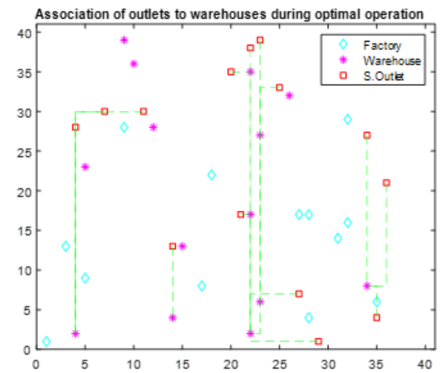


Figure 2(b)

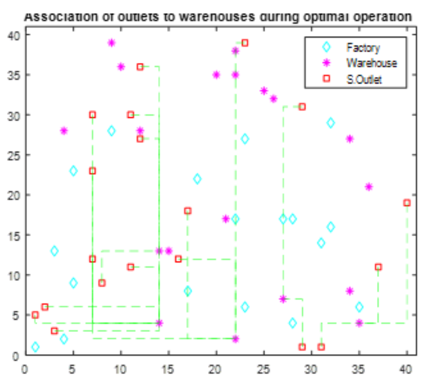


Figure 2(c)

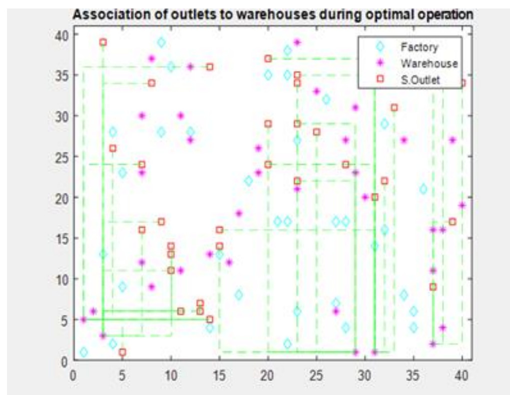
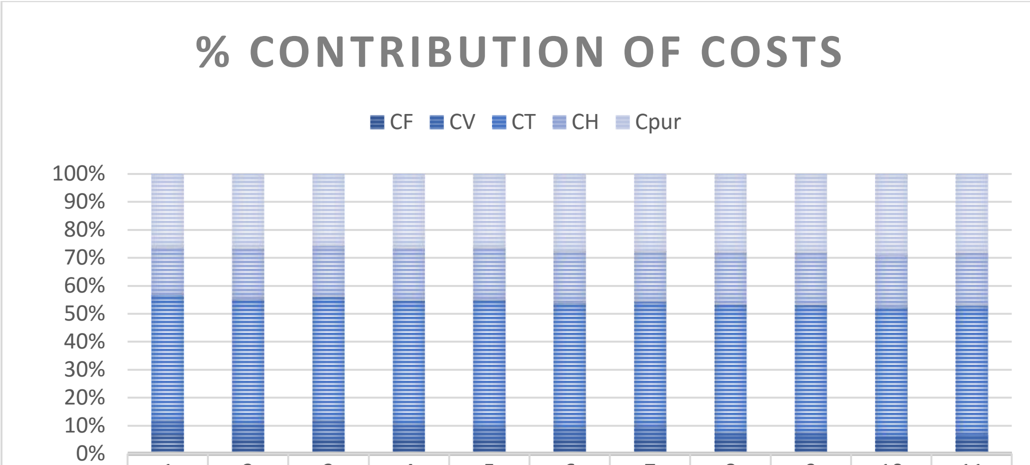


Figure 2(d)

areas are located in separate locations and that means when the densities of these facilities i.e. factories, warehouses and customer outlets are added the answer should be less or equal to one. This process applies to all the facilities. The objective function is plotted for all of the 11 numerical examples. The PSO is used for the total costs of the supply chain. The final results are obtained by the implementation of the particle swarm optimization (PSO). This is because the average values obtained through this swarm method are lower.

Figure 3 shows the percentage contribution of each cost. From these data, it can be seen that the transportation costs are the major contributors to the total costs. The costs of purchasing raw material are the next highest contributor. The fixed costs and the variable costs are the lowest contributors. As the number of customers increases, this leads to an increase in the average costs values.



	1	2	3	4	5	6	7	8	9	10	11
Cpur	26.2	26.6	25.8	26.4	26.3	27.6	27.7	27.9	28	28.7	28.1
CH	17.05	18.1	18.08	18.8	18.6	18.5	18.07	18.71	18.83	18.93	19
CT	45.3	44.9	44.8	44.65	45.7	44.98	44.65	46	45.95	46.05	46.18
CV	4.42	5.3	6.2	5.025	4.285	3.815	4.462	2.27	2.145	1.217	1.601
CF	7.03	5.1	5.12	5.125	5.115	5.105	5.118	5.12	5.075	5.103	5.119

Figure 3: Percentage contribution of PSO cost components

There is a capacity constraint at the factory which makes sure that the produced products at the factory can be within factory limits. There is also a limit at the warehouse which translate to the warehouse capacity.

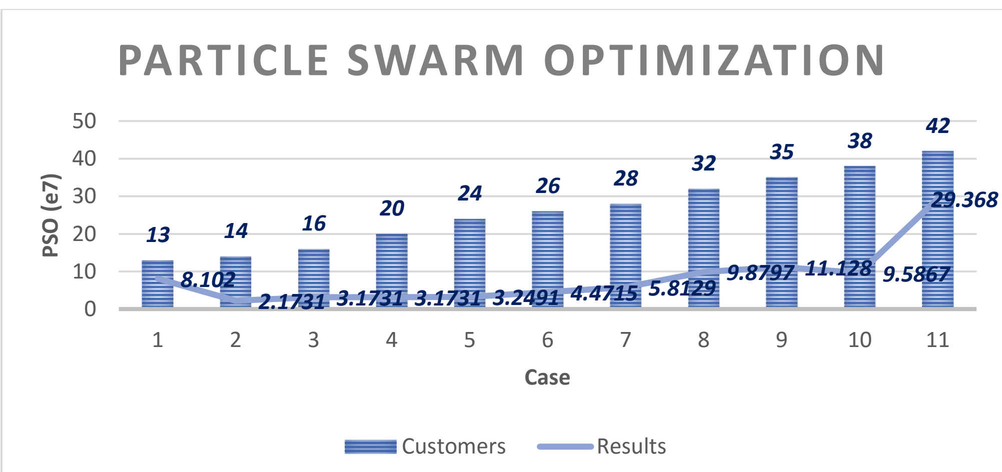


Figure 5: PSO Results for the 11 data sets

The PSO results have low average costs as shown in Figure 5. And hence, the final results are implemented with the help of the PSO. The final average value was taken as the optimization result. One of the most strategic decisions in a logistics system is to determine the structure and costs in terms of the number of facilities and the transportation strategy as these have significant influence on the long term profitability. This is a complicated decision making problem due to economic benefits. The solutions here emphasize profit expectations due to lower costs and also reliability. The model was tested with several test instances. The results also showed that the number of facilities can affect the configuration, costs and hence profitability

4. Conclusion

The problem also looked also looked at the environmental impact of nitrogen oxides from both the facilities and the transportation moving the produced products between the facilities. The PSO was initially used for cost evaluation. It caused a decrease in the average costs. However, particle swarm optimization had lower cost values. There were 11 random data that were tested with this model. The model took into account the various constraints of a typical optimization problem and these constraints included the factory and the warehouses constraints. The various numerical examples were helpful in showing the application of the model and the algorithm and some managerial implications are shared from these results. This research helped in developing a model for various facilities numbers under some requirements.

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