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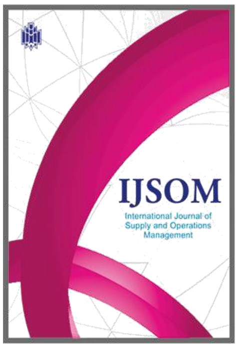


# A Mathematical Model to Evaluate Time, Cost and Customer Satisfaction in Omni-Channel Distribution

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## Abstract

Today, upon the higher internet usage and the Covid-19 pandemic, the use of omni-channel distribution has experienced significant growth. The shopping experience in omni-channel distributions is influenced by the physical environment of the buyer, delivery time, and the cost of production to distribution of the goods which have a significant impact on customer loyalty and customer satisfaction. The lack of comprehensive studies in this field, and the number of constant variables in most of the available studies in the literature, especially uncertainty-laden demand, illustrate the significance of this study. After a related literature review and experts' interviews, based on omni-channel Approach, all important factors influencing time, cost, and customer satisfaction have been included within a multi-objective mathematical model. Thus, defining constraints and decision variables, the objective functions have been solved within two new meta-heuristic algorithms, namely MOGWO and NSGA-II. Besides, these algorithms have been validated using NPS, DM, MID, and SNS indices. Upon comparing the outputs of these two algorithms and inserting 30 numerical instances, it has been shown that the MOGWO method has a stronger Pareto frontier and organized scattering for Pareto solutions. However, averagely, the NSGA-II algorithm produces fewer and more values compared with the first and second objectives, respectively.

**Keywords:** Omni-Channel; Supply chain; Mathematical programming; Optimization; NSGA-II; MOGWO.

## 1. Introduction

Nowadays, there is an observed growth in the use of mobile applications and the impacts of digital contact points have modified people's purchase behavior. Therefore, people are faced with multiple channels for searching and purchasing products. This means a higher chance of the retailers to connect to their customers; however, at the same time, it may cause many difficulties for success in undertaking marketing initiatives (Cummins et al., 2016; Hendalianpour et al., 2019). The customer's journey may start from searching for product information on the mobile platform, and it may continue further using social networking websites or email correspondences. Discussions regarding the required product may occur on both social and friendly platforms and the final act of purchasing may happen either in a physical store or online (Rao et al., 2011; Liu et al. 2021). Post-purchase communications may be introduced to the customers from different channels (Bala et al., 2017, Liu et al., 2021). The customers are continuously changing their own Omni-Channel experiences. They want the existing interactions on a channel (or device) to be transferred to another interaction channel. In other words, the customers are not necessarily looking for the same experience on different channels. On the contrary, they desire stability and fully personalized experiences throughout all channels (Badhotiya et al., 2019; Henlaianpour, 2020). Omni-Channel manages, predicts, and supports all customer purchase experiences on all channels, either in offline mode (e.g. physical attendance in the store, published media, on phone) or online mode (e.g. website, blog, email, mobile applications, social networking websites, etc.). Omni-Channels act in a way such that the purchase transfer process from a channel to another will be efficiently initiated for the customer and no change would be made in the customer's purchase result (Lim et al., 2018; Hendalianpour et al., 2020).

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Accordingly, the Omni-Channel distribution system has been elaborated in this study through a Multi-objective function for maximizing customer satisfaction as well as minimizing delivery time, and transportation costs. At first, the influential factors and objectives in distribution channel modeling in the form of Omni-Channel networks have been identified through a review of the related literature and investigating the impact of these factors on three variables of time, cost, and customer satisfaction simultaneously through a multi-objective mathematical model. Finally, the offered mathematical model has been solved using two meta-heuristic algorithms (Genetic Algorithm and Gray Wolf Optimizer) after results validation.

## 2. Literature Review

The literature in this domain involves many different approaches. For instance, Paul et al. (2019) studied the new capacity sharing strategy in Omni-Channel retail distribution. Ryu et al. (2019) studied retail clothes or fashion companies active in this field. Akter et al. (2019) expanded a wider concept of virtual, physical, and integration quality in this field. Sankaranarayanan and Lalchandani (2019) offered an integrated Omni-Channel architecture for air travel schedules facilitating access to trip information throughout all channels.

Kang (2019) studied the correlation between the lifestyle of social-local consumers as the personal characteristics and perception of the value of physical and virtual showrooms and sales within Omni-Channel distribution. Tao et al. (2018) investigated the impact of Omni-Channel strategy based on a dynamic system and retailer performance models. Von Briel (2018) studied a four-stage process of retail future in Omni-Channel distribution through the Delphi approach. Gawor and Hoberg (2018) found that monetary and administrative criteria for implementation of Omni-Channel distribution strategies by retailers is type B2C. Zhang et al. (2018) studied customers; behavior and reaction in a new Omni-Channel environment. Kembro et al. (2018) offered a new approached for enhancing the perceptions regarding warehousing and design operation influenced by a movement toward integrated Omni-Channel. Wollenburg (2018) found the strategy to fulfill customer orders lying in integrated Omni-Channel retail channels. Marchet et al. (2018) studied the acquisition of logistic variables in Omni-Channel administrative strategy. Galipoglu et al. (2018) identified, investigated, and defined the invaluable literature on retail in Omni-Channel. Murfield et al. (2017) studied the impact of procurement service quality on customer satisfaction and loyalty in an Omni-Channel retail environment. Hure et al. (2017) studied the Omni-Channel purchase value through an experimental design and Omni-Channel test model based on purchase value literature. Hagberg et al. (2016) expanded the digitization of retail initiatives in Omni-Channel through developing a conceptual framework. Mena & Bourlakis (2016) reviewed 27 papers in the same field under a conceptual design. Cummins e al. (2016) studies the sales management framework in Omni-Channel mode within six domains, namely, sales, technology impact, sales process, relations, corporation efficiency, and the role played by different relations. Hübner et al. (2016) studied the transfer of retailers from independent multi-channel networks to an integrated Omni-Channel.

As evident from the literature, most of the researchers (e.g. Hübner et al. (2016); Bernoon et al. (2016); Murfield et al. (201); Marchet et al. (2018); Paul et al. (2019)) attempted a heuristic study. Meanwhile, many other studies attempted offering a dynamic model through the Markov Approach (e.g. Hosseini et al., (2018), two-stage heuristic approach and Ants Colony Optimizer (e.g. Abdolghader et al., (2018)), application of log-log regression (e.g. Gover & Huberg, (2018)) application of dynamic system (e.g. Tao et al. (2018); Hosseinzadeh et al. (2020), machine learning algorithm (e.g. Sankaranarayanan & Lalchandani, (2019) and many other available techniques used by many other researchers. However, there are a limited number of applied studies and using mathematical programming. It can be argued that simultaneous investigation of different variables including delivery time, customer satisfaction, and cost through mathematical modelling is an area that has been neglected so far, was very limited, or wasn’t that extensive.

## 3. Problem Description

### 3.1. Omni-Channel Description

Omni-channel is a business model based on mutual relationships used by companies for increasing and improving their communications with their customers. In the healthcare and treatment sector, governmental sector, financial sector, retailing sector, and telecommunication industries, this approach includes channels like physical places, question-answer websites, social media, live chat, mobile applications, and telephone communications. Companies that use omni-channel believe that the customers value the ability to keep constant contact with the company in numerous ways in a given time (numerous communication channels in a simultaneous manner and with identical information). In a very simple term, OCM is the very multichannel marketing that is implemented correctly and perfectly. Of course, besides the traditional channels (website and email), social media and mobile have been added there. In omni-channel, all of the customer’s behaviors are perfectly predicted and supported in all of the communication channels and points in such a way that if the customer shifts from a communication channel to another in the course of purchase, no effect and reduction would be observed in the result of the purchase. In omni-channel, the individuals as well as the technology play key roles in the customer’s experience (de Carvalho & Campomar, 2014).

The retail industry is constantly changing. Most of the retailers believe that this industry is very competitive and part of it stems from the technological changes, customers’ demands, and changes in the consumers’ behaviors. Retailers that are incapable of matching with and responding to these challenges are presently challenged in terms of their growth and at risk of losing the industry. The ones capable of growing in the industry are strategically responsive to and consistent with the digital environment and can create a successful retailing experience for the customers such as the construction of modern retailing supply chains and, more importantly, the use of omni-channel retailing strategies (Hansen & Sia, 2015).

Omni-Channel marketing is a sort of strategic marketing with coordinated and integrated channel-based interventions in which the main focus is on the customers. All of the channels should work together and be managed using a full-scale strategy so that the customers can be provided with a successful experience. Omni-Channel retailing strategy improves the customers' experience and provides more channels for customers' purchase whether be it applied on mobile phones or in the stores. Availability of multiple purchase channels leads to an increase in sales and purchase traffic. The Omni-Channel customers spend money 15-30 percent more than the uni- or multi-channel customers (Paul et al., 2019).

Besides, omni-channel retailing allows consumers to complete purchases in various channels. Now, customers can see the goods available in the stores; they can reserve them online to purchase them from the closest store. This fixed information causes the creation of a better retailing process for the customers for the retailers can communicate with their customers and immediately interact with them through various kinds of purchase channels on a personal level (Hansen & Sia, 2015).

Another study by Harvard indicated that omn-channel customers establish communication more with retailing channels, especially digital terminals. This includes the use of mobile phone applications, downloading coupons and purchase kiosks, and other things in the digital connection tools. In the same way, the study that investigated 46000 buyers concluded that Omni-Channel customers are more valuable than unichannel customers (Paul et al., 2019). For growth in the competitive retailing industry, the retailers should design Omni-Channel retailing strategies that go beyond the online and in-store presence. Instead, they should provide an integrated purchase experience for their customers through preserving a strong physical store as well as using several online channels (as an example, social media or text messaging tools) and devices (mobile or computer). Various kinds of digital communication terminals enter the retailing industry. This includes interactive kiosks, smart shelf technologies, and automatic tablets. Based on an investigation by Forrester, digital communication terminals have influenced almost 49% of the whole retailers in the US. A successful Omni-Channel retailing strategy does not begin with the creation of an online store or by online presence rather it starts when the retailers guide their strategies with the latest supplementary digital communication technologies and the customers' intended goods at the right time and in the right place (Bashokouh & Alipour, 2013).

Generally, retailing industry is a constantly changing competitive space and it is influenced by various competitive, technological, and other aspects. Competition is stronger than ever; digital facilities are changing the quality of our purchases and the consumers' purchase habits are changing more. Business owners should find innovative methods for responding to the digital forces, patterns of consumers' behaviors, and other challenges and, as it has been shown, Omni-Channel retailing can be an effective solution (Paul et al., 2019).

### 3.2. Problem Definition

Online sale has experienced a significant growth rate due to increased use of the internet, increased number of mobile applications, and governmental conflicts on people's physical interactions as a result of Covid-19 pandemic. This is evident in an increased number of online sales in online channels (Hubner et al., 2017). The digitization process of retailers had a significant impact on the distribution and retail sector of the supply chain and changed the retail structure to a great extent. Although expanding online trade and mobile devices play a significant role, physical stores have remained as key retail spaces. Customers who have access to digital devices possess a higher amount of information and increased potential to complete their purchases. Omni-Channel buyer will get informed about the market and new product change through communication devices such as mobile and PC. They may use these technologies to find the best possible trade and are willing to complete their purchase in any possible location and time. The Omni-Channel approach is the logical evolutionary stage after the multi-channel approach and includes all possible purchase methods. In this approach, the consumers' experience in any channel is the same, and changes in the distribution channel won't result in receiving new or different information. This coordination in information provision made Omni-Channel more complex than more traditional multi-channel methods. Omni-Channel retail activated many of the businesses and provided them with a chance to invest in new opportunities (Sharma et al., 2008). Investigating distribution methods and their growing trend in recent years illustrated the superiority of the Omni-Channel approach by employing all up-to-date equipment and technologies. On the other hand, despite different fluctuations and future uncertainties, the distribution system has been considered constant throughout all previous studies. This may lead to lower precision of study results. Thus, a mathematical programming model has been proposed in this study within the Omni-Channel distribution system to reduce cost, time and increase satisfaction among customers while considering uncertainty in both distribution and retail networks, especially demand-related uncertainty.

### 3.3. Model Assumptions

- A multi-stage, multiple products supply chain with a multi-tier system including suppliers, retailers, and customers is assumed.

- The product will be shipped from the supplier to the retailer and from the retailer to the customer. The only people who are allowed to keep confidence inventory in each period are the retailers.
- The capacity and maintenance costs of the product in different distribution centers are different.
- Outdated products can be sold at a lower price without maintenance costs.
- Product demand and required time from the supplier in each period are certain and the product supply rate is usually higher than the sum of customers' demands.
- All the suppliers with similar properties are capable of procuring the retailers' orders.
- The location of suppliers, retailers, and customers is not known and constant.
- The sales price is not constant for all products and is dependent upon sales scenarios.
- The transportation costs of each mode are different and depend upon the distance traveled and the type of vehicle.

### 3.4. Subscripts

- I: products: $i$={1‹2‹3… ‹$I$}
- J: suppliers: $j$={1‹2‹3‹ … ‹$J$}
- C: online customers: $c$={1‹2‹3‹ … ‹$C$}
- D: distribution channels: $d$= {1‹2‹3‹ … ‹$D$}
- R: retailers: r= {1‹2‹3‹ … ‹$R$}
- S: scenarios: s={1‹2‹3‹ … ‹$S$}
- V= transportation vehicles v= {1‹2‹3‹ … ‹$V$}
- T: time periods t= {1‹2‹3‹ … ‹$T$}

### 3.5. Parameters

- $\bar{C}_{ijt}^{s}$: the cost of supplying each product unit of i by supplier j during period t based on scenario s;
- $\bar{R}_{idct}^{s}$: the cost of selling each product unit of i to customer c through distribution channel d during period t based on scenario s;
- $\tilde{R}_{idct}^{s}$: the cost of selling each expired product unit of i to customer c through distribution channel d during period t based on scenario s;
- $R_{vjrt}$: the cost of transportation of each product unit of i through vehicle v supplier from j to distribution center r during period t;
- $R_{vrct}$: the cost of transportation of each product unit of i using vehicle v from distribution center r to customer c during period t;
- $A_{ijt}$; the constant cost of ordering product i from supplier j during period t;
- $\bar{C}_{vt}$:the constant cost of v vehicle during period t;
- $FC_{rt}$:the constant cost of establishment of distribution center r warehouse during period t;
- $h_{irt}$: the cost of product i maintenance in distribution center r warehouse during period t;
- $P_{ijrt}$: the cost of purchasing each product unit of i by distribution center r from supplier j during period t;
- $d_{rc}$: the transportation cost between distribution center r and customer c;
- $\widetilde{LT}_{ijrt}^{s}$:the product i delivery time by supplier j to distribution center r during period t;
- $LT_{idct}^{s}$: Product delivery time i through distribution channel d to customer c in time period t;
- $T_{irt}$: maintenance duration for the product i in distribution center r warehouse during period t;
- $ELT_{idct}^{s}$: the expected time of customer for delivery of Product i through distribution channel d during period t;
- $AG_{idt}$: the agility in delivering product i through distribution channel d during period t;
- $U_{ijt}$: the favorability of j supply in terms of volume and timely delivery of product i to retailer r during period t;
- $q_{ij}$: the quality level provided by the supplier based on the j outdated product's percentage for the product i.
- $Pe_{dt}^{s}$: the customers' demand percentage through distribution channel d during period t based on s scenario;
- $\alpha$: the minimum customer satisfaction about product accessibility level;
- $\beta$: minimum percentage of outdated products;
- $r$: return rate of outdated products;
- $\lambda_{ir}^{s}$: discount rate of retailer r for i outdated product;
- $Cap_{irt}$: r retailing capacity in supplying product i during period t;
- $Cap_{ijt}$: the capacity of supplier j in supplying product i during period t;
- $Cap_{ivt}$: the capacity of v transportation system for delivering product i during period t;
- $Wh_{mk}$: the capacity of k warehouse with the size of m;
- $Pb^{s}$: the probability of s scenario's occurrence;

### 3.5. Decision Variables

- $S_{jt}: = \begin{cases} 1 & \text{supplier j will be selected for period t} \\ 0 & \text{otherwise} \end{cases}$

- $X_{ijt}^{s} := \begin{cases} 1 & i \text{ product will be selected by supplier j on s scenario for period t} \\ 0 & \text{otherwise} \end{cases}$
- $X_{rct}^{s} := \begin{cases} 1 & \text{product will be sent from retailer r to customer c for period t based on s scenario} \\ 0 & \text{otherwise} \end{cases}$
- $X_{vrct} := \begin{cases} 1 & \text{v ehicle travels the distance between distribution center r and customer c for period t} \\ 0 & \text{otherwise} \end{cases}$
- $Y_{mk} := \begin{cases} 1 & \text{a warehouse with a capacity of m has been constructed in k location} \\ 0 & \text{otherwise} \end{cases}$
- $N_{ijrt}^{s} . = \begin{cases} 1 & \text{i products shipped from supplier j to retailer r for period t based on s scenario} \\ 0 & \text{otherwise} \end{cases}$
- $\overline{N}_{idct}^{s} ;= \begin{cases} 1 & \text{i products sold through d distribution network to customer c for period t based on s scenario} \\ 0 & \text{otherwise} \end{cases}$
- $\widetilde{N}_{idct}^{s} : \begin{cases} 1 & \text{i outdated products sold through distribution channel d to customer c for period t based on s scenario} \\ 0 & \text{otherwise} \end{cases}$
- $D_{idct}^{s} ; = \begin{cases} 1 & \text{product i through distribution channel d by customer c for period t based on s scenario} \\ 0 & \text{otherwise} \end{cases}$
- $I_{irt}^{s} : = \begin{cases} 1 & \text{i products maintained in r retail warehouse for period t based on s scenario} \\ 0 & \text{otherwise} \end{cases}$

### 3.6. Objective Functions

$$\begin{aligned} Min\ Z_1 = \sum_{s} Pb^{s} \Bigg[ & \sum_{i}\sum_{j}\sum_{t} A_{ijt} \cdot S_{jt} + \sum_{i}\sum_{j}\sum_{t} \bar{C}_{ijt}^{s} \cdot N_{ijrt}^{s} \cdot X_{ijt}^{s} + \sum_{i}\sum_{j}\sum_{r}\sum_{t} R_{vjrt} \cdot N_{ijrt}^{S} \\ & + \sum_{i}\sum_{j}\sum_{r}\sum_{t} P_{ijrt} \cdot N_{ijrt}^{s} + \sum_{i}\sum_{j}\sum_{r}\sum_{t} h_{ir} \cdot I_{irt}^{s}(1-q_{ij}) \\ & + \sum_{i}\sum_{r}\sum_{d}\sum_{v}\sum_{c}\sum_{t} R_{vrct} \cdot \overline{N}_{idct}^{S} \cdot X_{rct}^{S} + \sum_{i}\sum_{r}\sum_{c}\sum_{t} \bar{R}_{idct} \cdot \overline{N}_{idct}^{s}\,(1-q_{ij}) \\ & + \sum_{i}\sum_{r}\sum_{t} h_{irt} \cdot I_{irt}^{s} \Bigg] + \sum_{r}\sum_{c}\sum_{v}\sum_{t} d_{rc} \cdot X_{vrct} + \sum_{r}\sum_{k}\sum_{t} FC_{rt} \cdot Y_{km} \end{aligned} \quad (1)$$

$$Min\ Z_2 = \sum_{s} Pb^{s} \left[ \sum_{i}\sum_{r}\sum_{d}\sum_{c}\sum_{t} (LT_{idct} - ELT_{idct}) \cdot \overline{N}_{idct}^{s} \right] \quad (2)$$

$$\begin{aligned} \mathrm{Max}\ Z_3 = \sum_{s} Pb^{s} \Bigg[ & \sum_{i}\sum_{r}\sum_{d}\sum_{t} (1-\beta) \cdot \overline{N}_{idct}^{s} + \sum_{i}\sum_{d}\sum_{c}\sum_{t} AG_{idt} \cdot \overline{N}_{idct}^{s} \\ & + \sum_{i}\sum_{j}\sum_{r}\sum_{t} U_{ijt} \cdot N_{ijrt}^{s} \Bigg] + \sum_{i}\sum_{v}\sum_{r}\sum_{d}\sum_{c}\sum_{t} R_{vrct} \cdot d_{rc} \cdot D_{idct}^{s} \end{aligned} \quad (3)$$

Equation (1) displays the minimization of chain costs including constant ordering cost, product supply process cost, cost of transporting product from supplier to distribution center and from distribution center to the customer, cost of purchasing product by the retailer, cost of product maintenance in the retailer warehouse, cost of purchasing product by the customer, cost of transporting product per the shortest traveled distance, constant cost and warehousing cost by the retailer. Equation (2) displays the minimization of product delivery time including the minimization of delay in delivering the product to the customer, reduction in the quality level of the supplier defined by the percentage of the outdated product. Equation (3) displays the maximization of responding to customers' needs. This performance includes a reduction in the number of outdated products, favorability of supplier in terms of volume and timely delivery of the product, agility in delivering the product to the customer, maximization of delivery rate from the shortest path.

### 3.8. Constraints

$$\sum_{i}\sum_{j}\sum_{r}\sum_{t} \overline{N}_{ijrt}^{S} \leq Cap_{ijt}.X_{ijt}^{s} \qquad \forall\ i،j،t،s \quad (4)$$

Equation (4) illustrates the capacity of each supplier for delivering products to the distribution center during any period.

$$\sum_{i}\sum_{j}\sum_{r}\sum_{t} N_{ijrt}^{s} - \sum_{i}\sum_{d}\sum_{c}\sum_{t} \overline{N}_{idct}^{s} \geq 0 \quad \forall s \quad (5)$$

Equation (5) displays the warehousing of part of products sent from the supplier to the distribution center during any period.

$$\sum_i \sum_j \sum_r \sum_t \left(N_{ijrt}^s + I_{irt}\right) \geq \sum_i \sum_d \sum_c \sum_t \bar{N}_{idct}^s \qquad \forall\ s \tag{6}$$

Equation (6) ensures fulfilling customers' demands by the retailer through distribution channels.

$$\sum_{ma} \sum_k Y_{mk} \leq 1 \tag{7}$$

Equation (7) clarifies the existence of a maximum number of warehouses in any candid location for any facility.

$$\sum_i \sum_j \sum_t Cap_{irt} \cdot N_{ijrt}^s \leq Wh_{mk} \cdot Y_{mk} \qquad \forall r،m،k \tag{8}$$

Equation (8) suggests the maximum warehousing capacity of products by the distribution center in any period.

$$\sum_i \sum_d \sum_c \sum_t \bar{N}_{idct}^s \geq D_{idct} \qquad \forall i،d،c،ts \tag{9}$$

Constraint (9) defines the fulfillment of customers' demand for each product in any period and completed in that period. By maintaining the inventory as the confidence storage, it would fulfill the accessibility and fulfilling customers' demands.

$$\sum_i \sum_j \sum_r N_{ijrt}^s \leq Cap_{irt} . X_{ijt}^s \qquad \forall\ t \tag{10}$$

Equation (10) displays the capacity limit for any of the distribution centers. In other words, in the case of product delivery from supplier to distributor, the number of products to be shipped must be smaller than or equal to the distributor's capacity.

$$\sum_i \sum_j \sum_t N_{ijrt}^s \leq Cap_{ijt}.X_{ijt}^s \qquad \forall s \tag{11}$$

According to Constraint (11), the total specified order of any supplier in any period must be smaller than or equal to its maximum capacity.

$$\left(\widetilde{LT}_{ijrt} + T_{irt}\right) \cdot Y_{mk} \leq LT_{idct} \qquad \forall i،j،r،d،c،m،k،t \tag{12}$$

By computing the duration of delivery to the customer, constraint (12) suggests that the sum of product delivery time by the supplier and the time of maintaining the product in the retailer warehouse must be smaller than the required time for delivering product through the distribution channel to the customer.

$$0 \leq q_{ij} \leq 1 \quad \forall \text{i}،j \tag{13}$$

Equation (13) displays the percentage of outdated inventory (due to the change in technology or introduction of new products, etc.)

$$\sum_i \sum_d \sum_c \sum_t \bar{N}_{idct}^s \leq Cap_{ivt}.X_{ijt}^s \qquad \forall i،v،t،s \tag{14}$$

Constraint (14) suggests the maximum transportation system's capacity in delivering products from the distribution center to the customer during each period.

$$\sum_i \sum_d \sum_c \sum_t Pe_{dt}^s \cdot \bar{N}_{idct}^s \geq \beta \qquad \forall s \tag{15}$$

Constraint (15) defines the minimum customer satisfaction in terms of products' accessibility.

$$\sum_i \sum_d \sum_c \sum_t \bar{N}_{idct}^s = \sum_i \sum_j \sum_t N_{ijrt}^s \cdot (1-\alpha) \qquad \forall s \tag{16}$$

Constraint (16) defines the possibility of α percentage expired products shipped from suppliers to distribution centers.

$$\bar{R}_{idct}^s = \tilde{R}_{idct}^s (1-\lambda_{ir}) \qquad \forall i،d،c،t،s \tag{17}$$

Equation (17) suggests the retailer discount percentage for outdated products.

$$\sum_i \sum_d \sum_c \sum_t \widetilde{N}_{idct}^s = r \cdot D_{idct} \tag{18}$$

Equation (18) displays the relationship between product demand and returned outdated products as a percentage of customers' demands.

$$X_{ijt}^s، X_{rct}^s، X_{vrct}، Y_{mk}، S_{jt} \in \{0،1\} \tag{19}$$

Equation (19) ensures that all variables are binary ones.

## 4. Solutions of model

### 4.1. Gray Wolf Optimizer and Adjustment of MOGWO Algorithm's Parameters through Taguchi's Approach

Grey Wolf Optimizer (GWO) is a meta-heuristic algorithm that has been inspired by grey wolves' hierarchical structure and social behavior while hunting. This algorithm is population-based and is simply generalized to large-sized problems. There are four degrees of hunting for the wolves which are modeled through a pyramid-like structure, as displayed in Figure (1). The most suitable solution is alpha and the other possible solutions are beta, delta, and omega respectively. It is noteworthy that hunting is guided by $\alpha, \beta, and \delta$.

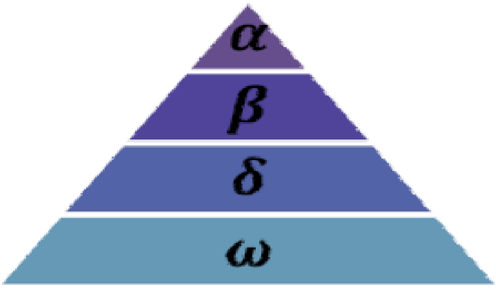


**Figure 1.** The hierarchical structure of grey wolves hunt

In short, these stages are as follows:

1. Fitness values of all possible solutions are computed and the three best solutions are selected as $\alpha, \beta, and \delta$.
2. In each iteration, the three best solutions are good at estimating the hunting situation and will perform it in each iteration.
3. After defining the position of wolves in each iteration, the status of other solutions would be updated.
4. At the end of all iterations, the position of the alpha wolf will be declared as the optimal point.

Compared with single-factor and factorial methods, the Taguchi method is superior in terms of the lower number of experiments, lower cost and duration of the experiment, the potential to study mutual impacts, and conducting experiments in parallel to each other, and finally predicting the optimal answer. To design the experiments in MOGWO, at first three different levels will be defied for their parameters and will be run in this algorithm. The recommended values for the study parameters are listed in Table (1).

**Table 1.** Parameters and their values for the MOGWO algorithm

| Parameter | The values of each level | | |
|---|---|---|---|
| | Level 1 | Level 2 | Level 3 |
| Maximum number of Iterations (Max iter) | 50 | 100 | 200 |
| Number of search agent (N_S) | 50 | 100 | 150 |
| Change position rate (PR) | 0.2 | 03 | 05 |

Then, different experimental designs have been developed through Taguchi's L9 plan and the MOGWO algorithm has been run for each of them. The results are displayed in Table (2).

**Table 2.** Values for the response variable in Taguchi's technique for the MOGWO algorithm

| **Run Number** | **Algorithm parameters** | | | **Indicator MID** |
|---|---|---|---|---|
| | Max_iter | N_S | PR | |
| 1 | 1 | 1 | 1 | 0.697 |
| 2 | 1 | 2 | 2 | 0.712 |
| 3 | 1 | 3 | 3 | 0.682 |
| 4 | 2 | 1 | 2 | 0.663 |
| 5 | 2 | 2 | 3 | 0.702 |
| 6 | 2 | 3 | 1 | 0.681 |
| 7 | 3 | 1 | 3 | 0.647 |
| 8 | 3 | 2 | 1 | 0.739 |
| 9 | 3 | 3 | 2 | 0.739 |

Now, through inserting these outputs in MINITAB software, the S/N diagram will be depicted as in Figure (٢).

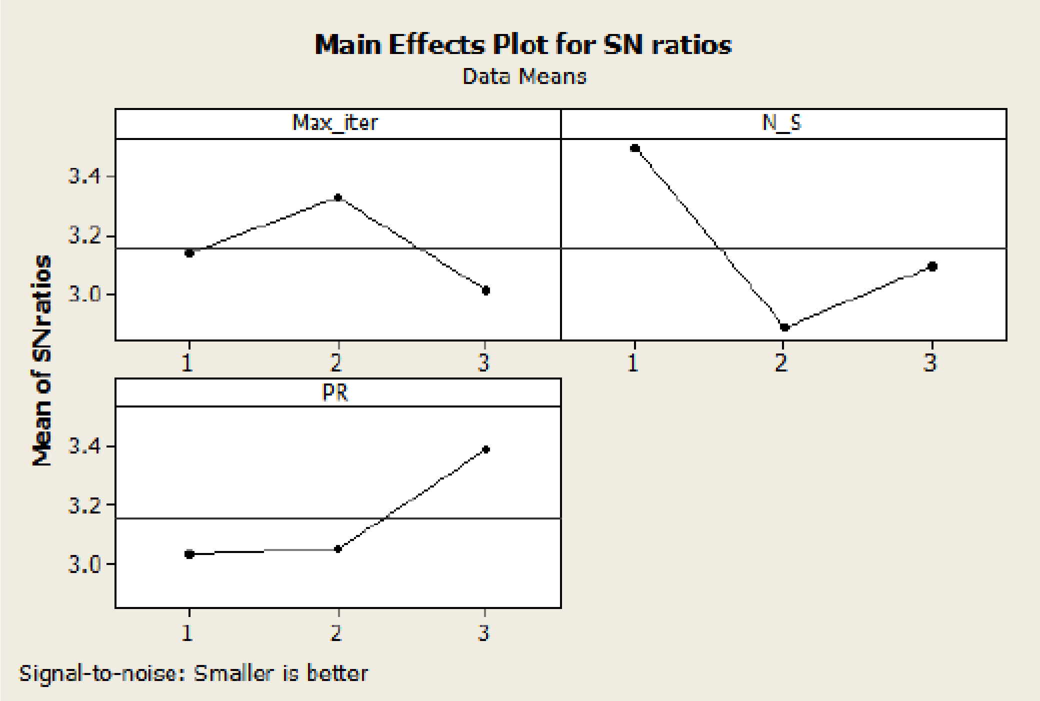


**Figure 2**. MINITAB output for Taguchi's approach in MOGWO algorithm

Now, based on the output values displayed in Figure (2), the best possible value for each parameter is defined and other values of algorithm parameters will be run. The optimal values are displayed in Table (3).

**Table 3**. The optimal value of study variables in MOGWO

| Parameter | The optimal amount |
|---|---|
| Maximum number of Iterations (Max iter) | 200 |
| Number of search agent (N_S) | 100 |
| Change position rate (PR) | 0.2 |

### 4.2. Multi-objective Genetic Algorithm and Adjustment of NSGA-II Algorithm's Parameters through Taguchi's Approach

Genetic Algorithm (GA) is a particular type of evolutionary algorithm in which evolutionary biological techniques such as inheritance, biological mutations, and Darwin's selection maxims are used to find the optimal formula for prediction or pattern matching. Problem's inputs are turned into solutions through a model of genetic evolution. Then, the solutions will be evaluated through a fitness function as the candidates and in case the problem's exit criteria would be satisfied, the algorithm would be ended. Generally, an algorithm is iteration-based and most of its pars are selected as randomized processes. Therefore, these algorithms consist of different sections including fitness, display, selection, and change functions.

The process of implementing GA will be as follows:

1. Introduction of problem's solutions a the chromosomes
2. Introduction of the fitness function
3. Gathering the primary population
4. Introduction of selection operators
5. Introduction of reproduction operators.

To design experiments in this algorithm, the following initiatives have been taken; at first, three different levels are defined for its parameters and pre-defined experiments are implemented in this algorithm. The recommended parameters are displayed in Table (4).

**Table 4**. Parameters and their levels for NSGA-II algorithm

| Parameter | The values of each level | | |
|---|---|---|---|
| | Level 1 | Level 2 | Level 3 |
| Population size (PS) | 50 | 100 | 200 |
| Crossover rate (CR) | 0.5 | 0.7 | 0.9 |
| Mutation rate (MR) | 0.2 | 03 | 05 |

Then, according to Taguchi's L9 plan, different experimental designs are developed and implemented for each NSGA-II algorithm. The results are displayed in Table (5).

**Table 5**. Values of the response variable in Taguchi's technique for the NSGA-II algorithm

| Run Number | Algorithm parameters | | | Indicator MID |
|---|---|---|---|---|
| | **PS** | **CR** | **MR** | |
| 1 | 1 | 1 | 1 | 0.534 |
| 2 | 1 | 2 | 2 | 0.612 |
| 3 | 1 | 3 | 3 | 0.537 |
| 4 | 2 | 1 | 2 | 0.491 |
| 5 | 2 | 2 | 3 | 0.576 |
| 6 | 2 | 3 | 1 | 0.637 |
| 7 | 3 | 1 | 3 | 0.599 |
| 8 | 3 | 2 | 1 | 0.973 |
| 9 | 3 | 3 | 2 | 0.642 |

Now, inserting these output values in MINITAB software, the S/N diagram will be depicted as in Figure (3).

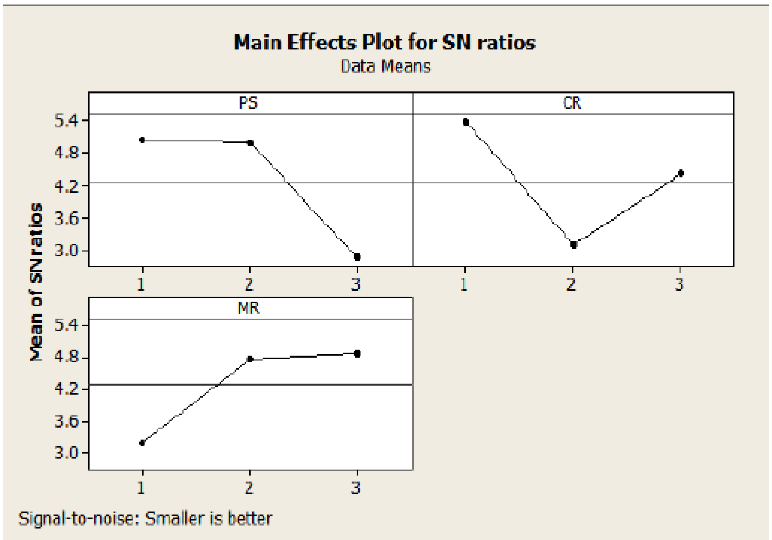


**Figure 3**. MINITAB output for Taguchi's approach in NSGA-II algorithm

Now, according to the output displayed in Figure (3), the value of each parameter is defined and other examples will be run according to these algorithm parameters. Table (6) displays the optimal values of each parameter.

**Table 6.** The optimal values of variables in NSGA-II

| Parameter | The optimal amount |
|---|---|
| Population size (PS) | **200** |
| Crossover rate (CR) | **0.7** |
| Mutation rate (MR) | **0.2** |

### 4.3. Validation of Meta-Heuristic Algorithms

To validate meta-heuristic algorithms, a numerical example with two products, one supplier, two online customers, three distribution channels and three retailers has been considered. The problem's input parameters have been generated out of the continuous uniform distribution and the Pareto frontier of this problem has been computed after optimizing it with the abovementioned algorithms. The results are displayed in Figures (4) and (5). Besides, the Pareto set of solutions obtained from each algorithm are displayed in Table (7).

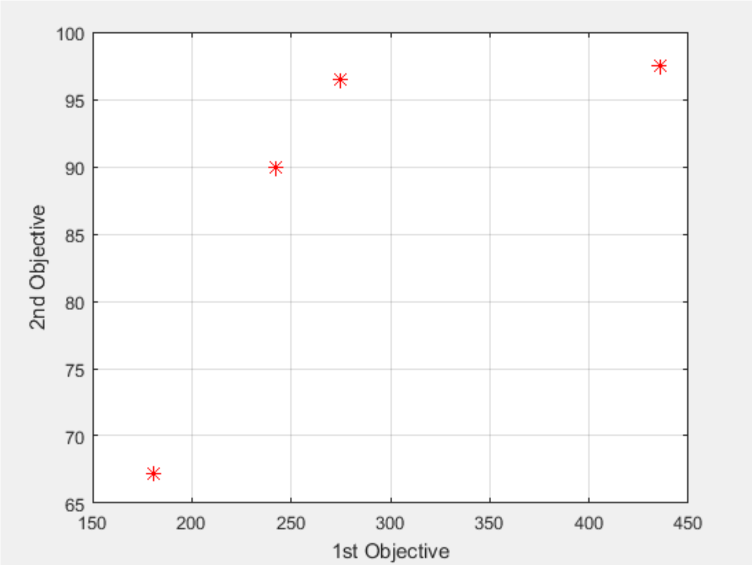


**Figure 4.** The resultant Pareto frontier obtained from the NSGA-II algorithm

**Table 7**. A set of Pareto solutions obtained from the NSGA-II and MOGWO algorithm

| Pareto answer number | MOGWO algorithm | | | NSGA-II algorithm | | |
|---|---|---|---|---|---|---|
| | The first objective function value | The second objective function value | The third objective function value | The first objective function value | The second objective function value | The third objective function value |
| 1 | 128.209271940452 | 0.91 | 0.93 | 180.833046305476 | 0.87 | 0.86 |
| 2 | 815.463111962212 | 0.92 | 0.89 | 435.922804312979 | 0.88 | 0.84 |
| 3 | 720.020565617448 | 0.88 | 0.75 | 274.484612745086 | 0.76 | 0.79 |
| 4 | 243.093739996250 | 0.89 | 0.91 | 242.405846299339 | 0.79 | 0.87 |
| 5 | 162.949426671310 | 0.87 | 0.88 | 242.405846299339 | 0.91 | 0.94 |

According to Figure (4) and the set of Pareto solutions, it can be seen that any increase in the value of the first objective function increases the second objective function. In other words, the worse solutions in terms of the first objective function, the better they will be compared with the second objective function. Thus, none of the solutions are superior to each other and all the solutions are non-dominated.

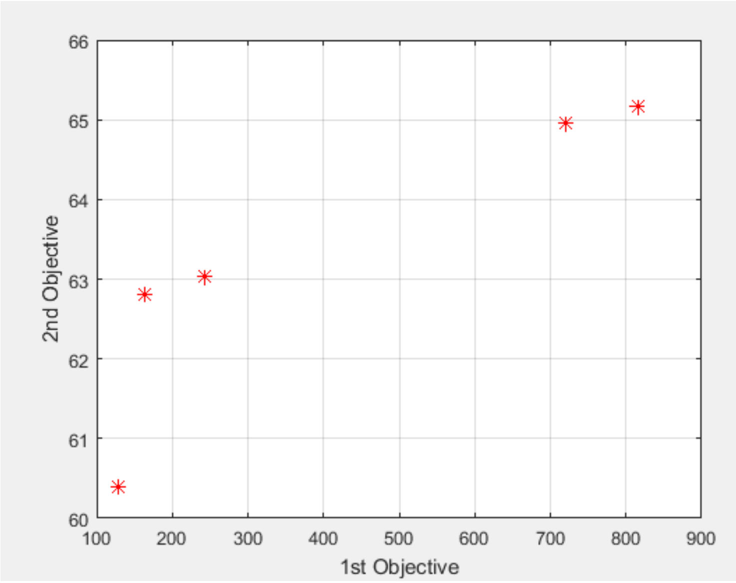


**Figure 5**. The resultant Pareto frontier obtained from the MOGWO algorithm

According to Figure (5), in the MOGWO algorithm, the second objective function finds higher values upon any increase in the value of the first objective function. Therefore, all the solutions displayed in Table (7) are non-dominated and MOGWO algorithm's results are accurate enough. Upon considering the Pareto solutions obtained through both methods, displayed in Table (7), NPS, DM, MID, and SNS indices have been computed and reported in Table (8). According to this table, both algorithms reported five Pareto solutions, and their performance is the same the value of the DM index in MOGWO has been reported as 687.22 which is equal to 256.88 in the NSGA-II algorithm. The higher the value of this index, the more superior the algorithm will be. Therefore, the MOGWO algorithm's index has a %167.5 superiority compared with the index for the NSGA-II algorithm.

Considering the MID index, the difference between the two methods is minor. This index has been reported for MOGWO and NSGA-II as 0.3587 and 0.3084, respectively. NSGA-II algorithm proved to be superior concerning this index and it performed %16 better than the MOGWO algorithm. Finally, concerning the SNS index, the reported values for MOGWO and NSGA-II were equal to 570.966 and 336.71, respectively. MOGWO algorithm proved to be %70 superior to NSGA-II algorithm concerning SNS index.

**Table 8.** A comparison between meta-heuristic algorithms with different indices

| Indicator | NPS | DM | MID | SNS |
|---|---|---|---|---|
| Algorithm MOGWO | 5 | 687.27 | 0.3587 | 570.966 |
| Algorithm NSGA-II | 5 | 256.88 | 0.3084 | 336.971 |
| Superior algorithm | Equal conditions | MOGWO | NSGA-II | MOGWO |
| Percentage of superiority | 0% | 167.<br>5% | 16.30% | 69.44% |

### 4.4. Numerical results

In the validation problem, the efficiency of the two algorithms has been studied. Considering the small superiority of the NSGA-II algorithm regarding the MID index, we can introduce the MOGWO algorithm as the superior algorithm. Since this analysis may not be complete and sufficient, 30 numerical problems have been generated in different dimensions and the comparison indices for both algorithms have been computed. The input information in the form of 30 problems exists in different sizes. Besides, the results for different indices in MOGWO and NSGA-II algorithms are presented in tables (9). To understand the increased dimensions of the problem, the growth rate of any problem parameters is displayed in Figure (6).

After solving 30 sample problems, the intended results have been realized and presented in Tables (9). As reported in Tables (9), both algorithms could provide optimal solutions for all 30 problems and the trend of resulted values are displayed logically. In the following sections, the results for each index are displayed graphically.

The comparison between the outputs of NSGA-II and MOGWO algorithms displayed in Table (9) and Figure (7) suggests that MOGWO performs %25 better than NSGA-II in terms of DM index. That's why DM mean values for MOGWO and NSGA-II algorithms were 583.07 and 468.12.

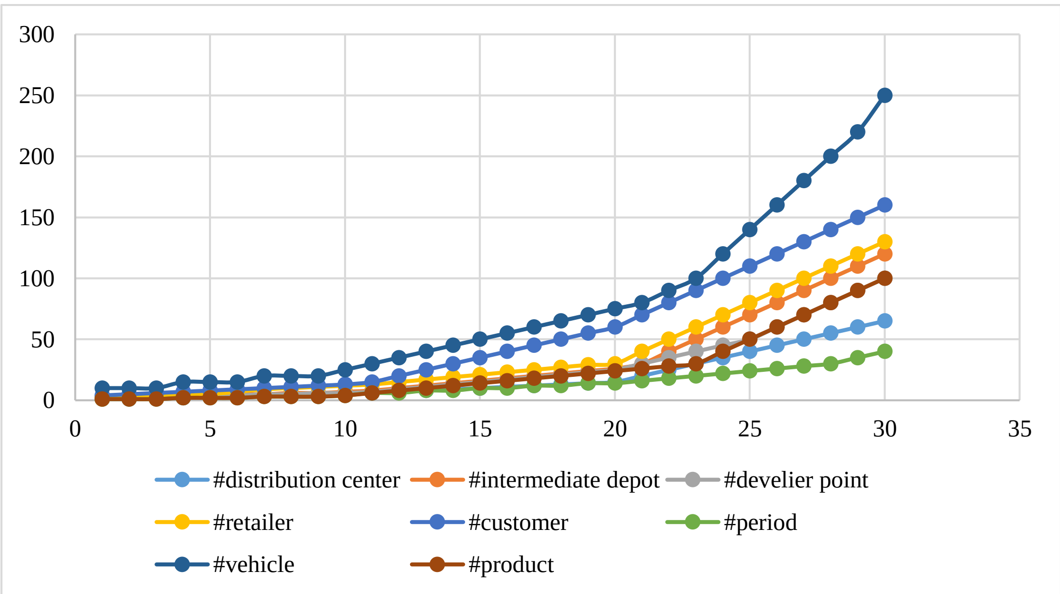


**Figure 6**. The increasing trend of problem's dimensions

According to the value of the MID index for both algorithms reported in Tables (9) and Figure (8), it can be observed that the mean values of this index for MOGWO and NSGA-II were 0.434 and 0.424, respectively. Thus, it can be concluded that the NSGA-II algorithm is superior in terms of the MID index because the MID index for the MOGWO algorithm has been %2 higher than the one for the NSGA-II algorithm.

The results of both algorithms in terms of the SNS index are displayed in Tables (9) and Figure (9). They suggest that the mean SNS values for MOGWO and NSGA-II algorithms were 732.93 and 613.77 respectively. Thus, MOGWO performed better than the NSGA-II algorithm in terms of the SNS index. The comparison between both algorithms' output illustrated in Tables (9) and Figure (10) suggests that the MOGWO algorithm performed %13 better than the NSGA-Ii algorithm in terms of NPS index. That is why the mean values of the NPS index for MOGWO and NSGA-II algorithms were 7.83 and 6.87.

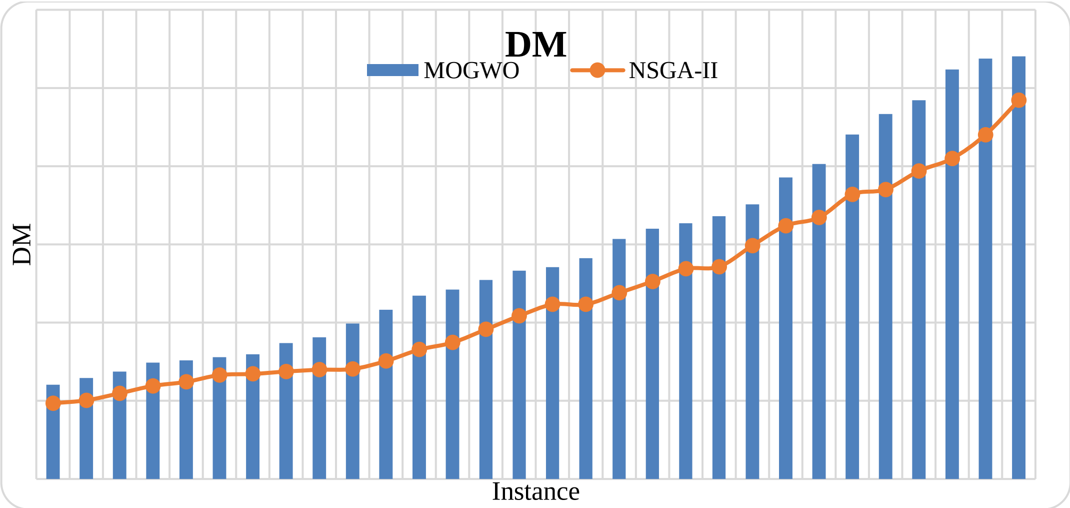


**Figure 7**. A comparison between meta-heuristic algorithms based on DM index

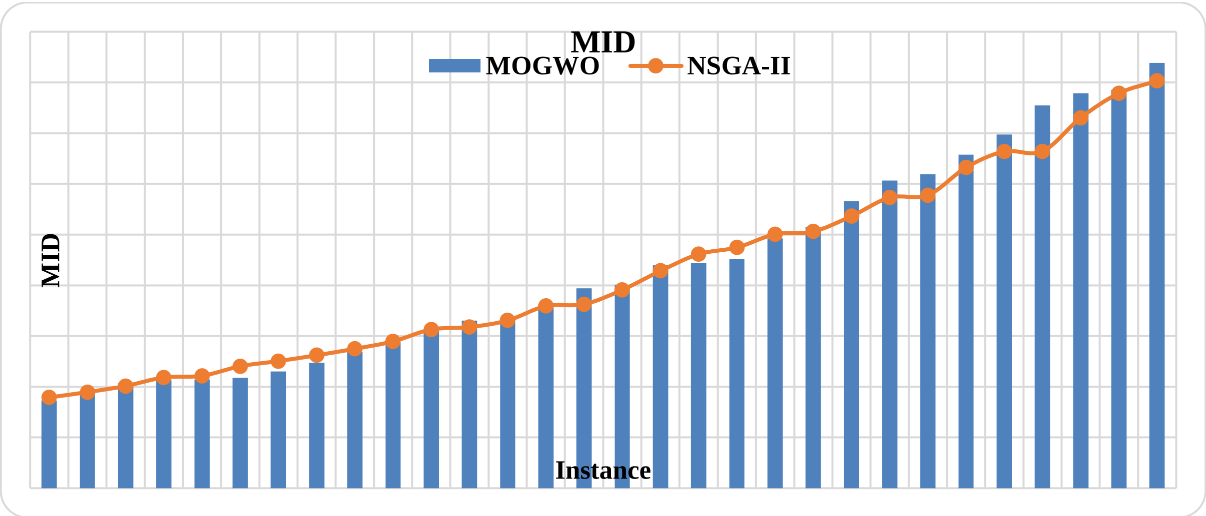


**Figure 8**. The comparison between meta-heuristic algorithms in terms of MID index

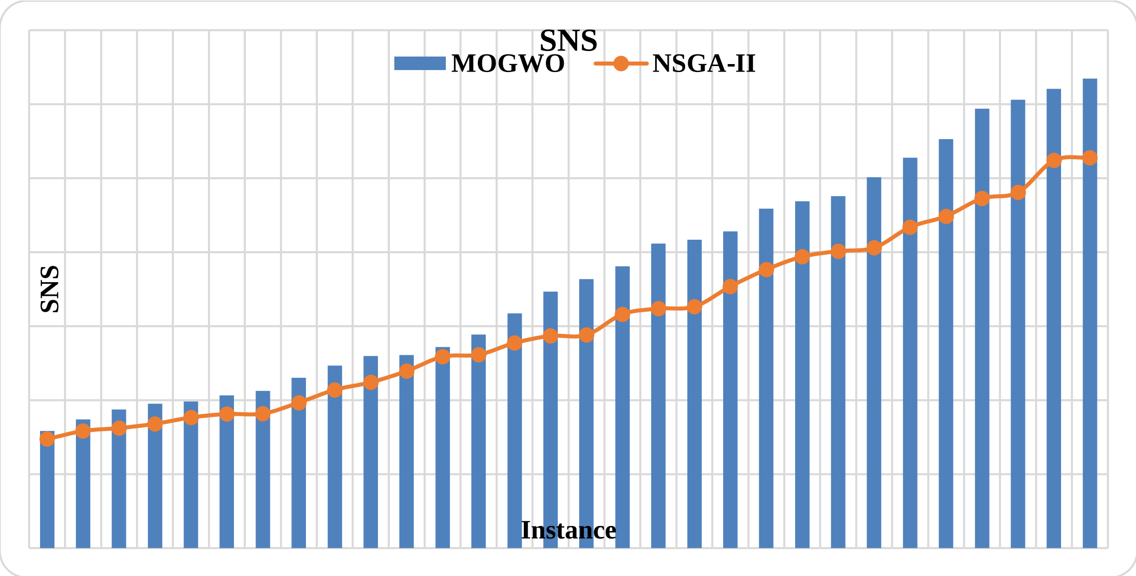


**Figure 9**. The comparison between meta-heuristic algorithms in terms of SNS index

**Table 9**. The values of evaluation indices for NSGA-II and MOGWO algorithm

| Indicator | | DM | | MID | | SNS | | NPS | |
|---|---|---|---|---|---|---|---|---|---|
| Algorithm | | NSGA | MOGWO | NSGA | MOGWO | NSGA | MOGWO | NSGA | MOGWO |
| Small dimensions | 1 | 193.721 | 241.196 | 0.179 | 0.173 | 294.72 | 316.431 | 3 | 3 |
| | 2 | 201.2351 | 258.283 | 0.189 | 0.189 | 316.51 | 347.553 | 3 | 3 |
| | 3 | 219.083 | 274.296 | 0.201 | 0.206 | 324.37 | 374.511 | 3 | 3 |
| | 4 | 238.058 | 297.818 | 0.218 | 0.213 | 335.87 | 390.030 | 3 | 4 |
| | 5 | 248.270 | 303.227 | 0.221 | 0.214 | 353.10 | 396.462 | 4 | 4 |
| | 6 | 265.822 | 311.752 | 0.240 | 0.217 | 362.47 | 412.615 | 4 | 4 |
| | 7 | 268.582 | 318.567 | 0.250 | 0.230 | 363.44 | 424.654 | 4 | 5 |
| | 8 | 274.798 | 347.526 | 0.262 | 0.247 | 393.23 | 460.26 | 4 | 5 |
| | 9 | 279.380 | 361.971 | 0.274 | 0.268 | 427.87 | 493.717 | 4 | 5 |
| | 10 | 281.318 | 397.637 | 0.289 | 0.289 | 448.08 | 519.449 | 4 | 5 |
| Medium dimensions | 11 | 301.666 | 432.603 | 0.312 | 0.311 | 478.61 | 521.575 | 5 | 6 |
| | 12 | 330.819 | 468.866 | 0.317 | 0.330 | 517.45 | 543.823 | 5 | 6 |
| | 13 | 348.891 | 484.383 | 0.330 | 0.334 | 522.77 | 577.05 | 5 | 7 |
| | 14 | 382.543 | 508.801 | 0.359 | 0.362 | 554.50 | 634.301 | 5 | 7 |
| | 15 | 417.119 | 532.661 | 0.362 | 0.393 | 573.48 | 693.263 | 5 | 7 |
| | 16 | 446.468 | 542.115 | 0.391 | 0.400 | 576.11 | 727.036 | 6 | 7 |
| | 17 | 446.576 | 564.761 | 0.428 | 0.439 | 632.24 | 761.8105 | 6 | 7 |
| | 18 | 476.016 | 613.950 | 0.461 | 0.444 | 647.32 | 823.358 | 7 | 8 |
| | 19 | 505.149 | 640.15 | 0.474 | 0.451 | 652.73 | 833.3822 | 7 | 8 |
| | 20 | 537.561 | 654.266 | 0.500 | 0.492 | 707.16 | 855.7497 | 8 | 8 |

**Table 9.** Continued

| Indicator | | DM | | MID | | SNS | | NPS | |
|---|---|---|---|---|---|---|---|---|---|
| Algorithm | | NSGA | MOGWO | NSGA | MOGWO | NSGA | MOGWO | NSGA | MOGWO |
| Large dimensions | 21 | 542.913 | 672.366 | 0.506 | 0.514 | 753.014 | 917.4001 | 8 | 9 |
| | 22 | 596.914 | 702.198 | 0.536 | 0.565 | 787.730 | 937.9264 | 8 | 10 |
| | 23 | 647.765 | 771.149 | 0.573 | 0.606 | 802.701 | 951.754 | 9 | 11 |
| | 24 | 668.586 | 805.623 | 0.577 | 0.619 | 811.838 | 1002.409 | 10 | 12 |
| | 25 | 728.059 | 880.766 | 0.632 | 0.657 | 867.753 | 1055.105 | 10 | 13 |
| | 26 | 740.416 | 933.581 | 0.663 | 0.697 | 897.246 | 1105.337 | 11 | 13 |
| | 27 | 787.703 | 968.587 | 0.664 | 0.754 | 945.319 | 1187.458 | 12 | 13 |
| | 28 | 819.618 | 1047.115 | 0.730 | 0.778 | 961.630 | 1212.151 | 13 | 13 |
| | 29 | 880.428 | 1075.16 | 0.778 | 0.785 | 1048.00 | 1241.729 | 14 | 15 |
| | 30 | 968.346 | 1080.784 | 0.803 | 0.838 | 1055.75 | 1269.637 | 14 | 15 |
| Average | | 468.1279 | 583.0724 | 0.424 | 0.434 | 613.771 | 732.9315 | 6.877 | 7.836 |

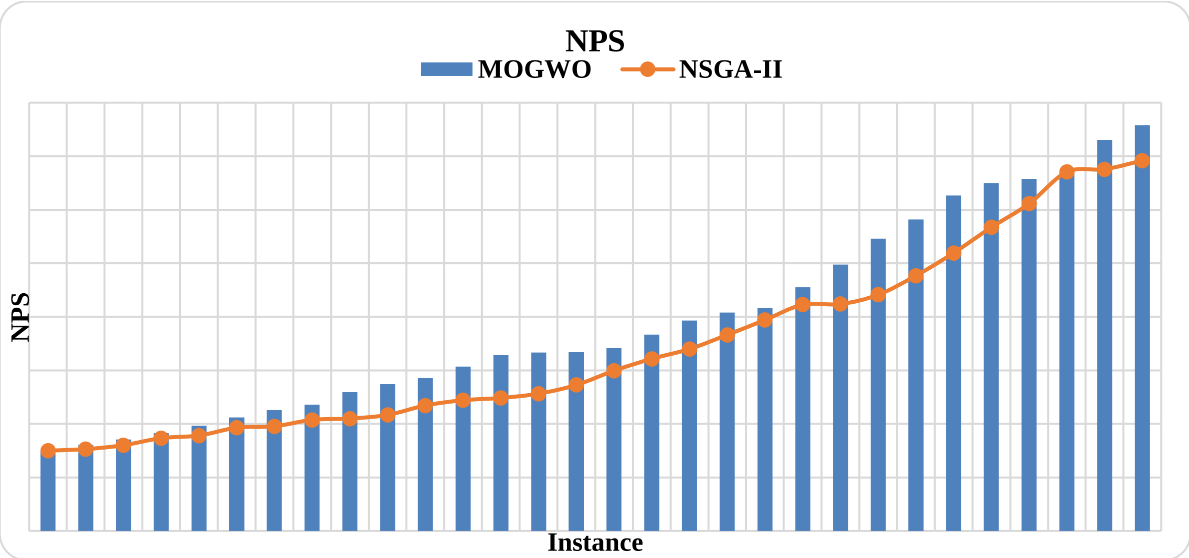


**Figure 10**. The comparison between meta-heuristic algorithms in terms of NPS index

## 5. Conclusion

Innovations in the retail industry will result in increased expectations of the buyers from their purchase. Therefore, many factors including cost, delivery time, customer satisfaction, are considered vital for gaining higher profits and sustaining in this competitive market. To this end, after the identification of factors influencing these variables and mathematical modeling, the optimal value of three variables has been simultaneously studied through the Omni-Channel distribution network. Then, the problems have been solved using two meta-heuristic algorithms, i.e. MOGWO and NSGA-II as modern and efficient optimization procedures. After validating these algorithms, it has been observed that the Pareto frontier of two algorithms extracts the non-dominated solutions of the optimization problem efficiently, such that MOGWO performed better than NSGA-II in terms of DM, SNS, and NPS indices. Moreover, NSGA-II performed better than MOGWO in terms of the MID index. To put it differently, the MOGWO algorithm generates highly and neatly scatteredness for Pareto solutions; however, the NSGA-II algorithm seemed to be efficient only in producing lower values than the first objective and higher values than the second objective. To study the features of these two algorithms in a more precise manner, 30 numerical instances have been produced and the comparison between these two algorithms show that the MOGWO algorithm proved to be significantly superior in terms of DM and SNS indices. For MID index, both algorithms provided similar results, such that the statistical results for comparing both algorithms did notprove to be significant. In short, due to the accessibility of modern and stronger instruments, it can be argued that MOGWO meta-heuristic algorithm generates a better and stronger Pareto frontier on the developed model compared with the NSGA-II algorithm. Thus, it is recommended that researchers study the intended problem under different scenarios to analyze optimal solutions for different situations. Besides, it is recommended to increase the number of parameters under study and implement more iterations using different distribution methods such as Cross-channel. It is also recommended to apply this study results as a roadmap in different industries and use Z-numbers calculations to enhance computational precision and more similarity of the variables to the real environment in further studies to increase the quality of findings.

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