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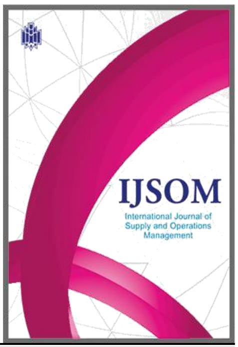

A Bi-objective Integrated Production-distribution Planning Problem Considering Intermodal Transportation: An Application to a Textile and Apparel Company

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Abstract

This paper addresses a bi-objective tactical integrated production-distribution planning problem for a multi-stage, multi-site, multi-product and multi-period Supply Chain network. The proposed model considers sea-air intermodal transportation network in order to enhance the responsiveness and flexibility of the distribution planning. This framework aims at making the trade-off between two conflicting goals. The first objective function considers the minimization of the overall costs associated with production, distribution, inventory and backorders. The second goal is to enhance the customers' service level by maximizing the on-time deliveries over a tactical time horizon. Therefore, to solve the bi-objective model, the ε-constraint method is applied to generate efficient Pareto set of optimal solutions. In fact, the obtained Integer Linear Programming model (ILP), solved using LINGO 18.0 software optimization tool. Computational results are based on a real-life case study from a textile and apparel industry. From a practical point of view, the obtained results prove the pertinence of the proposed model in terms of responsiveness and efficiency of the supply chain to handle peaks demand.

Keywords: Supply chain; Intermodal transportation; integrated production-distribution; textile and apparel industry.

1. Introduction

In today's increasingly global and competitive clothing market, apparel companies must improve their performance offer better services to customers in terms of delivery dates. The fashion industry is known for its product rapid obsolescence, quick response time as well as large product variety differentiated by color, size, etc. (Ngai et al., 2014). The sales seasons are very short in comparison to their long production and delivery times. Moreover, the manufacturing process of garments often involving several collaborating entities within a production and distribution network. On the other hand, the supply chain network includes mainly suppliers, manufacturers, wholesalers, and retailers through whom raw materials are acquired, transformed into finished products through several processing stages, and finally delivered to consumers. Furthermore, handling decisions of different functions of the apparel supply chain such as production and distribution planning, are vital for companies to reach an optimal strategy that enhances the global performance. However, due to the high complexity of such supply chain, it is not usually easy to develop a model that includes all the decisions. In fact, the textile and apparel industry, which is chiefly characterized by make-to-order policies, can produce and deliver the customers' demand within a very short lead-time. Hence, it would be worth establishing a closer interaction and collaboration between these functions in an integrated way instead of being optimized sequentially with little or no integration. Indeed, inappropriate response leads to late deliveries or lost sales on demands that cannot be met. Therefore, production and distribution functions are closely interconnected and must be planned to emphasize the speedy delivery and accelerate the response times.

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In fact, this paper extends the work of (Felfel, Ayadi and Masmoudi, 2016), which is considered as a bi-objective, multi-stage, multi-site, multi-product and multi-period production planning problem. This extension concerns the integration of the distribution network into the specific production planning model while considering intermodal air-maritime transportation in the context of textile and apparel supply chain network. Therefore, to explicitly tackle the customer**'s** satisfaction issue, we develop a bi-objective scheme distinguishing two conflicting objectives of the decision-maker. The first objective consists in minimizing the total costs over the textile and apparel supply chain covering production, storage, backordering and distribution costs while the second aims at satisfying the customers' demands on time. The main contribution of the proposed research is to make important decisions of air-sea intermodal transportation that meet the customers' expectations in an efficient way.

This paper is organized as follows: Previous research on the related works is summarized in Section 2. The third and fourth sections are devoted respectively to the description of the industrial problem statement and the mathematical model. Then, the solution approach for the proposed bi-objective problem is displayed in section 5. Section 6 describes the data used in the industrial case study while section 7 presents the corresponding computational results. On the other hand, sensitivity analysis and some managerial implications are given in section 8. Finally, section 9 concludes the paper ends up by providing some concluding remarks and further scopes of research.

2. Literature review

In line with the scope of this paper, the literature review presented here has some relevant researches on the integrated production and distribution planning problems. In recent years, this problem has been a major issue for both academics and practitioners to ensure the overall efficiency of the supply chain management. Therefore, for comprehensive reviews of the integrated production-distribution planning models in the supply chain environment, the readers may refer to (Sarmiento and Nagi, 1999), (Bilgen and Ozkarahan, 2004), (Fahimnia et al., 2013), (Díaz-Madroñero, Peidro and Mula, 2015) and (Kumar et al., 2020). In fact, the core problems in the Supply Chain network are production planning and distribution planning. Historically, these different activities have been sequentially solved: the optimized outputs of the production problem have become the inputs to the distribution problem. However, as these problems are mutually related, they should be simultaneously considered in an integrated way (Thomas et al., 1996). In this regard, a summary review of the main studies in the literature related to the production and distribution planning problems is presented in table 1. However, many literature models have considered only one single criterion for Supply Chain management. Accordingly, the authors consider costs minimization such as (Bertazzi and Zappa, 2011), (Cóccola et al., 2013), (Goodarzian and Fakhrzad, 2021). Moreover, (Weskamp et al., 2018) and (Kumar et al 2019) consider the profit maximization as the most important ones for the measurement of the Supply Chain performance. However, regarding the supply chain optimization, multi-objective approaches are obvious in most practical decision-making problems. Consequently, the decision-makers may simultaneously consider multiple conflicting goals along with costs minimization. Accordingly, the service level is one of the fundamental objective functions considered in the literature since it is generally based on some measures of the customer's responsiveness by considering the maximization of the product defective rate as presented by (Torabi and Hassini, 2009), that of the sales as mentioned by (Nemati and Hosein, 2019), the minimization of lost sales as presented by (Rafiei, Safaei and Rabbani, 2018), (Liu and Papageorgiou, 2013), then the extension of the late deliveries and delay as mentioned by (Mirzapour Al-E-Hashem, Malekly and Aryanezhad, 2011), (Sanowar and Mosharraf, 2018). Moreover**,** another common objective function is to incorporate environmental issues into the production-distribution planning in order to limit the greenhouse effect and the gas emission. As summarized in table 1, a few studies in the literature focused on intermodal distribution networks is that composed of at least two different transportation modes.

Table 1. Summary of literature review on the integrated production-distribution planning problems

Paper/Study	Number of chain level				Objective functions		Mathematical model-ling	Commerci-al solver	Heuristic / Meta-heuristic	Industrial application
	Multi-site	Multi-product	Multi-period	Modes of transport	Mono	Multi				
(Weskamp *et al.*, 2018)	√	√	√		P		MILP	CPLEX		Apparel industry
(Mirzapour Al-E-Hashem, Malekly and Aryanezhad, 2011)	√	√	√			TC, CSL	MINLP	LINGO		Wood and paper industry
(Sanowar and Mosharraf, 2018)	√	√	√			TC, TDT	LP			Precision machinery and transmission components
(Liu and Papageorgiou, 2013)	√	√	√			TC, TLT, CSL	MILP	CPLEX		Agrochemical industry
(Torabi and Hassini, 2009)	√	√	√			TC, P, Q, CSL	MIP	OSL		Automobile industry
(Nemati and Hosein, 2019)	√	√	√			TC, CSL	MILP	CPLEX		Dairy industry
(Aini *et al.*, 2020)	√	√	√		P		MILP	LINGO		Dairy industry
(Yao and Hsu 2009)	√		√		TC		MINLP		GA	-
(Goodarzian and Fakhrzad, 2021)	√	√	√		TC		MINLP		SA, ACO	-
(Bertazzi and Zappa, 2011)	√	√	√	Sea/Air	TC			CPLEX		Textile machinery sector
(Safra and Jebali, 2018)	√	√	√	Sea/Air	TC		MILP	CPLEX		Textile and apparel industry
(He, Guo and Wang, 2018)	√	√		Road/ Sea/Air	TC				MA	Apparel and footwear industry
(Babazadeh and Razmi, 2012)	√			Transportation modes	TC		MILP	CPLEX & LINGO		-
(Mirzapour Al-E-Hashem, Baboli and Sazvar, 2013)	√	√	√	Road/Rail/Sea/ Air	TC		MINLP	CPLEX		-
(Cóccola *et al.*, 2013)	√	√		Fleet of trucks	TC		MILP	CPLEX		Chemical industry
(Govindan and Fattahi, 2015)	√	√	√	Road/ Rail	TC		MILP	CPLEX		Glass industry

Table 2. Continued

Paper/Study	Number of chain level				Objective functions		Mathematical model-ling	Commerci-al solver	Heuristic / Meta-heuristic	Industrial application
	Multi-site	Multi-product	Multi-period	Modes of transport	Mono	Multi				
(Meisel, Kirschstein and Bierwirth, 2013)	√	√	√	Road/Rail		TC, GHG	MILP	CPLEX	B&C, HD	Chemical industry
(Chanchaichujit, Saavedra-rosas and Kaur, 2016)	√	√		Road/rail; Road/ Sea		TC, GHG	LP			Rubber industry
(Entezaminia, Heidari and Rahmani, 2016)	√	√	√	Heterogeneous fleet of vehicles		TC, GHG	MIP	CPLEX		Wood and paper industry
(Mokhtari and Hasani, 2017)	√	√	√	Transportation modes		TC, GHG	MILP	LINGO	GA	Home appliances manufacturing
(Jabbarzadeh, Haughton and Pourmehdi, 2018)	√	√	√	Rail/ truck/Air		TC, GHG				Pharmaceutical enterprise
(Rafiei, Safaei and Rabbani, 2018)	√	√	√	Heterogeneous fleet of vehicles		TC, CSL	MILP	OSL		-
(Badhotiya, Soni and Mittal, 2019)	√	√	√	heterogeneous fleet of vehicles		TC, TDT, CSL	MILP	CPLEX		Automobile industry
The proposed research	√	√	√	**Sea/Air**		**TC, CSL**	**ILP**	**LINGO**		**Textile and apparel industry**

TC	Total Costs	**MILP**	Mixed Integer Linear Programming	**GA**	Genetic Algorithm
P	Profit	**MINLP**	Mixed Integer Non-Linear Programming	**MA**	Memetic Algorithm
CLS	Customer Satisfaction Level	**LP**	Linear Programming	**HD**	Heuristic Decomposition
Q	Quality	**MIP**	Mixed Integer Linear Programming	**B&C**	Branch & Cut
TDT	Total Delivery Time	**ILP**	Integer Linear Programming	**LSM**	L Shaped Method
GHG	Greenhouse Gaz Emission	**MILP**	Mixed Integer Linear Programming	**SA**	Simulating Annealing
TLT	Total Lead Time			**ACO**	Ant Colony Optimization
FR	Financial Risk				

Therefore**,** the present paper can be distinguished from the existing literature in the following ways. First, the purpose of taking into account multiple transportation ways is mainly based on the trade-off between economic and environmental impacts in terms of the minimization of greenhouse effect and the gas emissions (Meisel, Kirschstein and Bierwirth, 2013), (Chanchaichujit, Saavedra-rosas and Kaur, 2016), (Entezaminia, Heidari and Rahmani, 2016), (Jabbarzadeh, Haughton and Pourmehdi, 2018). In fact, to the best of our knowledge, the proposed integrated production-distribution model is can incorporate the sea and the air transportation, which has not been too much tackled in the literature in order to improve the customers' satisfaction level in terms of the extension the delivery time as a second criterion along with costs. Moreover, with reference to the related research works, there is a shortage of studies in the field of the industrial industries of seasonal products, such as those of fashion and apparel industry. In this industrial field, an application ensures flexibility of the planning, especially in terms of speed and accurate responses to manage the rapid changes in the fashion market (Ngai et al., 2014). Thanks to a real case study of the apparel industry, we contemplate a more realistic opinion by considering a range of the assumptions, the variables and the constraints in the considered production-distribution planning problem. In the context of the apparel industry, (Weskamp et al., 2018) proposed two-stage stochastic programming to develop an integrated production and distribution planning problem while considering the postponement of strategies. In this vein, (He, Guo and Wang, 2018) addressed an integrated scheduling problem of production and distribution which aims at minimizing the total costs of production, transportation, inventory and penalty costs for a shortfall. (Safra and Jebali, 2018) developed an integrated production and distribution planning problem with air and marine transportation**.** In fact, the goal of these authors is to minimize the total costs of production, inventory and transportation. Unlike the works of (Weskamp et al., 2018), (He, Guo and Wang, 2018) and (Safra and Jebali, 2018), the proposed integrated production-distribution model can incorporate a bi-objective scheme so as to simultaneously measure the impacts on the economic performance of the textile-apparel supply chain in terms of the minimization of the total costs of the regular and overtime production, inventory, distribution and the backordering level. The second goal is to maximize the customers**'** service level by ensuring the maximization of on-time deliveries. Besides, the proposed network is distinguished from the other networks by considering different manufacturing stages describing the textile and apparel processing activities and multiple transportation modes in order to improve the flexibility and responsiveness of the apparel Supply Chain network.

3. Problem Statement

This study simultaneously combines production and distribution planning decisions to tackle a bi-objective decision-making problem in the context of a textile and apparel industry. More precisely, it is intended to achieve the best use of available resources along the entire tactical planning horizon, which includes period t ($t \epsilon \{1, 2... |T|\}$) so that all the customers' demands are met at a minimum cost. In fact, in figure 1, we present the proposed multi-stage and multi-site centralized textile-apparel supply chain network. The design of the network consists of N stages ($j \epsilon \{1,2... N\}$) with production plants i ($i \epsilon \{1, 2..., |I|\}$ producing several garment products p ($p \epsilon \{1, 2... |P|\}$) to satisfy the targeted market demands composed of customers' k ($k \epsilon \{1, 2..., |K|\}$). The distribution network is composed of two transportation modes m ($m \epsilon M= \{m=1$: maritime transportation, and $m=2$: air transportation$\}$). We suppose that the company has Make-To-Order policy in order to avoid products 'obsolescence and inventory level.

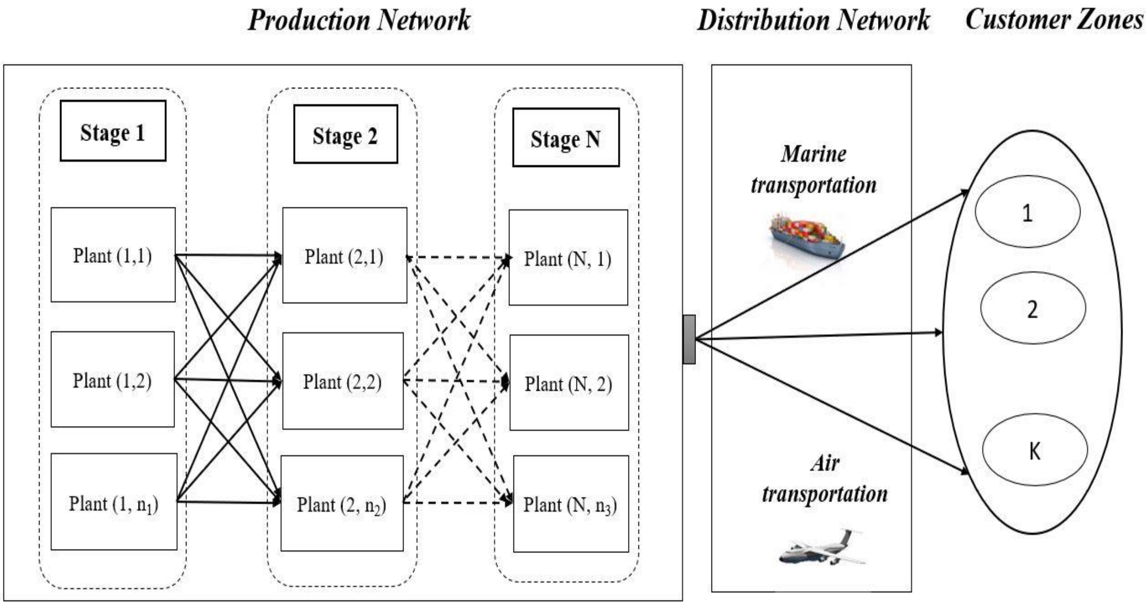

Figure 1. Textile and apparel Supply Chain Network

On the other hand, the considered textile-apparel industry has two seasonal collections; a Fall-Winter collection, which is released precisely in July-August and a Spring-Summer collection released in January-February with a make-to-order strategy. The production process includes the stages of cutting, embroidery/serigraphy, clothes making and packaging. In fact, the raw materials are submitted to the cutting process then, the semi-finished products pass by the embroidery and/or serigraphy phases. The next step is the tailoring stage. From a production planning point of view, the clothes making chain represents the critical phase as it is considered the bottleneck of the chain that contains the main resources (the workforce and the machines) and the maximum diversity of operations and physical flows. Then, the packaging activity is the last step dealing with accessorizing by sewing on buttons and zips. Finally, the finished products are pressed, labelled, folded and enveloped. However, there is a problem in determining the regular and overtime production, the inventory, and the distribution decisions to ensure the fulfilment of the demand. To extend the production rate, we assume that overtime production and sub-contracting are available in (~~at~~) all plants. Therefore, it is important to note that unmet demands are considered as backorders. However, they are penalized at known penalty costs defined by each customer because they lead to the minimization of the customer's service. Regarding the distribution network, it combines multiple transport modes, such as maritime and air transportation, which provide a service based on-time delivery taken into

account. Compared to air transport, maritime transport could provide cheaper prices, and more loads of once delivery for international transport, but it spends more travel time. Clearly, air transport has much higher transport efficiency than maritime transport as it provides a fast way for firms to cope with emergencies where the top priority is the delivery of orders in the shortest possible time although it is the most expensive transport mode. Thereby, using intermodal sea and air transportation with reasonable costs, while considering the volume, regularity of shipments and priority of delivery, remains crucial for the companies to improve responsiveness, and ensure the desired customer’s service level.
For the studied problem, we assumed that:

- All parameters are supposed to be known at the beginning of the planning horizon.
- There is no inventory at the manufacturing plants at the start and at the end of planning horizon.
- All plants can produce products of the same quality.
- Manufacturing sites from the last stage export products directly to overseas customer zones bypassing the distribution network (airplane and maritime transportation modes).
- Shortages are permitted in each period; where the demand is assumed to be partially backordered, which is penalized because it leads to the deterioration of the customer’s service level. However, all the customers’ demands should be firmly satisfied at the end of the planning horizon (lost sales are not allowed).

4. Mathematical formulation

A bi-objective Integer Linear Programming (ILP) deterministic model is formulated for the considered integrated production-distribution planning problem for a medium-term planning horizon. As explained above, this model can make the trade-off between the cost savings and the customers’ satisfaction level.
Let us consider the following notations:

Sets

S_j	set of production’s stage j ϵ {1, 2... N}, N is the number of stages
I	set of plant i indexed by i ϵ {1, 2... |I|}
$SUCC_i$	set of production plants which are the direct successors of plant i, i’ ϵ SUCCi and i ϵ {1, 2…, |I|}
K	set of customers indexed by k ϵ {1, 2..., |K|}
P	set of products indexed by p ϵ {1, 2..., |P|}
T	set of periods indexed by t ϵ {1, 2... |T|}
M	set of transportation modes m ϵ M= {m=1: maritime transportation, m=2: air transportation}

Parameters

CP_{ip}	unit regular production cost of product p by plant i [Monetary unit]
CO_{ip}	unit overtime production cost of product p by plant i [Monetary unit]
$CSH_{ii'p}$	unit shipping cost of product p from plant i to plant i’, i' ϵ $SUCC_i$ [Monetary unit]
CD_{ipkm}	unit distribution cost of product p from plant i, i ϵ S_N to customer k using transportation mode m [Monetary unit]
CB_{pk}	unit backorder cost of product p in supplying the demand of customer k [Monetary unit]
CI_{ip}	unit inventory holding cost of product p in plant i [Monetary unit]
D_{pkt}	demand of customer k for product p in period t [Product unit]
$CAPP_{it}$	maximum regular production capacity of plant i in period t [Minute]
$CAPI_{it}$	maximum storage capacity of plant i in period t [Minute]
$CAPD_{mt}$	distribution capacity of transportation mode m in period t [Product unit]
$CAPSH_{i,i't}$	shipping capacity between plant i and its successor i’ in period t [Product unit]
α	fraction of overtime production capacity allowed in period t, α ϵ [0..1].
β	fraction of backorder variation allowed in period t, β ϵ [0..1].
PLT_{ip}	production Lead Time of product p in plant i. [Minute]
DLT_m	distribution Lead Time using transportation mode m [Minute]

Decision variables

P_{ipt}	quantity of product p produced by plant i in regular time of period t [Product unit]
O_{ipt}	quantity of product p produced by plant i in overtime of period t [Product unit]
I_{ipt}	inventory level of end product p at plant i at the end of period t [Product unit]
SF_{ipt}	inventory level of semi-finished product p at plant i at the end of period t [Product unit]
$SH_{ii'pt}$	number of product unit p shipped from plant i to plant i' in period t, i' ϵ $SUCC_i$ [Product unit]
OQ_{ipkmt}	amount of finished product p transported from i ϵ Sj to customer k in period t using transportation mode m [Product unit]
B_{pkt}	backorder level of product p incurred by customer k at the end of period t [Product unit]
R_{ipt}	Amount of product p received by plant i in period t [Product unit]

Mathematical model

The corresponding formulation is described by equations (1) - (15)

$$MIN\left(F_1\right)=\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{i',i=1}^{I}CP_{ip}P_{ipt}+CO_{ip}O_{ipt}+CI_{ip}\left(I_{ipt}+SF_{ipt}\right)+CSH_{ii'p}SH_{ii'pt}$$
$$+\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{p=1}^{P}CB_{pk}B_{pkt}+\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{i\in S_N}\sum_{k=1}^{K}\sum_{m=1}^{2}CD_{ipkm}OQ_{ipkmt} \tag{1}$$

$$MAX\left(F_2\right)=\frac{\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{k=1}^{K}\left(D_{pkt}-B_{pkt}\right)}{\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{k=1}^{K}D_{pkt}} \tag{2}$$

Subject to

$$I_{ipt}=I_{ipt-1}+P_{ipt}+O_{ipt}-\sum_{i'\in SUCC_i}SH_{ii'pt},\forall p\in P,t\in T,i\in S_{j\le N-1} \tag{3}$$

$$I_{ipt}=I_{ipt-1}+P_{ipt}+O_{ipt}-\sum_{i\in S_N}\sum_{k=1}^{K}\sum_{m=1}^{2}OQ_{ipkmt},\forall p\in P,t\in T \tag{4}$$

$$SF_{ipt}=SF_{ipt-1}-P_{ipt}-O_{ipt}+R_{ipt},\forall p\in P,t\in T,i\in I \tag{5}$$

$$B_{pkt}=D_{pkt}+B_{pkt-1}-\sum_{i\in S_N}\sum_{m=1}^{2}OQ_{ipkm\left(t-DLT_m\right)},\forall p\in P,k\in K,t\geq DLT_m \tag{6}$$

$$B_{pkT}=0,\forall p\in P,k\in K \tag{7}$$

$$R_{i'pt+1}=\sum_{i'\in SUCC_i}SH_{ii'pt},\forall i\in I,p\in P,t\in T \tag{8}$$

$$B_{pkt}\leq\beta D_{pkt},\forall p\in P,k\in K,t\in T \tag{9}$$

$$\sum_{p=1}^{P}PLT_{ip}P_{ipt}\leq CAPP_{it},\forall i\in I,t\in T \tag{10}$$

$$\sum_{p=1}^{P}PLT_{ip}O_{ipt}\leq\alpha CAPP_{it},\forall i\in I,t\in T \tag{11}$$

$$\sum_{p=1}^{P}I_{ipt}+SF_{ipt}\leq CAPI_{it},\forall i\in I,t\in T \tag{12}$$

$$\sum_{p=1}^{P}SH_{ii'pt}\leq CAPSH_{ii't},\forall i\in I,i'\in SUCC_i,t\in T \tag{13}$$

$$\sum_{i\in S_N}\sum_{p=1}^{P}\sum_{k=1}^{K}OQ_{ipkmt}\leq CAPD_{mt},\forall m\in M,t\in T \tag{14}$$

$$\left\{OQ_{ipkmt},B_{pkt},SH_{ii'pt},I_{ipt},SF_{ipt},R_{ipt},O_{ipt},P_{ipt}\right\}\in\square,\forall i\in I,p\in P,t\in T,k\in K,m\in M \tag{15}$$

The first objective function (1) aims at minimizing the total expected costs of the whole supply chain, including respectively production costs in normal working hours and overtime, inventory holding cost for both semi-finished and finished products, shipping costs between plants, shortage costs and distribution costs to customers.

On the other hand, the second objective (2) seeks to maximize the customers' satisfaction level by maximizing the amount of products delivered on time. Then, constraint (3) is the flow balance constraint for the plants in production stages S_j, $j=1... N-1$, where production amounts are either stored in inventory or further transported to its successor plants. Constraint (4) corresponds to the inventory balance at plants from the last production stage. It will be equal to the inventory of the previous period and the production amounts minus the shipped products to customers. Constraint (5) ensures that the quantity shipped from one production plant will be received by its successor. Eq. (6) states that the customers' demand over the period must be satisfied or partially backordered. The backorder level of the product for customer k in period t is equal to the maximum difference between his demand and the quantity shipped from the plants from the last stage to the customers' zones by taking into account the distribution lead-time. Constraint (7) ensures that the demands of customers for every product and for the entire planning horizon are satisfied. In fact, the backorder level in the last period should be zero in order to avoid lost sales. Eq.(8) states that the shipping amount of products from the plants to its successor is received in the next period. Then, the limit of backorder's rate is illustrated in constraint (9). On the other hand, Eq. (10) & (11) limit the production amounts to the available production capacity in regular and overtime, respectively. Constraint~~s~~ (12) limits the product inventory levels of production plants to their related inventory storage capacities. The shipping quantity of products between plants is delimited in eq. (13) and the distribution capacity to customers in constraint (14). The constraint~~s~~ set (15) enforces the non-negativity and integers restrictions on the decision variables.

5. Resolution approach

There have been huge research efforts over the last decades in the field of multi-objective optimization as almost all the real-world industrial optimization models need to be modelled using conflicting objectives. Therefore, it would be preferable to optimize all the objective functions at once. However, the optimization process has to search for the best optimal solution because of the conflicting nature of these goals (Chiandussi et al., 2012). Moreover, the presence of multiple objectives ensures a number of Pareto-optimal solutions, instead of a single one. Actually, there are several methods that cope with multi-objective models including the a priori, interactive, and a posteriori approaches (Mirzapour Al-E-Hashem et al., 2011).

In a priori methods, the decision-maker expresses his preferences before the solution process like in the scalarization methods, such as the weighted-sum (Ehrgott and Wiecek, 2005). The purpose of a posteriori method is to optimize all the objective functions simultaneously. Initially, the efficient solutions of the Pareto set are generated. Afterward, at the end of the search process, the decision-maker is involved in selecting the most preferred efficient solution among the Pareto set. Regarding the interactive approach, the phase in which the decision-maker formulates his preferences and the phase of calculation are interchanged, then the decision-making process generally converges to the best efficient solution.

Principally, the solutions of a multi-objective problem are called the Pareto-optimal solutions, which are defined as follows (Marler and Arora, 2004):

Definition 1: Pareto Optimal: A point, $x* \in X$, is Pareto optimal if there is no other point, $x \in X$, such that $F(x) \leq F(x*)$, and $F_i(x) < F_i(x*)$ for at least one function.

Definition 2: Efficient and Inefficient: A point $x* \in X$ is efficient if there is no other point for $x \in X$ such that $F(x*) \leq F(x)$ with at least one $F_i(x) \leq F_i(x*)$. Otherwise, $x*$ is inefficient.

Definition 3: Non-Dominated and Dominated Points: A vector of objective functions $F(x*) \in Z$ (Feasible criterion space), is non-dominated if there is not another vector $F(x) \in Z$ such that $F(x*) \in F(x)$ is with at least one $F_i(x) \leq F_i(x*)$. Otherwise, $F(x*)$ is dominated.

In the Pareto set, the optimal solution of an objective function will be reached by diminishing the performance of the other objective functions. Consequently, the decision-maker has to select the most preferable objective function among the Pareto optimal solutions according to his policies.

In this framework, we applied one of the efficient multi-objective optimizing solvers based on the well-known a posteriori approach ε-constraint as it is considered as more efficient than the sum-weighted approach. This method which was introduced by (Haimes, Lasdon and Wismer, 1971), can serve a representative subset of the non-dominated solutions.

The ε -constraint method has several important advantages over the traditional weighting method, as it combines the objective functions of the multi-objective optimization problem by weighted sum to build a single objective function. These advantages can be summarized in the following points (Mavrotas, 2009):

- For linear problems, the weighting method generates only efficient extreme solutions. While , the ε -constraint method produce**s** non-extreme efficient solutions

- Despite the weighting method, the ε -constraint method can produce unsupported efficient solutions in multi-objective mixed integer programming problems.

- In the ε -constrained method the scaling of the objective functions is not necessary but sometimes needed in the weighting method.

- In the ε -constraint method, the number of generated efficient solutions can be controlled by properly adjusting the number of grid points in each one of the objective function ranges.

The bi-objective optimization problem presented in the previous section is transformed into a mono-objective optimization problem where the first objective function (1) is minimized while the second goal (2) is treated as a constraint bounded by fixing threshold values ε_2^k (Eq (**Error! Reference source not found.**)) (Aghaei, Amjady and Shayanfar, 2011)

$$F_2 \geq \varepsilon_2^k \qquad (16)$$

The problem is regularly solved for different values of ε_2^k for the aim of generating the entire Pareto set of optimal solutions. The formulation of the ε_2^k is shown in Eq (17)

$$\varepsilon_2^k = F_2^N + k * \frac{r_2}{q}, k = 0,1,\ldots,q \qquad (17)$$

To calculate ε_2^k , it is worth determining the payoff table for the optimization problem by calculating the utopia and the nadir points:

Utopia point F_i^U is a specific point, where the objectives are at their best possible values. It is denoted in Eq (**Error! Reference source not found.**) as:

$$F_i^U = \left[F_1^*, F_2^* \right] \qquad (18)$$

Nadir point F_i^N is a point in the objective space where objective functions are at their worst values. It is written in Eq (**Error! Reference source not found.**) as:

$$F_i^N = \left[F_1, F_2 \right] \qquad (19)$$

Then, the ideal points F_1^* and F_2^* are found along the main diagonal of the payoff table (Eq (20)). They are obtained by simply optimizing each objective function individually over the feasible region. Then, the remaining values of the payoff table are calculated considering the already calculated value of F_1^* and F_2^*.

$$\Phi = \begin{pmatrix} F_1^* F_2 \\ F_1 F_2^* \end{pmatrix} \qquad (20)$$

Then the range of the second objective function (r_2) should be determined and calculated as shown in Eq (21

$$r_2 = F_2^U - F_2^N \qquad (21)$$

The algorithm of ε -constraint method could be described as follows:

- Select one of the objective functions as the main objective function,
- For each objective function, solve the problem and find the optimal values of each objective function,
- To specify the amount of ε_2^k the interval between two optimal values of objective sub- functions should be divided into q equal interval then the ε_2^k will be calculated with a recursive equation.
- Solve, at any time, the main objective function (F_1) with each value of ε_2^k.
- Repeat the steps until Pareto's solutions are detected.

In fact, the main advantage of the ε-constraint approach that it can achieve efficient points in a non-convex Pareto curve. The multi-criteria production–distribution problem~~s~~ is solved using the solver LINGO 18.0, a software, which uses a traditional exact method: Branch and Bound technique linked to its libraries to obtain Pareto optimal solutions.

6. Description of the considered real case study

In order to investigate the pertinence of the presented ILP model, we consider a real Tunisian textile-apparel supply chain case. The chosen company was founded in 2000 in Sfax city, in the south of Tunisia, which in the south of Tunisia, which totally exports its products to the European markets. After collecting the actual data derived from the textile company's manufacturing process, a logical model of a supply chain network is illustrated in figure 2. There are three customer~~s~~ centers located in France, which firstly store the fashion products in their warehouses and secondly sell these readymade garments to immediate consumers or end users through their fashion shops and stores. The distribution lead-time between the plant from the last stage and the customer's zone, which depends primarily on the used transportation modes is 3 weeks (3 periods) if the products are exported by ship and at the same time if the decision maker chooses the airplane. It is assumed that raw materials (fabric and accessories) are fully available and without defects at the beginning of the planning horizon. In this real case study, the planning production-distribution occurs within three months planning horizon with 12 weekly periods of summer collection. Backorders are allowed at a known penalty cost fixed by each customer in a range of 10 % to 20 % higher than the unit product price. The overtime production costs are reckoned as 70 % higher than the production costs in normal working hours. The inventory holding unit cost is approximately 20 % of the unit production cost. However, the production capacity differs from one period to another and depends on the number of the present labor force and its performance. Overtime production capacity is 25% of production capacity in regular times.

The customers' orders, which are deterministic, are presented in table 2 then, the unit production cost per site and per product in normal working hours is provided in table 3 while the unit distribution cost per product, per transportation mode and per customer is outlined in table 4.

Table 3. Customers' demand (Product unit)

		Period T				
Product P	***Customer K***	***T1-T8***	***T9***	***T10***	***T11***	***T12***
P1	***K1***	0	10211	0	0	0
	K2	0	0	10073	0	0
	K3	0	0	7620	8751	0
P2	***K1***	0	0	3336	0	4366
	K2	0	6203	8360	0	0
	K3	0	0	0	7029	0

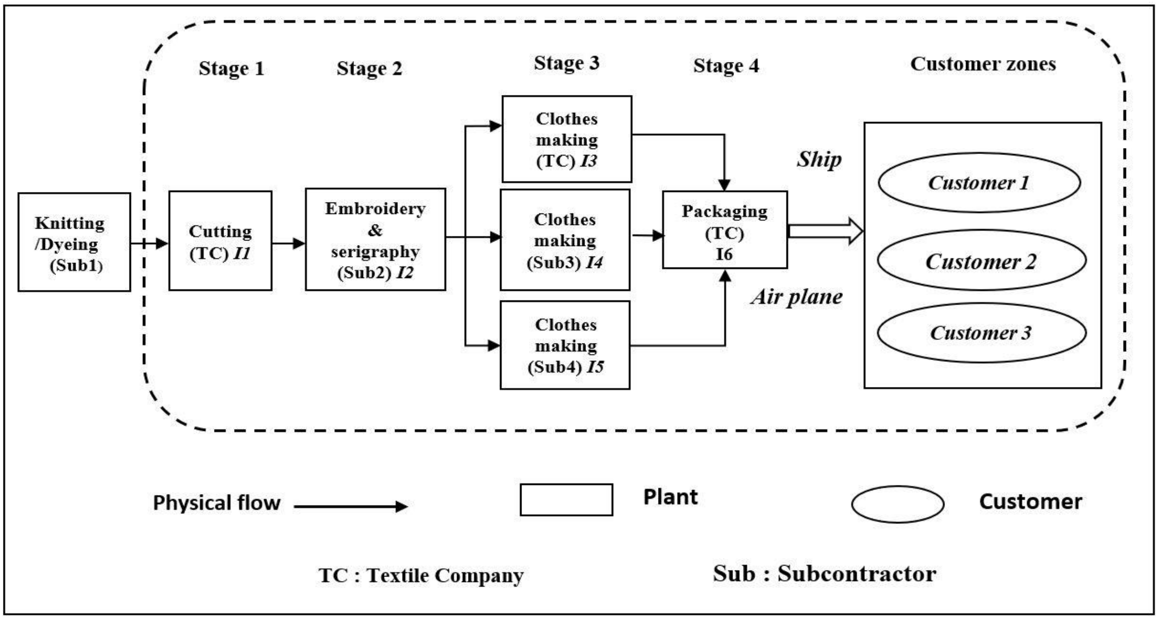

Figure 2. Supply Chain Network of TE-INTER

Table 4. Unit production cost in normal working hours [Monetary Unit]

	Product P	
Plant I	**P1**	**P2**
I1	3.47	3.45
I2	4.5	3
I3	18.41	9.3
I4	20.251	11.2
I5	19.8	10.5
I6	2.5	4

Table 5. Distribution costs [Monetary Unit]

		Customer K		
Product P	Transportation mode M	***K1***	***K2***	***K3***
P1	Maritime transportation M1	0.86	0.95	1.15
	Airplane transportation M2	5.69	7.19	6.59
P2	Maritime transportation M1	1.13	1.20	1.50
	Airplane transportation M2	3.95	4.99	4.57

7. Computational results

The ILP model was solved using the exact method Branch and Bound accessed through the solver LINGO 18.0. We used this optimisation software tool because it is simple, convenient, fast and efficient in solving complex planning problems and importing/exporting data and solutions from databases and spreadsheet**s** (MS Excel, MS Access, etc.) (Lindo Systems INC, 2003). The machine used to run the program is a PC Intel Core i5 with a 2.71-GHz processor and 8Go memory. This problem involves 974 integer variables and 1786 constraints. The objective values for all model runs were found with an optimality gap of 0 and no more than 2 seconds as running time.

Then, the Pareto curve for the total costs (F_1) and the customers' satisfaction level (F_2) of the solved model and the current results of the textile company are graphically given in figure 3. Therefore, to generate the Pareto-optimal solutions, ε is varied using the range calculated in equations (22) and (24) as follows:

$$r_2 = F_2^U - F_2^N = 1 - 0.869011 = 0.130989 \qquad (23)$$

$$\varepsilon_2^k = F_2^U - k * \frac{r_2}{q} = 1 - k * \frac{0.130989}{10}, \quad k = 0,1,\ldots,10 \qquad (24)$$

where F2U and F2N are respectively the utopia and the nadir point value of F2. Thereafter, the range of r_2 is divided into q=10 equal intervals and the value associated with the 11 optimal solutions of the Pareto front.

We assume that q=10, as we expected it, have 11 Pareto optimal solutions. However, this value depends on the decision maker's choice and the number of the Pareto solutions we want to obtain.

Table 6. Payoff table

	Minimum value of the objective function	Maximum value of the objective function
F_1 [Monetary Unit]	337560	358284.4
F_2 [Ratio]	0.869011	1

Based on the Pareto optimal solutions shown in figure 3, it is interesting to notice that the company can obtain 337560 as total costs only if the backorder level equals 13.0989%. On the other hand, the firm can mitigate the amount of the late deliveries to 0 % if the second objective function is considered at its maximum level (F2=1). However, in this case the obtained costs increase to 358284.4. In other words, considering the highest customer's satisfaction level in the multi-objective function of the proposed model causes the loss of 20724.4 (5.78% loss) in profit. This situation indicates the contradictory nature of these two objective functions. In fact, it seems that an increase by one % of one_function causes the decline of the other because the on-time delivery loading effect will entail a high increase of both the distribution and the overtime production costs, which strongly leads to the decrease of the profit.

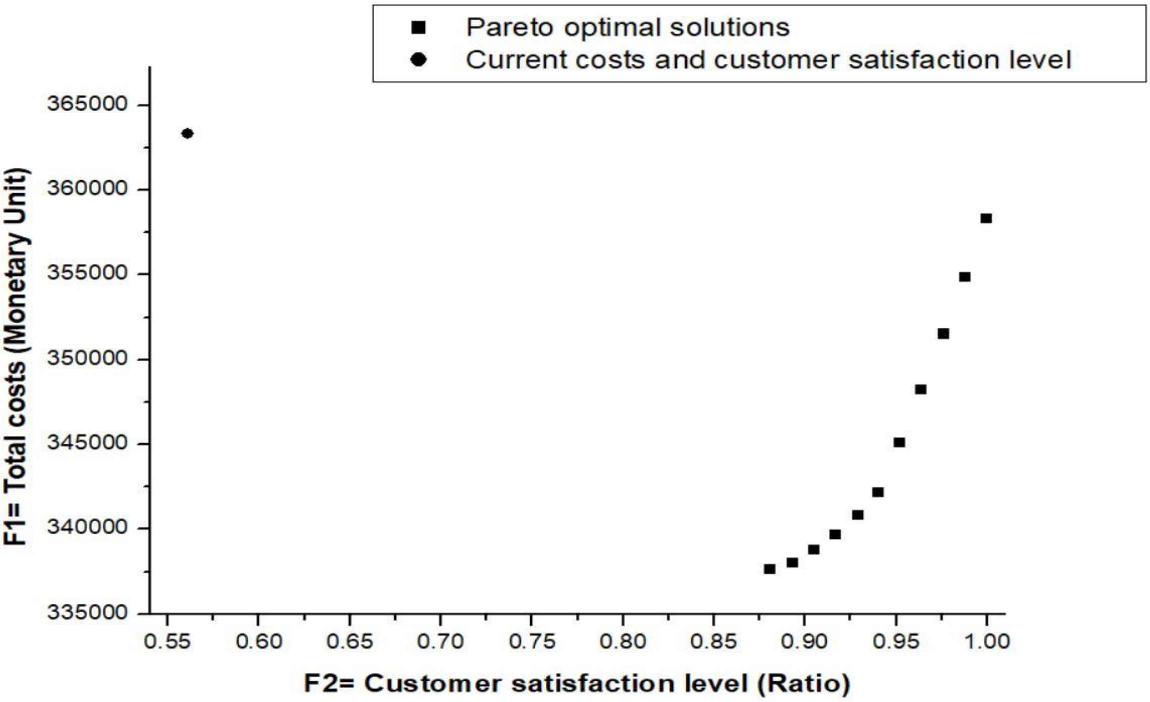

Figure 3. Pareto set of optimal solutions

Table 6 presents a summary of computational results including respectively: the value of the total costs (F_1), the customer's satisfaction level (F_2), airplane transportation, overtime production ratio, the percentage of the backordering level and the subcontracting ratio. These last four ratios are consecutively defined in equations (25), (26), (27) and (28) as follows:

$$Overtime\ production\ (\%) = \frac{Amount\ of\ \ overtime\ production}{Amount\ of\ \ regular\ time\ production} \tag{25}$$

$$Airplane\ transportation\ \ (\%) = \frac{Amount\ of\ airplane\ transportation}{Total\ demand} \tag{26}$$

$$Backorder\ level\ (\%) = \frac{Amount\ of\ late\ deliveries}{Total\ demand} \tag{27}$$

$$Subcontracting\ ratio\ \ \ (\%) = \frac{Amount\ of\ subcontracting\ production}{Amount\ of\ total\ production} \tag{28}$$

Moreover, in order to show the importance of modelling an integrated production-distribution planning problem, we compare the proposed model with the results of the current planning approach, which has already occurred in real practice. In fact, the value of the current industrial cost, 363295.86, is associated with 56.08% as a customer's satisfaction level. It is rather clear from the Pareto front that the cost of the proposed approach strongly dominates the current costs of the company. Furthermore, it is noteworthy that the savings in costs and better meeting customers' requirements when using the proposed model are remarkable. For instance, comparing the 1st and 11th solutions of Pareto front (presented in table 9) to the current company-planning practice, the company could make 1.38% (solution 1) and 7.06% (solution 2), respectively, as a cost saving and 43.92% (solution 1) and 36.34 % (solution 2) as a gain in the customer's satisfaction level compared to the present practice of the firm. To the best of our knowledge, the current decision-making processes involved in the production planning are time-consuming and heavily reliant on human experience. Therefore, any decision delay would lengthen the entire lead-time and force the company to lose its performance. In fact, the main causes of the late deliveries are the tardiness of raw materials replenishment, subcontractors' availability and internal resource capacities. Consequently, the distribution planning would be disrupted resulting in a low customer's service under use of the maritime transportation mode. Thus, the amount of unsatisfied demands increases from one period to another and then the company must deliver the products to the customers' zone in small quantities. Understanding the unforeseen causes of the high costs and inefficiencies of the company requires making related decisions of production and distribution planning with respect to the profit of the whole supply chain. Moreover, it seems that having a larger view of the information in the supply chain, using the proposed model, leads to better overall costs by means of avoiding the behavior of locally optimizing production and distribution. The results revealed that the obtained optimal solutions give the company competitive advantages in terms of serving customers faster by urging the company to use the air transportation.

Table 7. Results of the proposed model and the current planning

	N° Solution	*F₁ [Monetary Unit]*	*F₂*	*Backorder level (%)*	*Overtime production ratio (%)*	*Subcontracting ratio (%)*	*Air transportation ratio (%)*	*CPU time (Seconds)*
Results of the implementation of the proposed model	1	358284.4	1.00	0.000	13.491	17.959	17.1	0.63
	2	354878.7	0.98	0.012	13.491	19.15	15.91	0.27
	3	351515.7	0.97	0.024	13.491	19.832	14.48	0.36
	4	348244.5	0.96	0.036	13.491	20.208	13.25	0.22
	5	345080.6	0.95	0.048	13.491	20.584	11.54	0.43
	6	342156.5	0.94	0.060	13.491	20.633	10.78	0.35
	7	340847.2	0.92	0.071	13.491	20.274	10.18	0.26
	8	339679.2	0.91	0.083	10.691	20.274	9.57	0.84
	9	338796.7	0.90	0.095	10.691	20.615	8.91	0.53
	10	338026.8	0.89	0.107	10.691	20.691	7.92	0.23
	11	337638	0.88	0.119	10.691	20.853	7.89	0.23
Real Case study without optimization	-	363295.86	0.56	0.439	1.2	11.88	0	-

In fact, in figure 4, we present the Pareto front (4.a) decomposition of total costs in terms of overtime production ratio (4.b) by sub-contracting activity ratio (4.c) and air transportation ratio (4.d). The solutions presented in table 9 demonstrate that delivering products to the customers' locations at a given due date implies a proper consideration of several tactical decisions of production and distribution planning. Concerning the production planning, the results showed that a fraction of the customers' order can be assigned to sub-contractors or produced overtime in order to satisfy pre-season orders. Consequently, the shortage of products is filled with either overtime production (4.b), subcontracting of clothes making activity (4.c) or combined sea-air transportation (4.d) in the hope of pushing forward the increase of production and distribution flexibility. Therefore, the results of the proposed model show~~s~~ that according to the customers' satisfaction level, the overtime production ratio varies from 10.691% to 13.491% while the ratio of the sub-contracting activities has shifted from 17.959 % to 20.853%. For the sake of comparing the current case study and the developed model, we should enlighten that the company uses only the maritime mode in its exportation, 1.2% as overtime production ratio and 11.88 % of the demand is allocated to sub-contractors. Therefore, the company tries to reject these corrective activities because of their expensive costs. However, despite its expensive cost, using the air transportation mode along with the air marine ways remains the suitable option for the company to respect the delivery time and serve products to clients on time. These numerical results ascertain the effect of considering multiple transportation modes on the supply chain performance where the economies of scale can be better exploited and the overall efficiency would be improved. In fact, every transport technique has its own characteristics, in terms of speed, availability, dependability, frequency and so on. Therefore, the decision maker should consider the high flexibility of airplane to immediately carry out the customer's delivery request compared to the sea transport.

However, air transport has a very high cost. Thus, an increase of the overall costs is recorded when the rate of use of the air transportation model increases, as clearly shown in curve 4.a and 4.d of figure 4. Nevertheless, we should notice that the highest costs (358284.4) associated with the best customer's satisfaction level (100%) of the proposed model is even lower than the cost of the solution considered by the company (363295.86) with 56.08 % of the customer's satisfaction level. In fact, this significant gain reflects the effectiveness of the approach developed to match the customer's demands at the minimum costs. Therefore, based on the short cycle life of the garments, integrated production-distribution planning problem using multi-modal transport could have an advantage over the unitary transport mode and consequently, achieve higher customer's expectations.

8. Sensitivity analysis and managerial implications

In this section, we provide the problem complexity as well as a sensitivity analysis of demand value variation indicating some managerial insights of the solutions obtained by the proposed model.

8.1 Sensitivity analysis

To discuss the complexity of the proposed planning problem, we present in Figure 5, CPU time evolution for the different problem sizes. It is clear from Figure 5 that the CPU time increases exponentially with problem size, especially when the number of products and customers is greater than 30.

Therefore, in order to further evaluate the model, we conducted a sensitivity analysis to test the impact of the customers' demand value variation on the optimal solutions of the model. Moreover, we randomly generated 6 instances on the demand variations while conserving the same supply chain structure of the industrial case study.

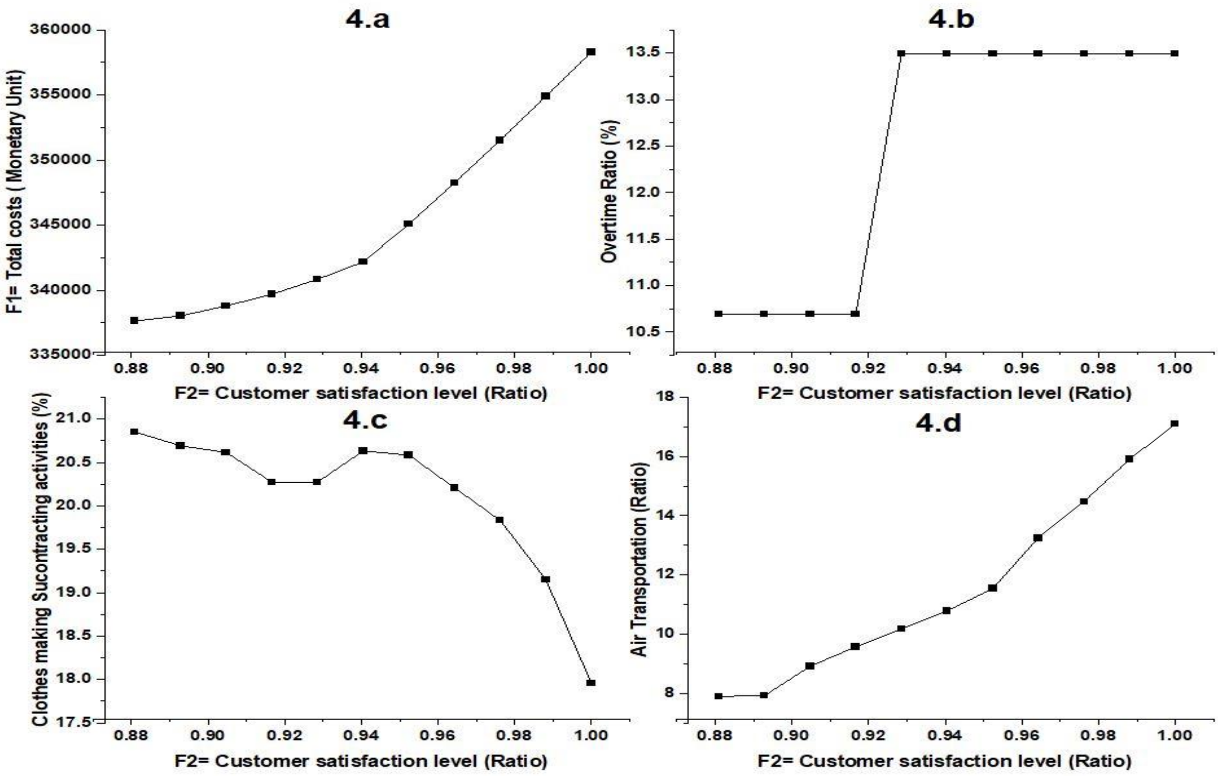

Figure 4. Results of real case study of the textile company

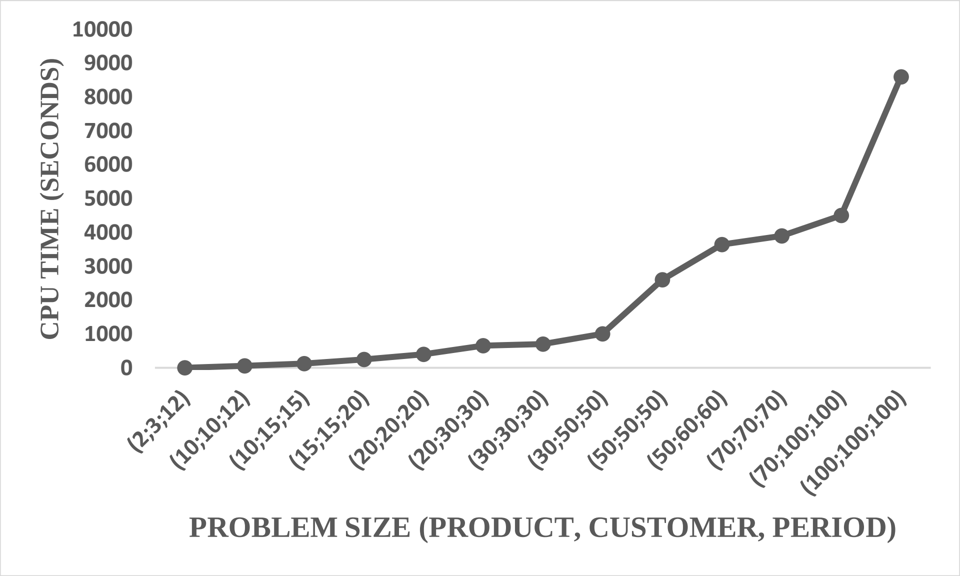

Figure 5. CPU under different problem sizes

Table 8. Total customers' demand of each instance (Product)

Instances	Total Customers Demand
Industrial case study	65949
Instance 1	84043
Instance 2	79957
Instance 3	74534
Instance 4	55242
Instance 5	46029
Instance 6	41632

We also proposed to compare in table 8 the results of 6 instances of models considering both intermodal and marine transportation. Then, in table 9, we provided a decomposition of the total costs of the model considering intermodal transportation. At first glance, it seems that the demand variability has a greater influence on both the entire costs and the customer's satisfaction level, in terms of on-time delivery. In fact, we noticed that the total cost values (F1) increase while the customer service level (F2) decreases when demand increases. Accordingly, as illustrated in table 8, the objective functions are more sensitive to the air transportation and overtime costs when compared to the demand of the customers' zones. For instance, concerning the relatively high-level demands (Instance 1-3), the costs increase (from 490935.8 to 407695.2) with the use of airplane (28.66% to 30.24 %) while the customer's service level decreases (varying from 0.8 to 1). For the relatively medium level of the demand (Instance 4), the decision maker needs to deliver small parts of the demand (0.94 % to 4.01 %) using the airplane in order to have a better customer's satisfaction level (varying from 0.83 to 1). Regarding the low level of the demand (Instances 5 and 6), the managers may deliver the products to the customers' zones using only the marine ways. To the best of our knowledge, the model considering the ship as the only option to deliver the products is literally unfeasible for a high level of demand and instance 4 (Customer's satisfaction level: F2=1) and feasible for the remaining customer's service levels. Based on these findings, it might be concluded that the demand parameter is significantly sensitive to the total costs as well as to the customer's service level. Additionally, the model considering intermodal transportation is considered relevant for the discussed problem.

Table 9. Summary of instances results of models considering intermodal transportation and marine transportation

	N° Solution	Model considering the intermodal transportation		Model considering the marine transportation	
		F_1 [Monetary Unit]	F_2	F_1 [Monetary Unit]	F_2
Instance 1	1	490935.8	1.000	No feasible solutions	
	2	485886	0.983		
	3	482152.8	0.965		
	4	478767.2	0.948		
	5	475738	0.931		
	6	472754.6	0.914		
	7	470679.2	0.896		
	8	469358.7	0.879		
	9	468626.3	0.862		
	10	468256	0.845		
	11	468032.2	0.827		
Instance 2	1	450633.3	1.000	No feasible solutions	
	2	446631.7	0.983		
	3	443200.5	0.967		
	4	439940	0.950		
	5	436830.2	0.933		
	6	433919	0.917		
	7	431892.8	0.899		
	8	430653	0.883		
	9	430094.9	0.866		
	10	429704.4	0.849		
	11	429555.3	0.833		
Instance 3	1	431031.5	1.000	No feasible solutions	
	2	427155.5	0.980		
	3	423877	0.962		
	4	420907.9	0.943		
	5	417987.8	0.924		
	6	415098.8	0.904		
	7	412255	0.885		
	8	410118.2	0.866		
	9	408781.8	0.847		
	10	408064.3	0.828		
	11	407695.2	0.809		
Instance 4	1	269782.3	1.000	267767	0.98
	2	267306.7	0.983	266632.8	0.97
	3	265560.8	0.967	264471.6	0.95
	4	264284.7	0.951	263543	0.94
	5	263009.2	0.935	261878.3	0.92
	6	261789.2	0.919	261323.7	0.91
	7	260939.8	0.902	260394.6	0.89
	8	260249.6	0.886	260058.2	0.88
	9	259752.2	0.869	259592.6	0.86

Table 9. Continued

	N° Solution	Model considering the intermodal transportation		Model considering the marine transportation	
		F_1 [Monetary Unit]	F_2	F_1 [Monetary Unit]	F_2
	10	259492.1	0.854	259437.9	0.85
	11	259245.1	0.837	259286.6	0.84
Instance 5	1	203262.9	1.000	203262.9	1
	2	203001.2	0.992	203001.2	0.992
	3	202780.7	0.983	202780.7	0.9832
	4	202567.1	0.975	202567.1	0.975
	5	202371.6	0.966	202371.6	0.966
	6	202284.5	0.958	202284.5	0.958
	7	202202.6	0.949	202202.6	0.949
	8	202122.5	0.941	202122.5	0.941
	9	202047.7	0.933	202047.7	0.933
	10	201972.9	0.924	201972.9	0.924
	11	201898.1	0.916	201898.1	0.916
Instance 6	1	179678.8	1.000	179678.8	1
	2	179668.3	0.997	179668.3	0.997
	3	179657.7	0.994	179657.7	0.994
	4	179647.2	0.991	179647.2	0.991
	5	179636.7	0.988	179636.7	0.988
	6	179626.1	0.985	179626.1	0.985
	7	179617.9	0.982	179617.9	0.982
	8	179609.6	0.979	179609.6	0.979
	9	179601.4	0.976	179601.4	0.976
	10	179593.1	0.973	179593.1	0.973
	11	179587.2	0.969	179587.2	0.969

Table 10. Decomposition of the total costs of the model considering intermodal transportation

	Model considering intermodal transportation			
	N° Solution	Overtime production ratio (%)	Subcontracting ratio (%)	Air transportation ratio (%)
Instance 1	1	12.83	19.73	30.24
	2	13.94	20.15	28.68
	3	13.88	20.21	27.78
	4	14.67	20.15	26.94
	5	13.41	20.11	26.09
	6	13.54	20.15	25.24
	7	12.48	19.57	26.24
	8	11.93	18.71	27.56
	9	10.98	18.10	27.96
	10	10.57	17.68	28.47
	11	8.92	17.21	28.66
Instance 2	1	14.41	19.78	25.75
	2	14.21	18.57	25.25
	3	14.13	18.42	24.29
	4	14.37	18.32	23.47
	5	13.50	18.41	22.85
	6	14.02	18.73	22.01
	7	13.88	18.47	21.65
	8	14.26	17.97	22.36
	9	13.85	17.25	22.74
	10	12.29	17.19	22.59
	11	12.89	17.16	22.07
Instance 3	1	11.42	20.56	24.34
	2	13.35	20.56	22.30
	3	14.91	20.82	21.21
	4	14.79	20.07	20.14
	5	15.10	20.07	19.18
	6	14.32	21.07	18.23
	7	13.09	21.70	17.55

Table 10. Continued

	Model considering intermodal transportation			
	N° Solution	Overtime production ratio (%)	Subcontracting ratio (%)	Air transportation ratio (%)
	8	11.84	21.07	17.78
	9	10.44	20.66	19.22
	10	11.58	19.48	19.75
	11	10.57	19.47	19.86
Instance 4	1	13.01	21.33	4.01
	2	12.72	19.98	3.46
	3	12.11	18.78	3.08
	4	11.85	18.78	2
	5	12.36	18.75	0.94
	6	13.1	18.51	0
	7	13.38	18.62	
	8	10.15	18.78	
	9	8.31	19.92	
	10	7.91	19.92	
	11	7.43	19.92	
Instance 5	1	0.91	19.20	0
	2	1.19	18.36	
	3	1.19	17.52	
	4	1.19	16.68	
	5	1.17	15.93	
	6	0.99	15.72	
	7	0.82	15.51	
	8	0.65	15.29	
	9	0.48	15.08	
	10	0.31	14.87	
	11	0.14	14.65	
Instance 6	1	1.00	11.53	0
	2	0.99	11.23	
	3	0.99	10.93	
	4	0.99	10.63	
	5	0.98	10.33	
	6	0.98	10.03	
	7	0.98	9.73	
	8	0.97	9.43	
	9	0.97	9.12	
	10	0.97	8.82	
	11	0.96	8.52	

8.2 Managerial implications

The proposed planning problem can acquire an important view from the implications derived from the computational results and the sensitivity analysis of the study. Thus, this research work would assist the textile and apparel industry to establish a collaborative planning of the supply chain among the stakeholders, subcontractors, managers and customers. The results of this sensitivity analysis proved that the proposed model can effectively support the development of an integrated production and distribution model with multiple transportation modes for the export-oriented companies in order to handle the urgent peak demand. From the managerial point of view, this model provides the links between production planning and distribution planning in an integrated way. Besides, the assumption of using multiple modes of transportation will influence the companies' network and improve the supply chain responsiveness and flexibility. Therefore, when the demand variability is high, in relative terms, the results show a great performance especially when the targeted customer's service level is high, which can be understood as another managerial implication of this work. Indeed, managers have to adopt various pertinent measures to their own situations to strive for satisfying both pre-season and in-season demand. To achieve their desired goal, companies need to expand their resource capacity of both production and transportation by sub-contracting some activities, planning overtime production and speeding up the delivery lead-time using the airplane.

9. Conclusions and further scope of study

The proposed framework addressed an integrated production-distribution model in the context of multi-stage, multi-site, multi-product textile and apparel supply chain network with multiple transportation modes. More importantly, the model has given insights regarding production, storage, outsourcing, distribution through two means of transportation and backordering planning. The main contribution of this work is to consider air-sea intermodal transportation that meets the quality expectations of the final customers in the most effective way. The presented framework has two objective functions to optimize; the first one corresponds to the minimization of the overall costs, including production, in normal working hours and overtime, inventory, transportation, and backorder through a medium-term planning horizon. While the second function is related to the customer's satisfaction level by maximizing the on-time deliveries. Moreover, a mathematical model of the production distribution system is formulated as an ILP problem, which is solved using the ε-constraint method and the Branch & Bound approach on the optimization software tool LINGO 18.0. Furthermore, a set of Pareto-optimal solutions have been generated, which showed the trade-off between the objectives and gave important insights. In fact, computational results showed that all solutions in the Pareto front of the integrated approach strongly dominate the results obtained in the real practice of the firm. Compared to the current company-planning practice, the company could make 7.06 % as a cost saving and 43.92 % as a gain in the customer's satisfaction level over the present practice.

From a managerial point of view, our goal is to develop a decision support tool for managers to guarantee the efficiency of their Supply Chain networks. Accordingly, the alternative of using the intermodal distribution network (Maritime / Air) ensures the satisfaction of the customers' orders on the required deadlines. Besides, decision-makers have the ability to increase production capacity by subcontracting some activities and planning more overtime production in order to improve the responsiveness and the efficiency of the Supply Chain, especially in the case of peak season.
Consequently, further studies may consider extending the scope of the production-distribution. We propose to extend the model in order to include the stages of the raw materials and distribution centers as well as considering other modes of transport such as land and rail distribution network. It would be also worth including one source of uncertainties deriving from production and distribution planning. Moreover, considering risk management in case of stochastic settings may be an attractive direction for future research.

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