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Enhancement of Textile Supply Chain Performance through Optimal Capacity Planning

Imen Safra and Kaouther Ghachem

Abstract

Manufacturing companies in the textile and apparel field face stiff competition due to the globalization of trade between suppliers, producers and customers. To meet this challenge, they need to be efficient by adopting new lean manufacturing approaches and new analysis and management tools leading to more flexible and agile production and distribution processes. For the textile and apparel industry, where products' life cycle is short due to fashion changes, a new integrated approach of production and distribution planning is needed. Based on linear programming techniques and integrating subcontracting activities, our approach takes into account the characteristics of demand, including its short life cycle, seasonality and fashion effect. For these reasons, a sequential approach is adopted, combining tactical and operational decision levels for production and distribution activities, in order to satisfy customer needs at lower cost by reacting quickly to changes and delivering on time. The deployed approach is structured according to the DMAIC lean tool. Validated on real instances, this approach proves its efficiency by achieving cost reduction when internal production capacity is adequately and efficiently planned.

Keywords: DMAIC lean tool, production-distribution planning, tactical and operational planning, Linear programming, textile and apparel case study

1. Introduction

The success of textile and apparel companies depends largely on supply chain management, which ensures the smooth flow of products to different markets and their availability to customers on time and at the lowest cost. However, this task has become increasingly complex with the expansion of supply chain actors that must be coordinated to ensure a final offer to customers at the desired time and place. There is therefore a need to improve the performance of the supply chain and optimize its management, which requires the simultaneous planning, coordination and management of production and distribution activities to ensure that customer demands are met in a cost effective manner by ensuring the delivery of products on time and at the required location. In this context, lean tools and approaches contribute to the development of the supply chain decision-making process in order to achieve better performance of textile and apparel companies in today's complicated world. That is why, in this chapter, we consider the DMAIC lean approach and we

focus on the integration of production and distribution operations managed by a textile and apparel supply chain manufacturer.

Our choice of the textile and apparel sector corresponds well to the problematic we are studying of a production chain with multiple actors geographically spread all over the world. The activities of these actors must be optimized in order to determine the adequate offer of each unit of the production chain. Moreover, the nature of the textile product, which is not a homogeneous good but highly diversified, short-lived and subject to the effects of fashion as described in the bibliographical references [1–7]. For these products, we distinguish two types of orders: (1) pre-season orders (PO) that include products for the next season with a medium delivery time and (2) replenishment orders (RO) that include products for the current demand season with a short delivery time. In addition, the textile and apparel industry is highly competitive worldwide and is rapidly changing due to the complexity of demand, which is subject to the effects of fashion and marketing. This results in changes on the supply side, with some businesses disappearing and others expanding depending on the degree of rapid reaction to demand and customer tastes, as an inadequate response to demand can result in unsold inventory and lost sales opportunities.

We considered in this work a planning approach integrating tactical and operational decision levels and taking into account textile and apparel industry specificities. Using a rolling horizon, the proposed approach identifies the quantities to be produced, stored and delivered while minimizing the total cost of production and distribution. Production flexibility is ensured by the consideration of low-cost overseas subcontractors to whom standard products with predictable demand can be assigned. Local subcontracting and overtime are short-term solutions to deal with the unpredictability of demand related to ROs at the operational level. This work is structured according to the DMAIC approach and will be detailed accordingly while defining the specifics of each phase.

2. Phase “define”

As detailed by [8], the ‘define’ phase of the DMAIC methodology presents a definition of the problem and what the customer requires. Hence, it is the backbone of a successful project. The define phase starts with clarifying the problem statement and analyzing the customer requirements and ensures that the project goals are aligned to these requirements.

2.1 The problem statement

Facing a worrying decline in market share for textile-apparel manufacturers in the context of the competitive battle, these manufacturers must act by creating new offers combining low prices, reduced lead times and improved services. This can be ensured by carrying out adequate resource planning at different levels of decision making and coordinating activities associated with the various stakeholders in the chain. Moreover, in regard to more selective consumer behavior, the emergence of customized products with short life cycles and taking into account the different types of orders, manufacturers must satisfy customers by being reactive, fast and more and more flexible while offering a better quality, price and lead time performance. In this context, a coordinated control of flows between suppliers, producers and customers can only lead to a fast, personalized and optimal response, in accordance with the expectations of end consumers. Traditionally, the various supply chain actors manage their resources independently, and the planning and

management of production and distribution resources is done with little or no coordination. This decentralized management can lead to additional costs due to the placement of unexpected and urgent orders at subcontractors' units or by scheduling costly overtime. On the other hand, additional delays may be caused by re-planned resources and the delayed arrival of a few productions due to the arrival of these urgent orders to be placed as soon as possible. Similarly, large inventories and long product cycles may occur as soon as the producer opts for large production quantities to anticipate demand for the entire season, not to mention the risk of increasing unsold stock.

Our work focuses on a global approach that integrates production and distribution activities. The related literature review is presented by [9–13]. In this work, we are interested in addressing the problem of production-distribution coordination applied to the textile and apparel field. A presentation of the different types of coordination at the supply chain level and a review of the literature dealing with this aspect are detailed by [14, 15].

Indeed, most studies on integrated production and distribution have focused on products for which demand is stable because they have a long-life cycle [16, 17]. But this is not the case for apparel products that have a short life cycle and whose demand can only be accurately estimated once the product is on the shelf once the season has started. Similarly, few production planning models have taken into account the flexibility of production capacities. However, our models provide this flexibility through outsourcing and overtime [18, 19]. Therefore, it is necessary to adapt production and distribution planning models to the reality of textile and apparel supply chains in order to optimize them, taking into account the unpredictable and unforeseen aspect of demand while aiming to reduce production and distribution lead times to better match production to demand. In this way, production can be flexible and can be adapted to market needs. Thus, it is necessary to define production and distribution planning models that take into account the specificity of the apparel supply chain. The objective of this study is to start filling this gap.

It applies to the case of a large Tunisian textile company (see **Figure 1**) that owns several units of apparel production and two warehouses located in Tunisia. It may also use outsourcing with local or overseas subcontractors in China to meet part of its demand. The company adopts a business model of delivery commitment. It commits to a delivery date for any order received and is responsible for shipping costs. Finished products are stored in warehouses until they are delivered on time to customers. The transportation modes used are trucks, ships and airplanes. The transportation cost includes fixed and variable fees. Each product has a production set-up cost and a variable cost.

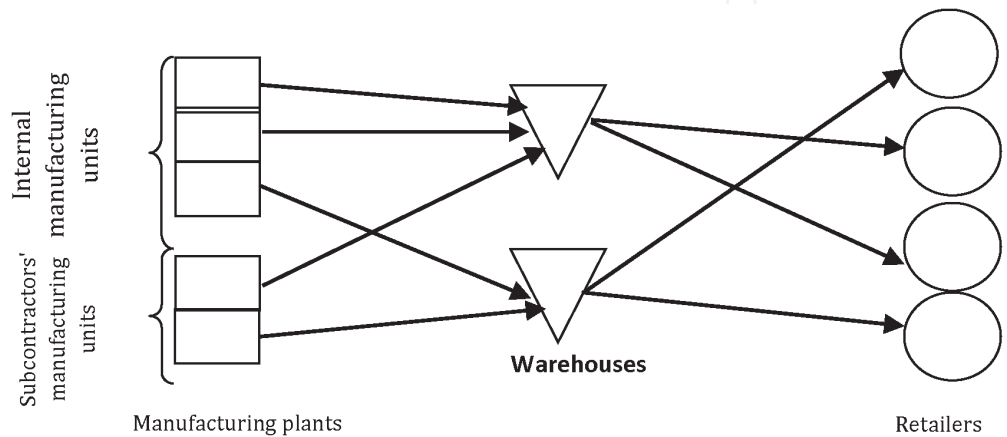


Figure 1.
The textile and apparel supply chain.

Received orders, over a season, cover a large number of product references. The number of product groups exceeds 100. The company receives two types of orders from local and overseas retailers: POs and ROs. POs, which have a lead time of several months, are planned and scheduled to satisfy the following season’s collections. However, urgent ROs, which have shorter delivery times, must be produced to fill retailer shortages or to replace unsold inventory. Due to changing fashion trends and the short life cycles of textile and apparel products, historical data alone cannot accurately predict next season sales [20]. Moreover, it is very difficult to forecast specific customer needs for apparel products, leading retailers to use in-season replenishment after revising their forecasts based on demand observed in the first few weeks of the current season. Therefore, it is a periodic process of adjusting retailers’ sales forecasts for different products taking into account new information from recent sales.

2.2 Challenges of the proposed planning approach

As detailed in **Figure 2**, the proposed approach is based on an integrated production-distribution planning at two decision levels while considering the specificities of the apparel supply chain. Thus, the approach involves decisions at the tactical and operational level and takes into consideration both POs and ROs. Also, the approach considers flexibility of production capacity to ensure a better match between supply and demand. We consider at the level of operational planning overtime and subcontracting activities to accommodate the internal capacity shortage caused by fluctuations of demand and short lead time of customer orders. The main goal of the current study is to reduce overall supply chain costs by approximately 10%.

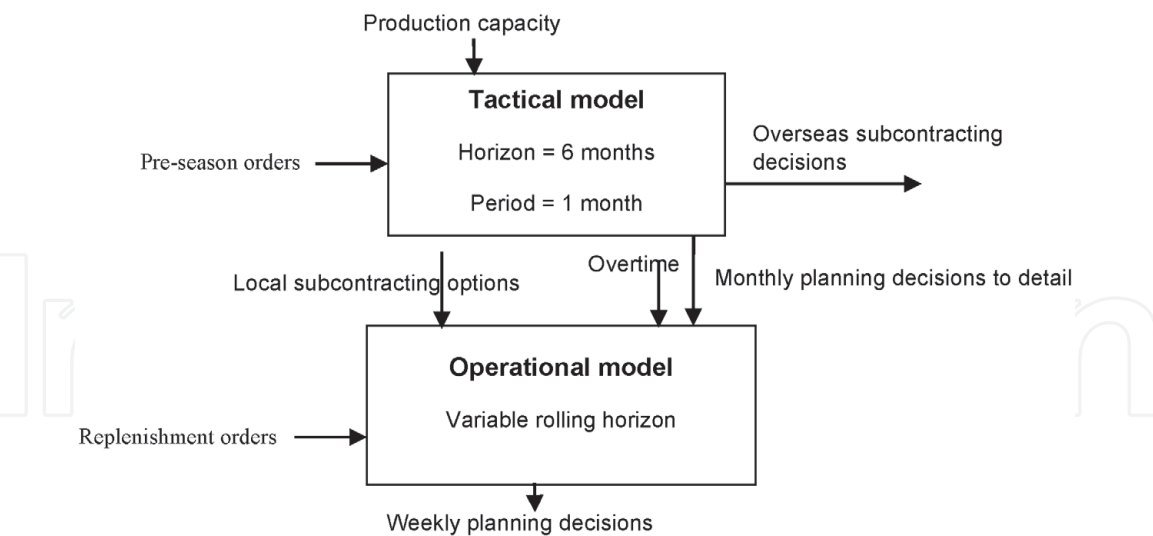


Figure 2.
Hierarchical planning approach.

2.3 The process definition

The definition of the high-level process map gives the team an eye of bird’s view about the project. One of the most used high-level map is the SIPOC which details the Supplier, Input, Process, Output and Customers. By completing the SIPOC, the detailed map (Swimlane Map) can be developed after a series of Gemba walk and several discussions with the teamwork.

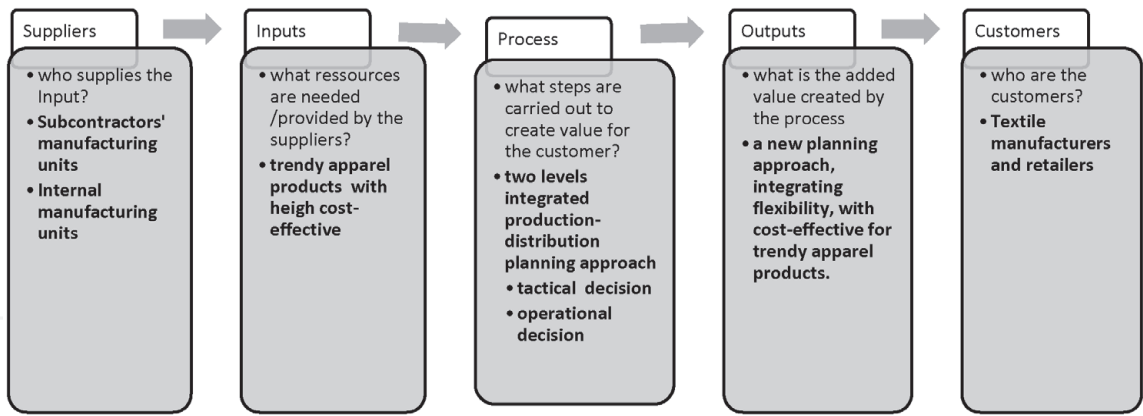


Figure 3.
SIPOC diagram.

The process definition of the SIPOC diagram, as detailed in **Figure 3**, ties the different steps of the new proposal solution to create the added value. In the current case, a new approach based on two level integrated production-distribution plan and composed of two level of strategies (tactic and operational) is developed. Knowing that textile and apparel manufacturers are currently dealing with unpredictable and short-term ROs when production for the next season is already ongoing. The company uses two types of sub-contractors: - overseas specialized subcontractors who offer products at very low prices but with long delivery times, and - local capacity subcontractors that the company uses in case of production saturation but who offer prices 20% higher than the internal production costs. In addition to this flexibility provided by subcontracting, the company can resort to overtime with higher costs than production in regular hours.

3. Phase “measure”

In this section, we will define the current state in order to analyze it and to identify the gap between the actual and the desired situations. To do this, we will structure this part in three phases. First of all, we will detail the developed measurement system. Then, we will detail our data collection plan and our experimental data. Finally, we will identify our desired situation and the gap with the current one.

3.1 The measurement system analysis

3.1.1 Approach description

Our measurement system aims to define our sequential production and distribution planning approach while evaluating the current situation of the company. The objective is to satisfy POs and ROs within the required deadlines, while minimizing the production, subcontracting, capacity under-utilization, storage and distribution costs.

Our approach is based on two mathematical models that are developed at two different decision levels [21, 22]. The first model focuses on a tactical level of a 6-month horizon with a monthly periodicity and decides on pre-season quantities to be placed internally and with overseas subcontractors with long lead times. Each

time a new order arrives, it is inserted with a rolling horizon in order to be placed optimally on the available resources.

The second operational model considers a monthly horizon with a variable periodicity between 8 and 11 weeks. This model is used to detail tactical confirmed quantities over weeks and to insert new urgent orders arriving through a rolling horizon.

At the operational level, urgent orders with short lead times are inserted progressively. However, when a new order with a long lead time for the pre-season arrives, the tactical model is run and the order is inserted on the rolling horizon to study the possibility of subcontracting it to overseas subcontractors. Thereafter, the production will be refined over weeks using the operational model, if the decision taken at the tactical level affects production internally. This operation is repeated until all orders for the season have been placed.

Our approach results in a production, storage and distribution plan that takes into account the assignments of overseas subcontractors and the assignments of new orders that arrive at the operational level. The latter are detailed by week during the first 2 months. Given the principle of the rolling horizon, decisions taken during the first week are fixed and the related costs are recorded. However, decisions taken in following periods will be revised once the model has been run in the second week.

3.1.2 Mathematical formulation

3.1.2.1 Tactical planning model

As detailed in appendix A, at the tactical level, the model decides on: - monthly quantities to be manufactured internally and at subcontractors, – monthly quantities to be stored, – monthly quantities to be distributed per period, taking into account the different modes of transport. The objective is to minimize the total cost of production, storage and distribution. It should be noted that for this current situation, the parameter α_{kt} considered in Eq. (3) and Eq. (6) is equal to 100%. Means that we are considering all the available production capacity at the tactical level.

3.1.2.2 Operational planning model

As shown in **Figure 4**, the operational horizon ranges from 8 to 11 weeks. The length of this horizon is defined according to the position of the first week in the month.

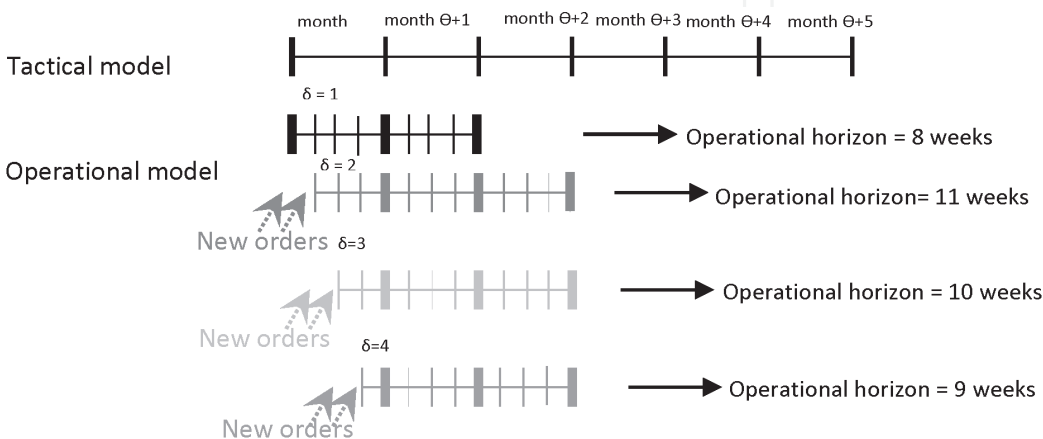


Figure 4.
Variable operational planning horizon.

For example, if the first week of the planning horizon corresponds to the second week of the month Θ , then the length of the planning horizon is set to 11 weeks because tactical decisions related to the month $\Theta + 2$ must also be taken into account.

We denote by a couple (t, s) the weeks in the operational planning model, where s is the position of the week in month t . Operational planning includes a set of periods $TS_{\Theta\delta}$ and takes place at the beginning of week δ of month Θ (as detailed in appendix B).

For the operational planning model, detailed in appendix C, the length of the planning horizon is justified by the fact that POs resulting from tactical planning should be reliably detailed at the operational level. Hence, to properly place decisions made at the tactical level, the operational planning horizon must reach the end of the month.

3.2 Data collection plan

Based on company reports translating historical data, Gemba walks and after meetings and team benchmarking, we were able to collect the necessary information to set the required parameters for the proposed models.

Before detailing experimental data, it is important to identify the established planning assumptions:

- Demand is dynamic and deterministic,
- Storage cost is defined according to the average level of storage between the beginning and the end of the period,
- Under-utilization capacity cost is estimated according to the average hourly cost of labor/machine.
- In the operational model, we consider only local subcontractors.
- Overtime is considered to allow greater flexibility when managing the unpredictability and short lead time of ROs.

3.2.1 Experimental data

The relevant company delivers about 200 references of products to 30 retailers per year through 3 knitting manufacturing plants located in Tunisia. Products are transferred to customers through two local warehouses storing finished products ordered by local and overseas retailers. These warehouses are characterized by their limited storage capacity and a storage cost of approximately 5% of the unit production cost per unit.

The shipments can be carried out by trucks, for local deliveries, or by aircraft and by ships, for overseas connections. Our mathematical models decide on the mode of transport to be adopted according to the delivery times involved. Indeed, a delay of at least 5 weeks is necessary to deliver the products by ship. However, aircraft shipments are made within the same week. The considered transportation costs are composed of fixed costs, depending on the number of shipments made, and variable costs depending on the shipped quantities.

Considering the 200 variety of manufactured products, the internal production costs vary from 3 to 35 euros. In order to accommodate the limited internal capacity, flexibility is ensured by scheduling overtime. However, overtime activity is limited to 25% of production capacity after regular working hours and costs 40% more. The internal flexibility is reinforced by a subcontracting activity with 10 local subcontractors and one overseas one located in China. The local subcontractors have

enough capacity to meet the ordered quantities and fill the limited capacity of the internal production sites. The latter offer products at prices 20% higher than the cost of internal production. As for the Chinese subcontractor, it can manufacture large volumes of products but with delivery times exceeding 2 months. The latter offers basic products at costs that are about half the internal production cost. Our planning models decide on production allocations based on available capacities and assigned lead times. The overall focus is to meet customer orders on time and at lower cost.

Our proposed approach is run over 6 months, generating a weekly production schedule identifying the quantities to be manufactured, stored and distributed. The proposed models are solved using the package ILOG OPL Studio V6.3/ Cplex 11 and are run on an intel Core i5 PC with a 2.3 Ghz processor and 512 MB of memory. The planning model at the tactical level takes into account approximately 122,000 constraints and 66,000 variables, of which more than 5,000 are binary. However, the operational model contains 55,000 constraints and 3,000 binary variables among the 25,000 considered variables in the model. An almost optimal solution, with a deviation of 10^{-4} from optimality, is obtained for all the executed models.

3.3 Current situation and the gap with the desired one

Our approach evaluates the current situation of the apparel manufacturer who incurs a logistic cost equal to 2864 k€ obtained for the 6 months.

In order to improve the situation, we aim at considering additional flexibility at the tactical planning level in order to better accommodate the unpredictable orders that will be placed at the operational level. A decrease of the overall logistic cost is expected.

4. Phase “analyze”

At the end of the six-month simulations, we obtain a weekly production, storage and distribution schedule for the various products, taking into account the tactical model’s assignments and the unforeseen and urgent demands that arrive at the operational level. The cumulative costs obtained for the first few weeks of the operational model applied on a rolling horizon, added to the tactical cost of production at overseas’ subcontractor, obtained by the tactical model, represent the total cost of production, storage and distribution for the six months. This cost, as reported in **Table 1**, is evaluated to 2 864 K€.

Period	Cost (K€)	Period	Cost (K€)	Period	Cost (K€)
Overseas sub Mars	320	May S 1	92	July S 1	86
March S 1	79	May S 2	69	July S 2	90
March S 2	99	May S 3	93	July S 3	105
March S 3	84	May S 4	92	July S 4	91
March S 4	98	Overseas sub June	223	August S 1	113
April S 1	83	June S 1	83	August S 2	106
April S 2	83	June S 2	90	August S 3	93
April S 3	87	June S 3	89	August S 4	108
April S 4	76	June S 4	218	Total cost	2864

Table 1.
Weekly logistics costs.

	Quantities	%
Internal manufacturer's production	259359	90,5
Internal overtime production	1833	0,6
Subcontractor's production	25507	8,9
Total produced quantities	286699	100,0

Table 2.
Production assignment

Weekly costs represent the sum of production costs in regular hours, overtime and at local subcontractors added to the costs of storage, underutilization of internal production capacity and product deliveries.

Obtained results for the current situation show that production is mainly affected to Internal manufacturing units 90.5%. However, 8.9% are affected to overseas subcontractors as shown in **Table 2**.

Based on these obtained results, we notice, on one hand, a production allocation that leads to an overload of internal production capacity and costly overtime. On the other hand, some productions get started in overtime, especially when the internal production capacity over regular hours is partially used. This is mainly due to the due dates position of the POs through the month. Indeed, since the productions planned in the internal units over a month are detailed at the operational level by week, it seems mandatory in some cases to massively produce during the first weeks of the month to meet the predefined delivery dates. Consequently, it is necessary to produce in overtime some products that the production capacity during regular hours cannot meet. Meanwhile, for the remaining weeks of the month, the capacity of the internal production is under-utilized. In this case, the ROs, which arrive at an operational level, are assigned to the subcontractors since the internal capacity of production is fully used by the production of the pre-season items decided at the tactical level.

This obtained cost seems to be too high because decisions at the tactical level are made without taking into account what may arrive at the operational level as urgent and unforeseen ROs. This cost can be improved to be more competitive in the market through greater flexibility at a tactical level. This flexibility could positively affect the allocation of orders that arrive at an operational level.

To analyze the current situation of the textile and apparel supply chain and try to identify the root causes of the performance decrease in this field, we establish the following Ishikawa diagram shown in **Figure 5**.

Based on this analysis, we confirm that it is necessary to reduce lead times through better resource management and better planning that will reduce the operational workload on operators. Taking into account the specificities of this sector and the requirements imposed by markets and customers, it is essential to adjust to needs, as soon as they are presented, through a better flexibility of resources at a tactical level.

The 5 P tool (**Figure 6**) is also used to identify the root cause of the problem so that the required actions can be taken to improve performance.

It is quite clear now that the solution is to provide some flexibility at the tactical planning and not to allocate rigidly anticipated productions without allowing sufficient flexibility to place the orders that arrive at the operational level.

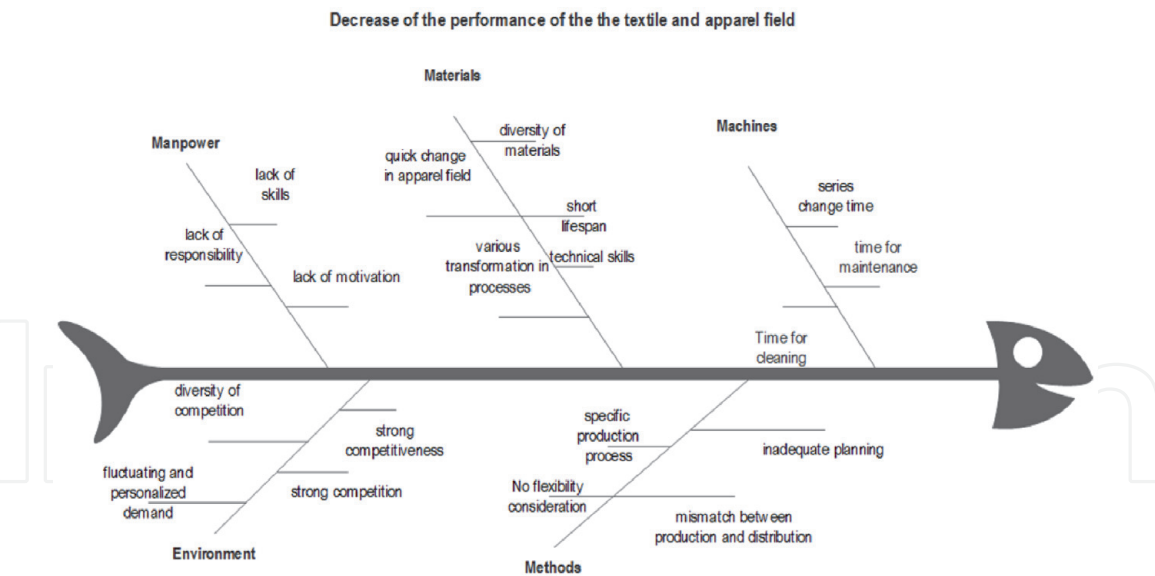


Figure 5.
Ishikawa diagram.



Figure 6.
5P tool.

5. Phase “improve”

To solve the root cause, at this phase, we have to introduce more flexibility at the tactical level by considering only a percentage of the production capacity. The other part of the production capacity is considered as reserve capacity. Thus, it can be used only at the operational level to efficiently meet RO with short due dates without disrupting the ongoing production. During this study, we need to achieve

one main objective: how to satisfy the retailers' pre-season in addition to the ROs that must be in time. This objective will be reached by minimizing the internal capacity underutilization, storage, distribution operation and also the overall supply chain cost incurred by internal production, subcontracting.

The availability of products based on ROs during the season is risky for the retailer since it largely depends on the flexibility, responsiveness and efficiency of the suppliers involved. Therefore, to meet retailer orders and ensure deliveries on-time, production flexibility becomes crucial and a key competitive issue for any textile or apparel manufacturing company.

At the tactical model a reserve production capacity (RPC) is considered. We denote the percentage of internal production capacity that can be used to fulfill POs by α . α_{kt} is the reserve related to an internal site k over a period t . As it can be noted, $(100 - \alpha_{kt})$ represents the percentage of internal capacity reserved to fulfill in-season ROs.

Meaning that the parameter α_{kt} considered in Eqs. (3) and (6) is less than 100%.

At the operational level, the RPC considered at the tactical level is released and the entire internal capacity can be used in addition to overtime. This will provide more flexibility to accommodate unforeseen and urgent ROs.

Let us now consider the operational level, the RPC considered at the tactical level is released. In addition, all internal capacity can be used to overtime. This will result in greater flexibility to respond to unexpected and urgent ROs.

5.1 The reserve production capacity estimation

The impact of considering the RPC at the tactical planning level on supply chain costs is investigated. During this experimentation, the same value for this RPC for all internal manufacturing units is used. Firstly, for each month of the six-month tactical planning horizon, a fixed RPC is considered. The percentage of the available internal production capacity for PO planning is therefore a fixed value (α). Secondly, a RPC with monthly variation is considered. The percentage of internal generation capacity at the tactical planning model level is therefore a value that varies monthly and is noted (α_t), with t indexed to the month.

The RPC needs to be estimated. Afterwards, the available two-years historical demand data is used to estimate the RPC ($1-\alpha$ or $1-\alpha_t$). Thus, it is obtained by calculating the ratio: reserve production/total internal production during regular hours. The resulting internal production capacity rates are shown in Table 3.

Month →	M1	M2	M3	M4	M5	M6	Average
Rate year N-2 (%)	62	90	89	71	61	76	75
Rate year N-1 (%)	75	91	72	91	87	95	85
Average rate	69	91	81	81	74	85	80

Table 3.
Observed internal production capacity rates used based on 2-year historical demand data

Hereinafter, different values of the RPC are tested. The objective is twofold. The first one is to underline the importance of integrating RPC into tactical planning to improve flexibility. The second one is to emphasize the need to develop adequate methods based on historical demand data and can provide an efficient estimation of the RPC.

5.2 Production and distribution planning using a fixed reserve production capacity

Different values of α are tested. These values vary from 70% to 100% with a difference of 5% between two consecutive values. The curve depicting the variation

in supply chain cost as a function of α is plotted in **Figure 7**. The curve is characterized by an almost convex shape. In addition, for α values equal to 70%, 75% and 100% higher costs are observed. Indeed, the reserve of 30 to 25% of production capacity for ROs leads to the allocation of many orders to subcontractors at the tactical level. Consequently, a significant underutilization of capacity is observed at the operational planning level. If no reserve capacity is being considered at the tactical planning level (which is the current practice in the company), We note that, at the operational planning level, many ROs are assigned to subcontractors or produced during overtime as internal production capacity is used during regular working hours to accommodate POs.

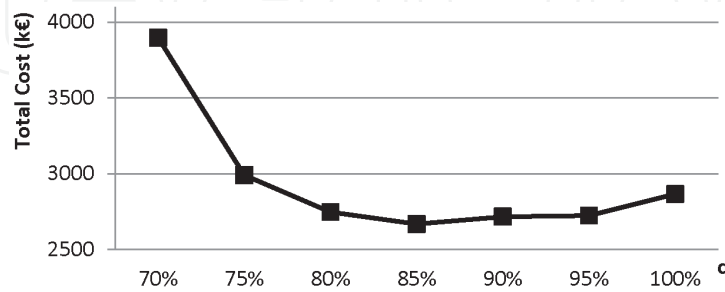


Figure 7.
Supply chain cost variation with α .

Note that in the considered real case study, the optimal supply chain cost is reached at a value α around 85%. Hence, a RPC of about 15% ensures a production flexibility that minimizes the cost of the supply chain. The average value obtained from the historical database (presented in **Table 3**) is equal to $\alpha = 80\%$. The cost of the corresponding supply chain is equal to 2,746 k€. This translates into a saving of 4% compared to current practice ($\alpha = 100\%$). When the proposed planning approach is used with α equal to 85%, the cost saving over current practice is equal to 7%.

5.3 Production and distribution planning with a variable monthly reserve production capacity

In this section, it is proposed to evaluate the monthly variable RPC. For each month t of year N , we take for each year $N - 1$ and $N - 2$ the average of the percentage of internal production capacity used as the value of α_t (represented in **Table 3**). A supply chain cost equal to 2575 k€ is obtained by introducing the values of α_t into the tactical planning model and sequentially applying the tactical and operational models. The cost of the supply chain is, as observed, less than that obtained when considering a fixed RPC equal to 20%. This method used to estimate the RPC leads to a 6% cost reduction compared to the previously used method. Furthermore, there is a saving of 10% compared to current practice (**Figure 8**).

This cost saving resulted from allocating six months of production to internal manufacturing units and subcontractors, as illustrated in **Figure 9**.

Firstly, when considering a monthly variable RPC at the tactical level, there is a better use of internal production capacity. Second, we find that some production is performed during overtime when the internal production capacity is not fully used during regular hours.

The reason for this can be explained by the position of PO due dates within the month. Since production in the internal manufacturing units over 1 month from tactical planning is detailed per week at the operational level, massive production in the first weeks of the month is sometimes necessary to meet the delivery due dates.

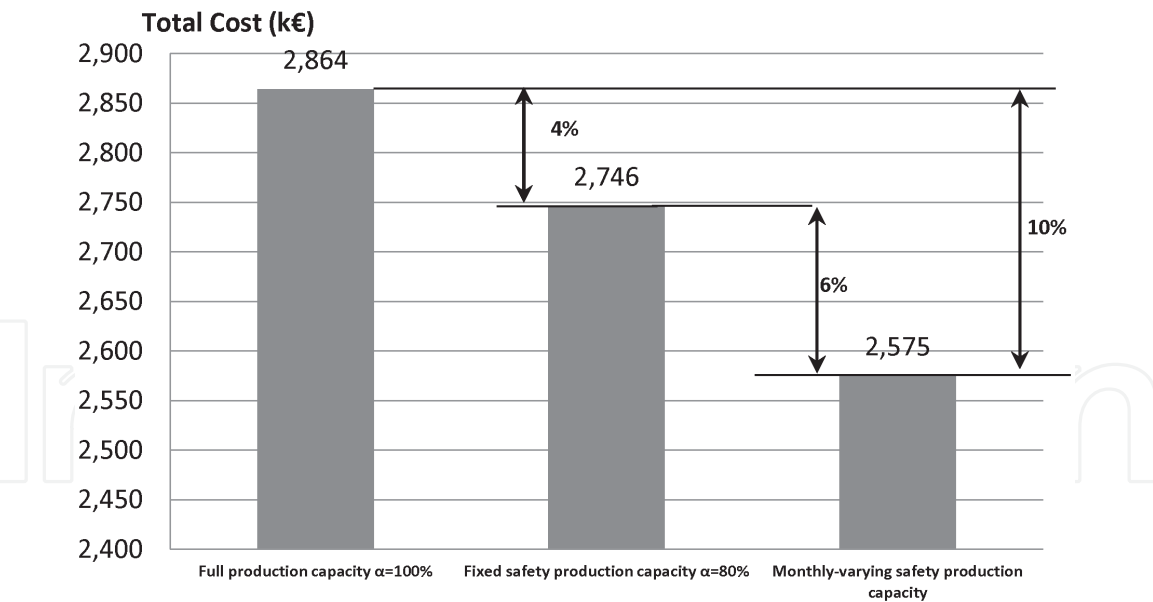


Figure 8.
Supply chain cost comparison.

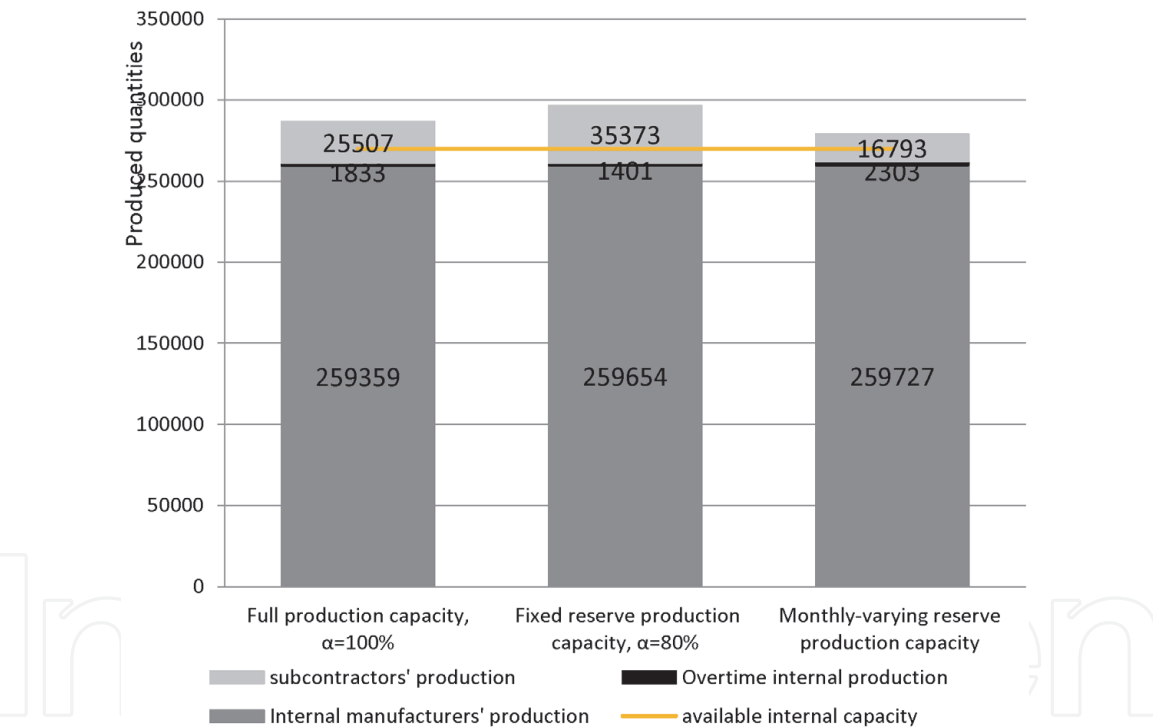


Figure 9.
Production assignment.

As a result, overtime is needed as production during regular hours cannot reach the requested quantities. Internal production capacity for the remaining weeks of the month may be underused.

When we consider a fixed RPC (for $\alpha = 80\%$ and $\alpha = 100\%$), the quantities produced at subcontractors' manufacturing units are bigger than those performed when a variable monthly RPC is considered. Consequently, the allocation of production to subcontractors is better optimized for a monthly variable RPC.

Considering this result, we emphasize the importance of the monthly variable RPC. This reserve is adjusted to ROs by assigning, at the tactical level, some productions to subcontractors while maintaining sufficient and accurate internal production capacity at the operational level to appropriately handle ROs.

However, the quantities produced in the subcontractors’ manufacturing units are particularly high when we consider, at the tactical level, a fixed α , equal to 80%.

Meanwhile, the total produced quantities over the 6 months are higher than those produced when considering α equal to 100%, or a monthly variable RPC. This is due to the demand monthly variation. Actually, when we consider a fixed α equal to 80%, two situations can arise. Firstly, the ROs to be satisfied during the month require more than the available capacity and consequently more than the RPC considered. In such a case, the subcontracting activity is the main solution. Second, ROs to be placed during the month require less than the available capacity and so less RPC. Therefore, ROs to be filled for next few weeks are processed in advance to minimize capacity under-utilization. When α is equal to 100%, ROs are assigned to subcontractors since internal production capacity is overloaded by POs.

As conclusion, the use of a variable RPC at the tactical level, allows efficient use of internal production capacity and optimizes the allocation of production to subcontractors. Nevertheless, the performance of capacity planning can be improved if more accurate and reliable historical demand data is used and if forecasting methods for predicting the monthly variable RPC are carried out.

By studying the three cases mentioned above, we underline the important effect of taking into account a suitably defined RPC on the supply chain cost.

6. Phase “control”

Due to intense competition, variable economic and environmental conditions, changing wage rates and fluctuating oil prices, the control phase of the DMAIC methodology will be focused on establishing the changes and standardizing the results given in the previous phases. Consequently, sensitivity analysis is chosen to assess the effect of changes in demand and variations in subcontracting and transportation costs on the supply chain cost. Three parameters are examined in this sensitivity analysis: demand, transportation cost and subcontracting cost to assess their impact on planning decisions and supply chain performance.

During our experimentation, fifteen scenarios are considered by varying (1) the demand, (2) the cost of transport and (3) the cost of subcontracting between –50% to +50% of their current values. By considering the three scenarios ($\alpha = 100\%$, monthly fixed α , monthly varying α), the cost of the supply chain is calculated for each case.

6.1 Sensitivity analysis of demand

A 50% increase in demand leads to an increase in supply chain costs, as explained in **Table 4**. Nevertheless, if we consider a RPC, a decrease in this total cost is recorded. For all considered scenarios, the best cost is obtained when a monthly variable RPC is considered.

	D–50%	D–20%	D	D+20%	D+50%
$\alpha = 100\%$ (k€)	1658	2152	2864	3285	3794
$\alpha = 80\%$ (k€)	1632	2020	2669	3067	3581
α variable (k€)	1596	1981	2575	2972	3389

Table 4.
Cost variation according to demand

These results confirm the importance of our approach and encourage the idea of using RPC to reduce supply chain costs. We note a saving of 4% compared to current practice when demand is reduced by half. This proves that the use of a monthly variable RPC yields better results. If demand is increased by half, the gain is 11%. The proposed approach becomes essential when demand is relatively high. If demand is low, the internal capacity will accommodate the demand without any additional costs. As a result, the RPC becomes less important and will avoid situations of under capacity due to urgent orders arriving at the operational level.

6.2 Sensitivity analysis of transportation and subcontracting costs

Identical trends are observed in transport and subcontracting costs savings are also obtained when we consider a RPC at the tactical planning level (**Figure 10**). It is worth noting that the greatest savings are achieved when considering a monthly variable RPC. Moreover, savings become more important with increases in these two costs. Lower transportation costs lead to the outsourcing of some internal production to overseas subcontractor's manufacturing unit, as the latter offers very competitive prices, especially for most basic products. Subsequently, at the tactical planning level, some internal production capacity is unused; therefore, enforcing a RPC is meaningless. For this reason, the lowest savings are observed when transport costs are halved. Nevertheless, outsourcing abroad is no longer the preferred option when transport costs increase. This promotes the use of a RPC to avoid the use of full production capacity at the tactical level. Internal production (regular and over-time) and locally subcontracting are the adequate options to cover capacity requirements.

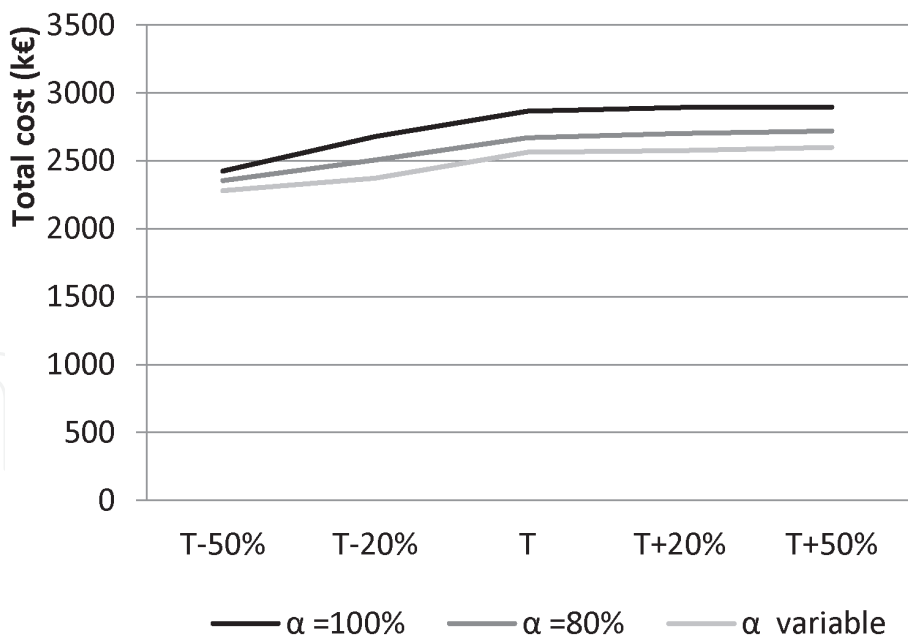


Figure 10.
Transportation cost variation.

When the cost of subcontracting is reduced by half, this activity is more profitable than the internal production. In this case, part of the internal production is manufactured at local subcontractors. In addition, the under-utilization cost prevents the full transfer of quantities to local subcontractors' plants. Internal production capacity is currently under-utilized; however, this situation results in lower supply chain costs due to lower production costs. In this case, the consideration of a RPC is no longer significant.

Nevertheless, increased supply chain costs are noted when the cost of subcontracting increases, especially for $\alpha = 100\%$ (current situation). In practice, subcontracting is prevented until internal production capacity is completely used; thus leading to local subcontracting at higher costs (**Figure 11**). In these situations, reserve capacity appears to be a substantial consideration in ensuring the use of foreign subcontracting (which is cheaper than local subcontracting) at the tactical level. If the cost of subcontracting is increased by half, taking into account a RPC that varies on a monthly basis makes it possible to achieve a cost savings of 11% regards current practice.

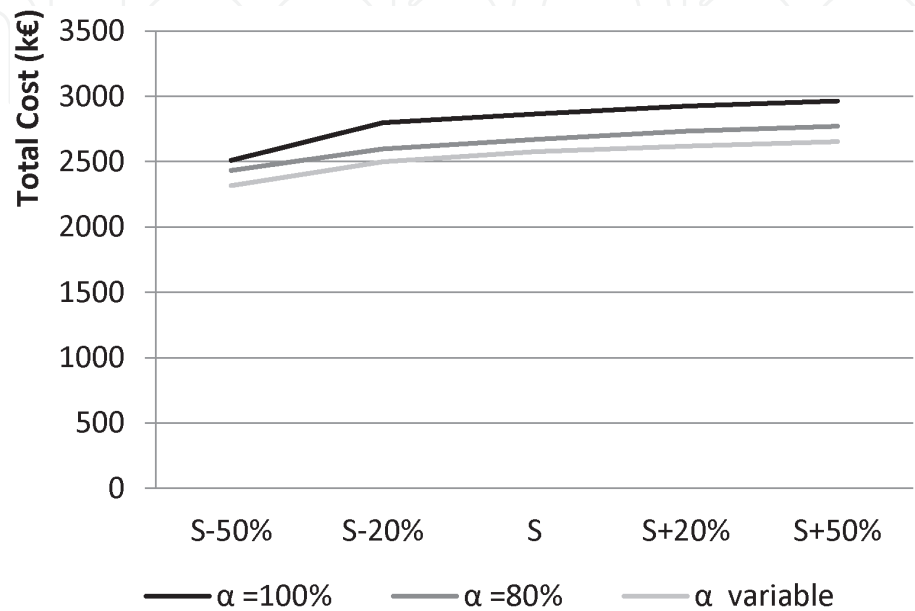


Figure 11.
Subcontracting cost variation.

The sensitivity analysis confirms the interest of our approach taking into account a RPC. Indeed, when demand or transportation or subcontracting costs increase, our approach allows us to adequately place urgent and unpredictable orders that arrive at the operational level at the lowest cost.

This approach provides a decision tool for textile and apparel manufacturers who are constantly faced with two types of orders: long lead time orders dedicated for the next season and urgent and unpredictable orders that are related to the current season. Moreover, this approach is applied to any type of industry where there are two types of customers: - premium customers with short lead time orders, - classic customers with long lead time orders. Indeed, through flexibility and responsiveness to needs, our approach will be able to place orders in the right location and at the lowest cost, taking into consideration a RPC and a rolling horizon. This will guarantee customer satisfaction that will gain in competitiveness, on both cost and lead time aspects, in today's highly competitive environment.

Furthermore, taking into account the type of information introduced, the performance of the supply chain can be improved. The more reliable this information is, the better the performance. Indeed, it is important for the customer to share his sales information with the producer so that the latter can prepare in advance, using adequate forecasting methods, to best accommodate these orders. In this case, the estimate of the RPC can be adjusted for more reliability and flexibility in order to forecast future orders that may come in. This is one of the perspectives and ideas to be explored for this work.

7. Conclusions

In this chapter, the DMAIC methodology was chosen and applied to perform a complicated problem of a textile company. Our aim is to satisfy customer needs at lower cost while ensuring prompt and punctual deliveries. To achieve this, a sequential approach integrating tactical and operational decisions for textile and apparel supply chain planning has been implemented with an emphasis on the flexibility provided by the consideration of RPC at the tactical level. As a result, newly arrived urgent orders, with short lead times, can be placed optimally at production sites, via the rolling horizon.

During the definition phase of the DMAIC methodology, we have defined the problem statement and presented the proposed planning approach. Then, we established the SIPOC diagram in order to identify the different steps of our approach which ensures flexibility of production and distribution activities' planning considering textile and apparel sector specificities: fashion effect, demand fluctuations.

In the first step, we have detailed our measurement system analysis by introducing the two mathematical models used to evaluate the performance of the current situation of the apparel company, taking into account the full available production capacity. Next, we presented our data collection plan by describing the experimental data that were collected. Finally, we outlined the desired situation taking into account additional flexibility at the tactical level.

In the "analysis" phase, we presented the obtained results when assessing the current situation by detailing production assignments over different locations. We also performed an extended analysis using the Ishikawa diagram and the 5P tool in order to underline the interest of our approach.

During the "improve" phase, we outlined the Improvements achieved in the current situation. To do so, we started by testing different RPC values in order to identify the optimal one to be taken into account at the tactical level. Then, we evaluated the performance of our approach by considering a fixed RPC then a monthly variable one. Finally, we evaluated the efficiency of our approach to optimally respond to urgent orders arriving at the operational level. Our approach is evaluated over a six-month planning horizon, but it remains applicable over longer planning horizons.

"Control" phase is devoted to sensitivity analysis while studying the effect of some parameters' variation on the cost of the supply chain. The three considered parameters are: demand, transport cost and subcontracting cost. The main focus of this section is to prove the interest of our approach to place, at the lowest cost, urgent orders that arrive at the operational level, even when demand and cost increase. For a better performance of the considered supply chain, the importance of cooperation between the manufacturer and the retailers, based on information sharing, was also emphasized.

Appendix A. The tactical planning model

In model formulation, we consider the following sets and indices, parameters, and decision variables.

Sets and indices:

K: set of manufacturing units $k \in K$; $K = U \cup V$.

U: set of internal manufacturing units, $k \in U$.

V: set of subcontractors' manufacturing units, $k \in V$.

I: set of retailers, $i \in I$.

J: set of warehouses, $j \in J$.

P: set of products, $p \in P$.

L: set of transportation modes, $L = \{\text{trucks, ships, aircraft}\}$, $l \in L$.

T: set of periods included in the planning horizon, $t \in [1 \dots |T|]$.

Parameters:

In the tactical model, the parameter (D_{pit}) expresses the need of retailer i , in product p , to serve during period t . During period t , the quantities to be delivered are manufactured in production sites k characterized by a limited capacity (U_{kt}). Production incurs variable and fixed production costs per product per period (C_{pkt} , S_{pkt}) or subcontracting costs (G_{pkt}). A monthly cost of under-utilization of internal production capacity (CSU_{kt}) is also considered to penalize the non-utilization of available internal resources. Each product is characterized by a production lead time (Tp_p) and a product unit volume (V_p). The quantities manufactured are then transported to warehouses and incur inventory holding costs (KP_{pjt}). The warehouses are characterized by a limited storage capacity (W_j). The delivery lead time is noted by (e_l). Each means of transport has limited capacity (Cap_l). Variable and fixed distribution costs from sites to warehouses (CT_{kjplt} , CF_{kjplt}) and from warehouses to retailers (CS_{jiplt} , CFS_{jiplt}) are also addressed.

Decision variables:

$Z1_{kjplt}$: quantity of product p to deliver, via transportation mode l , from manufacturing unit k to warehouse j over period t ,

$Z2_{jiplt}$: quantity of product p to deliver, via transportation mode l , from warehouse j to retailer i over period t ,

X_{pkt} : produced quantity, of product p , in manufacturing unit k over period t .

SU_{kt} : unused production capacity at internal manufacturing unit k over period t .

J_{pjt} : inventory level of product p in warehouse j at the end of period t .

$Y_{pkt} = 1$ if product p is produced in manufacturing unit k over period t ; 0 otherwise.

$N1_{kjlt}$: transported quantity from manufacturing unit k to warehouse j over period t by use of transportation mode l .

$N2_{jilt}$: transported quantity from warehouse j to retailer i over period t by use of transportation mode l .

Model formulation (M1)

The tactical production–distribution planning model is formulated as an ILP that aims at minimizing the overall cost in the considered supply chain network.

$$\begin{aligned} \text{Min} \left(\sum_{t \in T} \sum_{p \in P} \sum_{k \in U} C_{pkt} X_{pkt} + \sum_{t \in T} \sum_{p \in P} \sum_{k \in U} S_{pkt} Y_{pkt} + \sum_{t \in T} \sum_{p \in P} \sum_{k \in U} G_{pkt} X_{pkt} \right. \\ + \sum_{k \in U} \sum_{t \in T} CSU_{kt} SU_{kt} \sum_{j \in J} \sum_{t \in T} \sum_{p \in P} KP_{pjt} (J_{pjt-1} + J_{pjt}) / 2 \\ + \sum_{t \in T} \sum_{p \in P} \sum_{k \in K} \sum_{l \in L} \sum_{j \in J} CT_{kjplt} * V_p * Z1_{kjplt} + \sum_{t \in T} \sum_{p \in P} \sum_{k \in K} \sum_{l \in L} \sum_{j \in J} CS_{jiplt} * V_p * Z2_{jiplt} \\ + \sum_{t \in T} \sum_{p \in P} \sum_{k \in K} \sum_{l \in L} \sum_{j \in J} CF_{kjplt} * V_p * Z2_{jiplt} + \sum_{t \in T} \sum_{p \in P} \sum_{k \in K} \sum_{l \in L} \sum_{j \in J} CF_{kjplt} * N1_{kjlt} \\ \left. + \sum_{t \in T} \sum_{p \in P} \sum_{k \in K} \sum_{l \in L} \sum_{j \in J} CFS_{jilt} * N2_{jilt} \right) \end{aligned}$$

Subject to

$$J_{pjt} = J_{pjt-1} + \sum_{l \in L} \sum_{k \in K} Z1_{kjplt-e_l} - \sum_{l \in L} \sum_{k \in K} Z2_{kjplt}, j \in J; p \in P; t \in T \text{ and } t \geq e_l \quad (1)$$

$$\sum_{p \in P} J_{pjt} \leq W_j, j \in J \text{ and } t \in T \quad (2)$$

$$\sum_{p \in P} Tp_p * X_{PKT} \leq \alpha_{kt} * V_{kt}, k \in K \text{ and } t \in T \quad (3)$$

$$X_{pkt} \leq M * Y_{pkt}, k \in K, p \in P \text{ and } t \in T \tag{4}$$

$$Y_{pkt} \leq X_{pkt}, k \in V, p \in P \text{ and } t \in T \tag{5}$$

$$SV_{kt} \geq \alpha_{kt} * V_{kt} - \sum_{p \in P} T_{p_p} * X_{pkt}, k \in K \text{ and } t \in T \tag{6}$$

$$X_{pkt} = \sum_{j \in J} \sum_{l \in L} Z1_{kjplt}, k \in K \text{ and } t \in T \tag{7}$$

$$D_{pit} = \sum_{j \in J} \sum_{l \in L} Z2_{jiplt-e_l}, i \in I, p \in P, t \in T, t \geq e_l \tag{8}$$

$$\sum_p V_p * Z2_{jiplt} \leq N2_{jilt} * Cap_l, j \in J, i \in I, l \in L \text{ and } t \in T \tag{9}$$

$$\sum_p V_p * Z1_{kjplt} \leq N1_{kjlt} * Cap_l, j \in J, k \in K, l \in L \text{ and } t \in T \tag{10}$$

$$Y_{pkt} \in \{0, 1\} k \in K, p \in P \text{ and } t \in T \tag{11}$$

$$Z1_{kjplt} \in \mathbb{N}, Z2_{jiplt} \in \mathbb{N}, X_{pkt} \in \mathbb{N}, J_{pjt} \in \mathbb{N}, N1_{kjplt} \in \mathbb{N}, \\ N2_{jiplt} \in \mathbb{N}, SV_{kt} \in \mathbb{N} \quad k \in K, j \in J, p \in P, t \in T, l \in L \text{ and } i \in I \tag{12}$$

The objective function aims at minimizing the total cost composed of set-up cost, variable production cost, subcontracting cost, internal capacity underutilization cost, inventory holding cost, transportation costs from manufacturing units to warehouses and transportation cost from warehouses to retailers. Transportation costs are composed of variable and fixed costs. The first, depends on quantity to deliver using transportation mode. While the second is proportional to the number of shipments.

The constraints (1) determine the stock level of product p in warehouse j at the end of period t. Constraints (2) guarantee that over each period, the total stored quantity is limited by the storage capacity. Constraints (3) ensure that the produced quantities do not exceed production capacity. Constraints (4) and (5) establish the relationship between binary and integer variables. Constraints (6) with the objective function identify the underutilized internal production capacity. Constraints (7) guarantee the delivery of all produced quantities to warehouses. Constraints (8) ensure that delivered products from warehouses to retailers meet on time demand. Constraints (9) and (10) guarantee the respect of transportation capacity. Constraints (11) and (12) are integrity constraints.

B. The set of periods in the operational planning model

The set of periods in the operational planning model used at week δ of month Θ is presented at the table below. For example, to construct an operational planning at the beginning of the second week ($\delta = 2$) of month Θ , the periods involved are $(\Theta, 2)$, $(\Theta, 3)$, $(\Theta, 4)$, $(\Theta + 1, 1)$, $(\Theta + 1, 2)$, $(\Theta + 1, 3)$, $(\Theta + 1, 4)$, $(\Theta + 2, 1)$, $(\Theta + 2, 2)$, $(\Theta + 2, 3)$, and $(\Theta + 2, 4)$ and they are listed in the third column of table below ($TS_{\Theta\delta}$).

Set of periods in the operational planning model used at week δ of month Θ .

	$\delta = 1$	$\delta = 2$	$\delta = 3$	$\delta = 4$
$(t, s) \in \mathcal{M}$	$(\Theta, 1)$ $(\Theta, 2)$ $(\Theta, 3)$ $(\Theta, 4)$	$(\Theta, 2)$ $(\Theta, 3)$ $(\Theta, 4)$ $(\Theta + 1, 1)$	$(\Theta, 3)$ $(\Theta, 4)$ $(\Theta + 1, 1)$ $(\Theta + 1, 2)$	$(\Theta, 4)$ $(\Theta + 1, 1)$ $(\Theta + 1, 2)$ $(\Theta + 1, 3)$
$TS_{\Theta\delta}$				

$\delta = 1$	$\delta = 2$	$\delta = 3$	$\delta = 4$
$(\Theta + 1,1)$	$(\Theta + 1,2)$	$(\Theta + 1,3)$	$(\Theta + 1,4)$
$(\Theta + 1,2)$	$(\Theta + 1,3)$	$(\Theta + 1,4)$	$(\Theta + 2,1)$
$(\Theta + 1,3)$	$(\Theta + 1,4)$	$(\Theta + 2,1)$	$(\Theta + 2,2)$
$(\Theta + 1,4)$	$(\Theta + 2,1)$	$(\Theta + 2,2)$	$(\Theta + 2,3)$
	$(\Theta + 2,2)$	$(\Theta + 2,3)$	$(\Theta + 2,4)$
	$(\Theta + 2,3)$	$(\Theta + 2,4)$	
	$(\Theta + 2,4)$		

C. The operational planning model

The same predetermined parameters of the tactical model are maintained for the operational planning model except few adjustments. Since the tactical and operational models consider different periods, w has been added here to the parameters and decision variables to indicate that they are related to a one-week period. The operational planning model determines the weekly quantities to be produced, stored and delivered $(t,s) \in TS_{\Theta\delta}$. It is worth knowing that the production plans obtained from the tactical model, for month t such as $(t,s) \in TS_{\Theta\delta}$, represent inputs to be considered at the operational level and must be weekly detailed.

In addition to the notation introduced in the tactical planning model, we consider the following two parameters and two decision variables related to overtime:

Parameters:

UHW : overtime production capacity in internal manufacturing unit $k \in U$ at week s of month t with (t,s) in $TS_{\Theta\delta}$.

CHw_{pkts} : overtime production cost in internal manufacturing unit $k \in U$ at week s of month t with (t,s) in $TS_{\Theta\delta}$.

Decision variables

XHw_{pkts} : quantity of product p produced during overtime in internal manufacturing unit $k \in U$ at week s of month t with (t,s) in $TS_{\Theta\delta}$.

$YHw_{pkts} = 1$ if there is production of p during overtime in internal manufacturing unit k at week s of month t ; 0 otherwise with (t,s) in $TS_{\Theta\delta}$.

Model formulation (M2)

The main objective is to minimize the overall cost composed of: -weekly production cost, - weekly set-up cost during regular working hours and overtime, - weekly subcontracting cost, - weekly internal production capacity underutilization cost, - weekly holding inventory cost, - weekly variable and fixed transportation costs from manufacturing units to warehouses and from warehouses to retailers.

$$\begin{aligned}
\text{Min} \left(\sum_{(t,s) \in TS_{\Theta\delta}} \sum_{p \in P} \sum_{k \in V} Cw_{pkts} Xw_{pkts} + \sum_{(t,s) \in TS_{\Theta\delta}} \sum_{p \in P} \sum_{k \in V} Sw_{pkts} (Yw_{pkts} + YHw_{pkts}) \right. \\
+ \sum_{(t,s) \in TS_{\Theta\delta}} \sum_{p \in P} \sum_{k \in V} Gw_{pkts} Xw_{pkts} + \sum_{(t,s) \in TS_{\Theta\delta}} \sum_{p \in P} \sum_{k \in V} CHw_{pkts} XH_{pkts} \\
+ \sum_{(t,s) \in TS_{\Theta\delta}} \sum_{k \in V} CSVw_{kts} SVw_{kts} + \sum_{j \in J} \sum_{(t,s) \in TS_{\Theta\delta}} \sum_{p \in P} KPw_{pjts} (Jw_{pjts-1} + Jw_{pjts}) / 2 \\
+ \sum_{(t,s) \in TS_{\Theta\delta}} \sum_{p \in P} \sum_{k \in K} \sum_{l \in L} \sum_{j \in J} CTw_{kjplts} V_p Z1w_{kjplts} \\
+ \sum_{(t,s) \in TS_{\Theta\delta}} \sum_{p \in P} \sum_{i \in I} \sum_{l \in L} \sum_{j \in J} CSw_{jiplts} V_p Z2w_{jiplts} \\
+ \sum_{(t,s) \in TS_{\Theta\delta}} \sum_{p \in P} \sum_{l \in L} \sum_{k \in K} \sum_{j \in J} CFw_{kjplts} N1w_{kjplts} \\
\left. + \sum_{(t,s) \in TS_{\Theta\delta}} \sum_{l \in L} \sum_{p \in P} \sum_{i \in I} \sum_{j \in J} CFSw_{kjplts} N2w_{kjplts} \right)
\end{aligned}$$

Constraints (1), (2), and (8)–(12) of the tactical model are also included at the operational level while introducing weekly parameters and decision variables. They ensure the balance of production flows, the respect of storage capacity, the satisfaction of retailer demand, the respect of transportation capacity [(9) and (10)], and guarantee the integrity of the decision variables [(11) and (12)]. Constraints (3)–(7) are changed to incorporate full production capacity and overtime as follows:

$$\sum_{p \in P} T p_p * X H w_{p k t s} \leq V H w_{k t s}, \quad \forall \mathcal{U}; (t, s) \in T S_{\Theta \delta} \quad (13)$$

$$\sum_{p \in P} T p_p * X w_{p k t s} \leq V w_{k t s}, \quad \forall \mathcal{K}; (t, s) \in T S_{\Theta \delta} \quad (14)$$

$$X H w_{p k t s} \leq M * (Y H w_{p k t s} + Y w_{p k t s}), \quad \forall \mathcal{U}; \mu \in \mathcal{P}; (t, s) \in T S_{\Theta \delta} \quad (15)$$

$$X w_{p k t s} \leq M * (Y H w_{p k t s} + Y w_{p k t s}), \quad \forall \mathcal{K}; \mu \in \mathcal{P}; (t, s) \in T S_{\Theta \delta} \quad (16)$$

$$Y H w_{p k t s} + Y w_{p k t s} \leq 1, \quad \forall \mathcal{U}; \mu \in \mathcal{P}; (t, s) \in T S_{\Theta \delta} \quad (17)$$

$$Y H w_{p k t s} \leq X H w_{p k t s}, \quad \forall \mathcal{U}; \mu \in \mathcal{P}; (t, s) \in T S_{\Theta \delta} \quad (18)$$

$$Y w_{p k t s} \leq X w_{p k t s}, \quad \forall \mathcal{K}; \mu \in \mathcal{P}; (t, s) \in T S_{\Theta \delta} \quad (19)$$

$$S V w_{k t s} \geq V w_{k t s} - \sum_{p \in P} T p_p * X w_{p k t s}, \quad \forall \mathcal{U}; (t, s) \in T S_{\Theta \delta} \quad (20)$$

$$X H w_{p k t s} + X w_{p k t s} = \sum_{l \in L} \sum_{j \in J} Z 1 w_{k j p l t s}, \quad \forall \mathcal{K}; \mu \in \mathcal{P}; (t, s) \in T S_{\Theta \delta} \quad (21)$$

Constraints (13) and (14) guarantee the respect of the production capacity in regular working hours and on overtime. Constraints (15), (17) and (18) ensure that the cost of overtime is only taken into account if the same products are not previously produced. Constraints (16) and (19) establish the relationship between binary and integer variables. Constraints (20) with the objective function set the underutilized internal production capacity. Constraints (21) ensure that all production quantities are delivered to the warehouses.

Constraints (22)–(26) are also considered at the operational model:

$$\sum_{(t, s) \in T S_{\Theta \delta} / \delta \geq 1} X w_{p k t s} = X_{p k \theta} - \sum_{s=1}^{\delta-1} X w_{p k \theta s}, \quad \forall \mathcal{K}; \mu \in \mathcal{P}; t = \theta \quad (22)$$

$$\sum_{(t, s) \in T S_{\Theta \delta} / \delta \geq 1} X w_{p k t s} = X_{p k \theta+1}, \quad \forall \mathcal{K}; \mu \in \mathcal{P}; t = \theta + 1 \quad (23)$$

$$\sum_{(t, s) \in T S_{\Theta \delta} / \delta \geq 1} X w_{p k t s} = X_{p k \theta+2}, \quad \forall \mathcal{K}; \mu \in \mathcal{P}; t = \theta + 2 \quad (24)$$

$$Y H w_{p k t s} \in \{0, 1\}, \quad \forall \mathcal{K}; \mu \in \mathcal{P}; (t, s) \in T S_{\Theta \delta} \quad (25)$$

$$Y H w_{p k t s} \in \mathbb{N}, \quad \forall \mathcal{K}; \mu \in \mathcal{P}; (t, s) \in T S_{\Theta \delta} \quad (26)$$

Constraints (22), (23) and (24) guarantee coherence with the tactical decisions made. Finally, constraints (25) and (26) ensure the integrity of the new decision variables.

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