Case study of supply chain in textile industry: a dynamic product allocation decision problem

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ABSTRACT: *This paper tackles a supply chain strategic dynamic decision problem in textile industry. The supply chain studied is composed of several production locations on the three process stages. Different suppliers provide raw materials on production location of the first stage. Products can be grouped into 16 different categories. Supply chain costs are mainly due to transportation costs. The objective of this study is to determine where fabrics must be produced to satisfy the assembly demand at different locations. This problem has never been studied in textile industry application context. A mathematical model based on graph representation is proposed.*

KEYWORDS: *Supply chain, production allocation, optimization, mathematical model*

1 INTRODUCTION

In any industry, the supply chain is one of the most important part of organization. The supply chain decisions have a great influence on the rest of the system. The related costs are not negligible and are composed by inventory, production, and transportation costs. Depending on strategic decisions, the time to market can vary, or the service level can be significantly impacted. The Industry 4.0 revolution is accelerating the pace of supply chain transformations. This increases the necessity of agility and flexibility which can adapt to the constant changes in the market. Transportation must be reduced to the minimum to save time and money depending on the production and inventory locations. This is also motivated by a desire and need to move towards a more sustainable and ecological supply chain.

The case study in this paper is inspired from an industrial real case in textile industry. There are three main production stages (Figure 1):

- The first one is the creation of a knitting roll from the cotton yarn.
- The second step provides color properties and resistance to the fabric.
- The final one is the garment making. The knitting roll is cut into different pieces and these pieces are assembled.

Figure 1 – The three fabrication stages in textile industry

The first stage of this textile process was analyzed in Berthier et al. (2019). The authors focused on a dynamic layout of the workshop. The main subject is about the creation of groups of machines to balance the workload between all the operators and to propose a new implementation method of the machines. Nevertheless, the scope of the work of Berthier et al. (2019) was only at the tactical level and one component of the supply chain. Strategic work on the whole supply chain can conduct to better results if optimization is also conducted across the whole elements of the supply chain.

For each stage, several production locations can be used, each with different production costs. Currently, in the industrial case considered, two different locations for knitting and dyeing operations are available and four different locations for assembling operation. Transport is therefore necessary if the product changes from a location to an other between two production stages. The impact will be felt at stor-

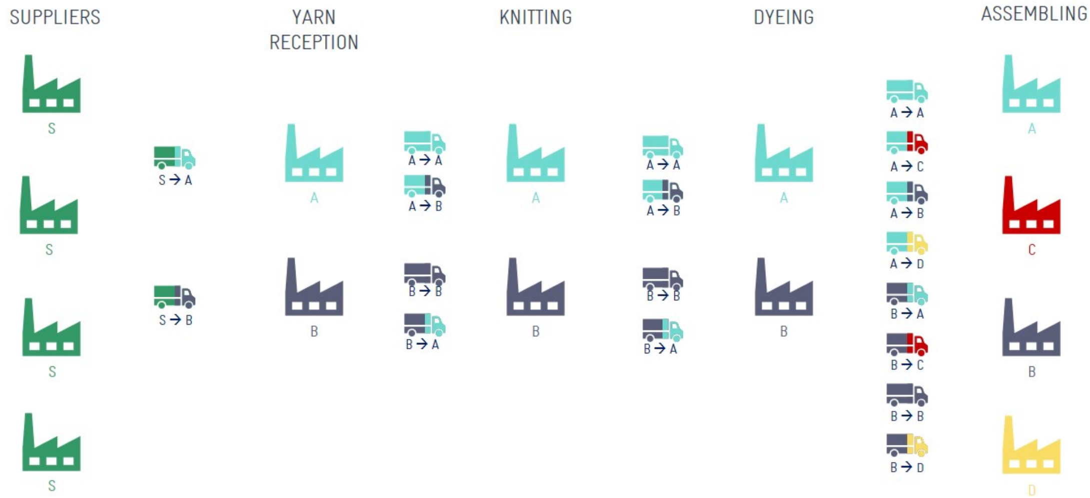

Figure 2 – The supply chain flow representation of the industrial case

age locations. Raw materials arrive from four different suppliers with different prices and costs.The costs vary depending on the location where the goods are delivered, due to different supplier transportation costs. Figure 2 shows the supply chain with the different possible locations of each stage from the suppliers to the assembling factories. Each letter represents a location. Location A and B can perform all three stages of production (knitting, dyeing and assembling) whereas location C and D may only carry out assembly operations. Each production location (A and B) is subject to production capacity $capa_{ij}$.

On the case study analyzed in this paper, the large diversity of products are grouped into four families. At each stage of the process excepting for the assembling, the available locations are qualified to make all the products. The dyeing operation has a production cost that varies according to the product family. Meanwhile, the costs do not present a large variation in the knitting operation. Therefore, the families are classified depending only on the dyeing operation:

- Bleaching: an unbleached fabric is transformed into a white fabric.
- Printing: a plain fabric is printed with a pattern using a printing process.
- Washing: the fabric is knitted directly with dyed yarns. The dyeing process only consists of a washing cycle.
- Dyeing: an unbleached fabric is transformed into a plain fabric. The darker the colour, the longer and more complex the process.

On each assembling location, the proportion of each family is known in advance and is determined by the production process. Table 1 presents the distribution of families of product on the different assembling locations. Each location makes a specific type of product. For instance, location C is specialized on underwear whereas location D is specialized on adult clothing. This two categories can use similar product families (fabrics) but do not use the same manufacturing processes to obtained different finished products.

	A	B	C	D
Bleaching	3%	13%	15%	70%
Printing	1%	24%	25%	50%
Washing	3%	28%	27%	42%
Dyeing	1%	22%	25%	52%

Table 1 – Finished product per location distribution for each product families

Each product family are divided into four, one for each assembly locations. So finally, we have 16 product categories as products are grouped by product family and assembling location. The assembling location d_k is the last assignment location for product category k.

This paper seeks to answer the question of where to produce fabrics at each stage of the manufacturing process to supply finished product assembly locations with the lowest possible costs on the whole chain. This represents a strategic choice assignment which is performed every six months. A dynamic decision model would be very useful for the company. Nowadays, a whole team is dedicated to decide where each product is manufactured at each stage. They only have standard calculation tools without any decision support. The study of this paper searches to provide them a dynamic decision support tool. The problem decision is to determine the quantity x_{kij} of product

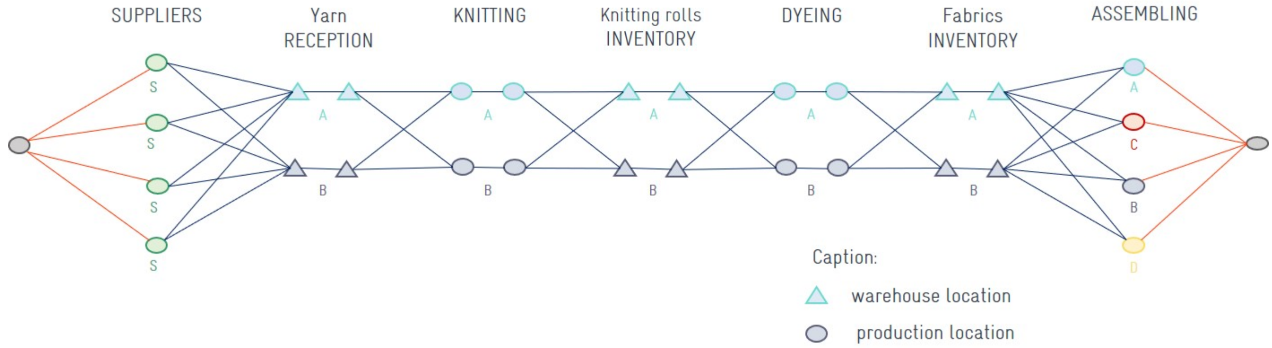

Figure 3 – The supply chain graph representation

category k assigned between nodes i and j.

The rest of the paper is organized as follows. Section 2 gives a literature review of similar problems. Section 3 presents the resolution method and the mathematical model proposed using graph theory. Section 4 provides preliminary results of the model on a real case instance. A conclusion and future research directions end up the paper in section 5.

2 STATE OF THE ART

In this section, a review of supply chain related problem and production allocation is conducted.

Supply chain is a set which includes all the related activities with commodities stream from raw materials to final product (Parsanejad and Nayebi (2020)). By the stream side, there are two other streams known as information stream as well as financial and credit resources stream (Giannoccaro and Pontrandolfo (2002)). The supply chain management is a collection of some methods that is used to integrate effectively the suppliers, producers, warehouses and stores. The supply chain includes all the direct and indirect steps which are involved in the completion of the customers orders. The supply chain is not just related to manufacturers and suppliers but it is also applicable to transportation, warehouses, retailers and even the customers.

In today's rapidly changing economic and political conditions, operations managers and planners need to address accurately questions such as which plants to operated on which product mix per plant (Tsiakis and Papageorgiou (2008)). There are several papers related to the production allocation and distribution. Mixed integer programming models have been developed to allocate customer order to forest product company with various plants located in different countries to reduce production and transportation costs (Aydinel et al. (2008)). The necessity to develop strategic and tactical planning models in the supply chain have been recognized by the industry. Particularly, by using quantitative approaches rather than the qualitative ones (Shapiro (2004)). This has created many challenges both for researchers and practitioners who wish to successfully implement supply chain support systems.

Previous attempts to improve the performance of supply chain networks have mainly focused on the logistic aspects rather that the business decisions associated. In an early attempt Arntzen et al. (1995) developed a mixed integer linear programming "global supply chain model" aiming to determine: the number and location of distribution centres, customer-distribution centre assignment, number of echelons and the product-plant assignment. The objective of the model is to minimise a weighted combination of total cost and activity days as a bill of material problem.

Guinet (2001) has examined the economics of multi-site production systems using a two-level approach to allocate production to sites and address the workshop scheduling problem. Kaihara (2003) has used an agent based approach to manage supply chains in terms of product allocation and resource distribution. Panicker et al. (2013) has solved a fixed charge transportation problem. Each route is associated with a fixed charge (or a fixed cost) and a transportation cost per unit transported. This author has used an algorithm based on ant colony optimisation to solve the distribution-allocation problem in a two-stage supply chain. The first problem instance used by this author is used in this paper to validate the proposed model.

For a more detailed state of the art on supply chain allocation problem, readers may refer to the recent review made by Di Pasquale et al. (2020). The authors have conducted a systematic literature review specifically regarding order allocation methods. The research aimed to evaluate how often and when the issue has been defined with an individual focus, independently of the supplier selection problem.

To the best of our knowledge, no previous papers have handled a supply chain management problem in the particular case of textile industry with production possible in different locations. This is an assignment problem of product on production locations.

3 RESOLUTION METHOD

In order to solve this problem, the supply chain flow is represented as a graph. A mathematical model based on this representation allows to solve this specific problem arising from the industry. Figure 2 can be translated into a graph as it is shown in figure 3. On this representation 30 nodes are necessary. On each arc, a cost value c_{kij} is assigned and a decision variable x_{kij} can be associated for each product category k between nodes i and j. To solve the most generic problem with a fixed cost f_{ij}, a binary decision variable b_{ij} is used too.

The quantity assigned to arcs of the first part of the graph (from the first node) are known (supplier procurement). The quantities purchased to each supplier are known beforehand. Similarly, the arcs of the last part (to the last node) are also pre-determined (figure 1). The proportion of each product category on each assembling locations are known on this study. They are considered as customers of the supply chain. On all the other arcs, a decision variable x_{kij} is available to determine the optimal quantity of category k between locations i and j. As it is explained in Introduction section, the number of product category is 16 according to the distribution of the products by family and assembly locations.

3.1 Notations

$\mathscr{N}$: Set of nodes
$N \in \mathbb{N}$: Number of graph nodes
$i, j = 1...N$: Nodes indexes
$\mathscr{K}$: Set of category products
$K \in \mathbb{N}$: Number of category products
$k = 1...K$: Products indexes
$c_{kij} \in \mathbb{R}$: Cost per unit of product k ($k \in \mathscr{K}$) between nodes i and j ($i, j \in \mathscr{N}$)
$f_{ij} \in \mathbb{R}$: Fixed cost between nodes i and j ($i, j \in \mathscr{N}$)
$d_k \in \mathbb{N}$: Last assignment node of product k ($k \in \mathscr{K}$) (location of assembly operation)
$q_k \in \mathbb{N}$: Quantity of product k ($k \in \mathscr{K}$)
$capa_{ij} \in \mathbb{N}$: Maximum capacity between nodes i and j ($i, j \in \mathscr{N}$)

3.2 Decision variable

$x_{kij} \in \mathbb{N}$: Quantity of product category k ($k \in \mathscr{K}$) assigned between nodes i and j ($i, j \in \mathscr{N}$)
$b_{ij} \in \{0, 1\}$: equal to 1 if quantities are assigned on the arc i,j ($i, j \in \mathscr{N}$), 0 otherwise

The decision variables determine over every arc the quantity to transit for each category of products. This ensures the full representation of product movement across the distinct stages considering the constraints in section 3.4.

3.3 Objective function

$$Minimize \sum_{k\in\mathscr{K}} \sum_{i\in\mathscr{N}} \sum_{j\in\mathscr{N}, i\neq j} x_{kij} c_{kij} + \sum_{i\in\mathscr{N}} \sum_{j\in\mathscr{N}, i\neq j} b_{ij} f_{ij} \quad (1)$$

The objective function (1) minimizes the supply chain total cost. The cost c_{ijk} takes the production, transportation and inventory cost per unit.

3.4 Constraints

$$\sum_{j\in\mathscr{N}} x_{k1j} = q_k, \forall k \in \mathscr{K} \quad (2)$$

$$\sum_{j\in\mathscr{N}} x_{kNj} = 0, \forall k \in \mathscr{K} \quad (3)$$

$$\sum_{i\in\mathscr{N}} x_{ki1} = 0, \forall k \in \mathscr{K} \quad (4)$$

$$\sum_{j\in\mathscr{N}} x_{kij} = \sum_{j\in\mathscr{N}} x_{kji}, \forall k \in \mathscr{K}, i = 2...N-1 \quad (5)$$

$$\sum_{i\in\mathscr{N}} x_{kij} \leq q_k, \forall k \in \mathscr{K} \quad (6)$$

$$x_{kd_kN} = q_k, \forall k \in \mathscr{K} \quad (7)$$

$$\sum_{k\in\mathscr{K}} x_{kij} \leq capa_{ij}, \forall i, j \in \mathscr{N} \quad (8)$$

$$\sum_{k\in\mathscr{K}} x_{kij} \leq \sum_{k\in\mathscr{K}} q_k * b_{ij}, \forall i, j \in \mathscr{N} \quad (9)$$

Constraint (2) initializes the first node with the total quantity of each product k. Constraint (3) ends the flow at node N. Constraint (4) starts the flow at the first node. Constraint (5) ensures the flow conservation between the input and output of each node. Constraint (6) guarantees that there is no return flow. Constraint (7) ensures that the product flow ends at the node d_k provided in data for the last production step. The constraint (8) ensures that capacity is respected between the different nodes. The final constraint (9) determines the value of b_{ij} on each arc.

4 PRELIMINARY RESULTS

In a first time, the model has been tested on the first problem instance from Panicker et al. (2013). The instance is a two stages supply chain composed of 9

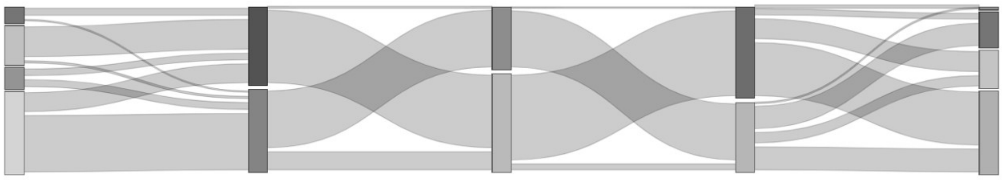

Figure 4 – Initial supply chain proportion between the different locations

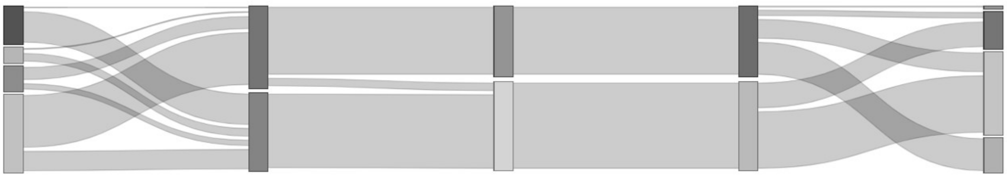

Figure 5 – Final supply chain proportion between the different locations

nodes. In this instance, the three retailers are considered as assembly location operation. This generate three category of product for the problem considered in this study and the corresponding retailer node of each category determined the data d_k. The quantity of each product is the demand of each retailers.
The model proposed in this study is different from the model proposed by Panicker et al. (2013) as decision variable are not decomposed by stages to be more generic. On this instance, the same objective function value, 112 600 is reached with the same product assignement per location.

In a second time, the model has been tested on real data set. This one does not consider the fixed cost. This part is deleted from the objective function and the variable b_{ij} is not useful in this case as well as the constraint 9. In the industrial data, there are 16 category products:

- 4 flow families: bleaching, printing, washing and dyeing
- 4 assembling locations

Two hypothesis have been made. The volumes of fabrics consumed by manufacturing locations remain the same. Material losses are not considered including between knitting and dyeing operations. The volumes of yarn supplied by each supplier are known per category of products.

For confidentiality reasons, results will not be detailed precisely. The mathematical model has been solved using the CPLEX-ILOG solver with an Intel Core i5 processor.

The total cost has been reduced by 3% on the entire supply chain. But the transportation cost was reduced by **37%** which is the most significant reduction on this study. The total cost does not decrease significantly because production level has to be maintained on the different locations. So the production cost is relatively identical. The main improvement is the streamlining of travel. Right from the start of the process, products are manufactured as close as possible to their assembly location. The evolution is shown by comparing figure 4 and figure 5. On these figures, larger lines represent bigger associated quantities. The first figure shows the proportion of production on each location with the transportation flows generated, before the implementation of the model. The second figure shows the same data when the MILP model is used to determine the flows. Clearly, the presence of cross-flows is less important in the second figure. The transportation costs are thus reduced.

		A	B	C	D
Bleaching	A	87%	263%	340%	29%
	B	-100%	-57%	-59%	-100%
Printing	A	39%	-78%	-77%	34%
	B	-100%	65%	58%	-100%
Washing	A	6%	83%	50%	51%
	B	-100%	-37%	-30%	-100%
Dyeing	A	17%	-100%	-100%	18%
	B	-54%	74%	45%	-55%
Total	**A**	**27%**	**-35%**	**-15%**	**33%**
	B	**-90%**	**21%**	**7%**	**-88%**

Table 2 – Transportation flow from dyeing to assembling stage difference between the initial supply chain and the MILP model flows proposition per product families

The final transportation is the most expensive. To go from location B to location D, products have to pass through A. Table 2 shows the comparison between initial transportation flow and flow determined by the the MILP model between dyeing and assembling stages. The flows between locations B and D are reduced by 88% in preference (+33%) to transportation between locations A end D closer.

These results can be used by the company as a dynamic decision tool to manage the affectation process of new product made at every collection launch. This represents a strategic choice assignment which is performed every six months, and can lead to keep the total supply chain costs as low as possible under the current configuration.

5 CONCLUSION

In this paper, a real case of textile industry problem has been studied. A production allocation problem in supply chain context is a very strategic decision problem for any company. The problem is explained in this paper. The production process is composed of three different operations and for each stage, multi-factories are available in different locations. The decision consists on determining which quantity of each product category will be manufactured at each location. The pursued of objective is to minimize the supply chain costs. The latter are composed by inventory, production and transportation costs.

Preliminary results are presented. The model proposed is first tested on an instance from Panicker et al. (2013). The same objective value and product assignment are found. In a second time, the model is used to solve the problem from an industrial company. However, due to confidential obligation, details can not be provided. Despite this, an important reduction on the transportation costs can be achieved by using the proposed mathematical model. The improvement in the transportation costs is of 37% when compared to the current product allocation. This study offers to the company a new dynamic decision support tool that can help them to take supply chain strategic product allocation decisions every six months (at every collection launch).

For future research, a profit model should be considerate. In this way, a variable selling price can be proposed depending on the production channel used. For instance, products 100% Made In France can be sold at a higher price. On the other hand, the number of sales and therefore of production can also vary according to the places of production of the different stages. The Made In France can be more attractive to customers.

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