Production planning in luxury textile industry: a conceptual model for multi-stage multi-site scheduling order

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Abstract: The fashion sector operates within a dynamic and diverse environment that undergoes frequent seasonal changes associated with collections. Collections change approximately every 6 months, necessitating a corresponding shift in the production of models to accommodate the introduction of new products. In the luxury sector, the determination of the number of garments per model to be produced occurs prior to the commencement of the sales season, and the produced goods must be ready for the launch of sales, following the make-to-order architecture. Manufacturers in this sector often resort to outsourcing certain phases of the production process, making the whole process multi-stage and multi-site. This study addresses the main challenges encountered during the planning process and proposes a framework for scheduling orders of multi-stage multi-site companies.

Keywords: production planning, textile industry, scheduling

1 Introduction

The Italian fashion industry is one of the most renowned in the world, with many brands that are an inspiration for the sector. The fashion environment is dynamic: new collection, so new models, are released approximately every 6 months, so the products are subjected to fast obsolescence. Behind the fashion industry there is an entire ecosystem of manufacturers that compose the supply chain of the luxury textile industry (Brun *et al.*, 2008). This industry is a peculiar sector characterized by many variables, parameters, and constraints during the production planning phase. Furthermore, while the collections changes rapidly, also the time for production is shortened and successive productions may also overlap, consequently representing a peak of utilization for the manufacturer. Also, textile manufacturers often rely on a subcontracting network to produce goods. Because of this the process could be modelled as a multi-stage, multi-site problem. The coordination of the stages of the supply chain becomes fundamental to deliver all the garments within the respected due dates and to respect the high-quality standards.

In this work we analyse the luxury textile sector production phase, highlighting the challenges and constraints that make it different from other systems, both from a literature and from practitioners' point of view. Furthermore, we propose a conceptual model to tackle the production phase to optimize the performances and give many advantages. This conceptualization will cover a field that has not been completely addressed in the literature and could help standardizing the process and serve as reference model for developing mathematical models or metaheuristics to optimize the planning of operations.

In Section 2 the literature on the topic is analysed and the contribution of the present work is analysed, in Section 3 the process is briefly described, in Section 4 the conceptual model is presented and in Section 5 conclusions are drawn.

2 Literature review

Fashion industry reports a growing trend during recent years, and it is predicted to continue growing. Being the fashion market large, companies are constantly trying to optimize the production, with better resources and materials management (de Kok and Fransoo, 2003), also begging to consider sustainable and ethical aspects (Giri *et al.*, 2019).

The main difference between the applications within the apparel clothing industry, is in the manufacturing strategy: most of the applications are either Make-To-Stock (MTS) or Make-To-Order (MTO). While MTS is a strategy adopted mainly by the fast fashion, that has a fast creative process and very few models, MTO is utilized by brands at the top end of the market. In MTO, the creative process is longer, the number of models is greater, and a high level of quality must be guaranteed (Caniato *et al.*, 2011).

The production planning in the textile clothing apparel sector has been tackled in different ways: it can be either formalized as flow shop or job shop scheduling problem (Perret, Schuck and Hitzegrad, 2022), as a parallel machine scheduling problem.

As mentioned earlier there are many peculiar characteristics, that are not simultaneously considered in the works found in literature (Rabbani, Niyazi and Rafiei, 2016). De Toni and Meneghetti (2000) propose a multi-site simulation model for the single-stage production on parallel uniform machines, while considering multi-period order arrivals. In (Liao, Lee and Tsai, 2016) a meta-heuristic for the minimization of the makespan of unrelated parallel machine with sequence dependent setup times is proposed, while in (Chi, Liu and Li, 2022) the authors aimed to reduce the makespan using an IG-TS algortithm. Fani, Bandinelli and Rinaldi, (2017) analyzed the scheduling problem of manufacturers that work for multiple brands by using simulation. In (Mok, 2011) a multi-objective genetic algorithm to optimize the sewing phase of multiple sewing lines with different operators skills has been developed. Rabbani, Niyazi and Rafiei (2016) developed a mathematical model to increase profit and resources utilization to produce yarns, under raw materials and workforce availability constraints. Felfel, Ayadi and Masmoudi (2016) tackle the multi-site multi-stage production to minimize the total expected cost , considering also the transportation constraint, while (Abid, Ayadi and Masmoudi, 2022) is an extension of the previous work that integrates the distribution network planning. Tesfaye *et al.* (2016) propose a linear programming model to optimize the production sequence and increase the profit of apparel manufacturing firms, considering a multi-stage single-site production. Ben Abid, Ayadi and Masmoudi, (2020) tackle the multi-site production and distribution planning for multi-site production for a medium size apparel company, by proposing a mathematical model to minimize the total production costs. Zhang *et al.* (2021) focus on the printing and dyeing process developing an evolutionary algorithm that allows grouping of different orders.

Following the framework proposed in (Lorente-Leyva, Alemany and Peluffo-Ordóñez, 2024), in Table 1 we highlight the environment of the present work with respect to the literature: we can see that the model lacks being multi-period, but this would not be suitable for the luxury fashion industry.

Table 1: environments of works in literature

Reference	MSi	MSt	MPr	MPe
(De Toni and Meneghetti, 2000)	X	X		X
(Mok, 2011)	X		X	
(Rabbani *et al.*, 2016)				X
(Felfel *et al.*, 2016)	X	X	X	X
(Tesfaye *et al.*, 2016)	X		X	
(Ben Abid *et al.*,2020)	X	X	X	X
(Zhang *et al.*, 2021)	X		X	
(Abid *et al.*, 2022)	X	X	X	X
Present work	X	X	X	

Msi: multi-site, MSt: multi-stage, MPr: multi-product, MPe: multi-period

In Table 2 we compare the constraint considered in the model, with other models in literature. The proposed model considers all the constraints mentioned in the table, except for the transportation constraint, therefore we can consider it completer and more innovative, and even considering possible company policy constraints that are peculiar of the luxury environment and not ascribable to a single company. Furthermore, the proposed model will consider also batch processing that is another element not thoroughly addressed in literature. The classification for the constraints considered is the following: Machines Capacity (MC) refers to the productive capacity of machines, Transportation Constraints (TC) refers to constraints related to the transports, Workforce Capacity (WC) refers to the productive capacity of operators, Aggregate Capacity Constraint (ACC) refers to constraints on the available capacity on different resources, Materials Availability (MA) refers to constraints related to materials availability, Demand Satisfaction (DS), Contracting Constraints (CC) refers to particular constraints related to contractual conditions with manufactures, and Company Policy constraints (CP) related to policies established by the brand.

Table 2: constraints of works in literature

Reference	MC	TC	WC	ACC	MA	DS	CC	CP
(De Toni and Meneghetti, 2000)	X			X	X			
(Mok, 2011)	X		X					
(Rabbani *et al.*, 2016)			X			X		
(Felfel *et al.*, 2016)	X	X						
(Tesfaye *et al.*, 2016)	X				X			
(Ben Abid *et al.*,2020)	X	X				X		
(Zhang *et al.*, 2021)	X							
(Abid *et al.*, 2022)	X			X		X		
Present work	X		X	X	X	X	X	X

MC: Machines capacity, TC: transportation capacity, WC; workforce capacity, ACC: aggregate capacity constraint, MA: materials availability, DS: demand satisfaction, CC: contracting constraints, CP: company policy constraint,

This work is inspired by a real case study of a luxury Italian brand, with the objective of addressing the production planning within this sector, by proposing a reference model that considers many of the different types of constraints simultaneously, resulting in a more comprehensive model, that can be used as a reference model to formalize mathematical models or metaheuristics that can optimize the planning.

3 The process

Before introducing the conceptual model, we briefly introduce the phases of the process from the creation of a collection to the production. As already mentioned, collections change at a very fast pace, so everything start with the creative process, which on the one hand maintains distinctive brand elements and on the other brings innovation. After this there is the prototyping phase: after the prototype has been positively evaluated there is the sampling phase, that consist in realization of sample model that are a repetition of the prototypes. After, samples go on exposition to the sales campaign. Once the sales campaign is over and the orders have been acquired, the production phase starts. In Figure 1 the phases for the creation and production of a fully fashioned knitwear are depicted. Fully fashioned knitwear refers to a process typical for more luxurious products.

Figure 1: phases for a collection release

The Supply chain configuration, in term of collection release and manufacturing strategy is the one of the firms defined as "quality Davids" by Caniato *et al.*, (2011), that consists in seasonal changes under unpredictable fashion trends. In our work we address the production phase of the fully fashioned knitwear process. It consists in 4 standard phases and 1 optional phase: knitting, sewing, fulling and washing, tailoring (optional) and ironing and final phases. Between the phases various control checks are performed (see Figure 3 for detail).

Among these phases, the most critical when dealing with production planning are the first two, knitting and sewing, because both usually represent the bottleneck and are subject to more stringent constraints. Reducing the production makespan of these two phases helps also to mitigate the overlapping effect of production, lowering the amount of resources needed. There is an outsourcing network that can be considered as an Hub & Spoke (O'Kelly and Miller, 1994). In this type of network, the products are transported by the company to each group in each phase. The logistics are depicted in Figure 2.

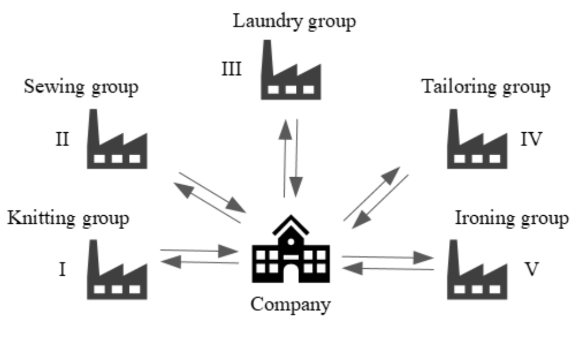

Figure 2: logistic of the network

From now on, we will refer to the manufacturers in the outsourcing network as groups, so we identify different groups for each phase: knitting groups, sewing groups, laundry groups, tailoring groups and ironing groups.

The knitting phase is strictly constrained by the Sampling phase (see Figure 1): the samples realisation may require up to 2 weeks, and during the sampling phase the realisation of the samples for a certain model is made by a certain group. However, during the production phase, a model may be assigned for production to a different group, so a new sampling for the model must be carried out before production. This characteristic of the process, that has not been investigated in the literature will have a central role in the conceptual model.

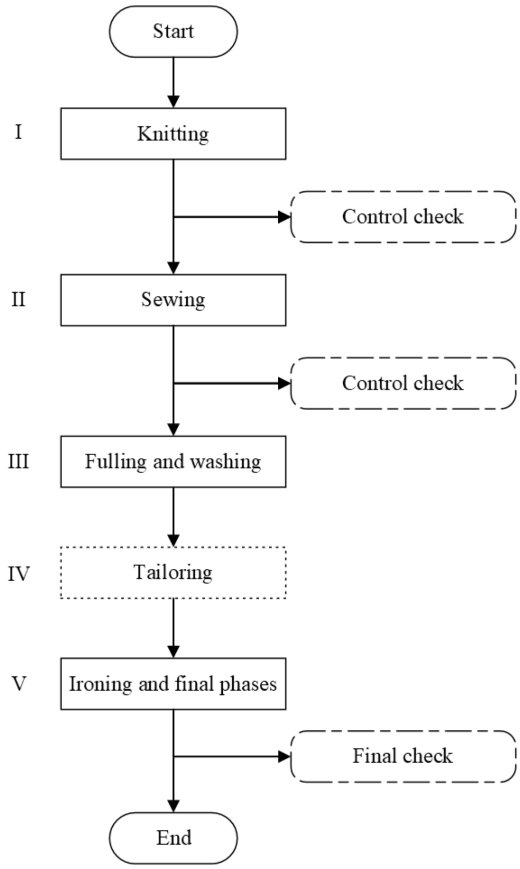

Figure 3: the fully fashioned knitwear process production phases

4 The conceptual model

The conceptual model can be viewed as a single period make-to-order, multi-stage, multi-site scheduling that consider batch processing.

Before introducing the model, we want to give an introduction on the entities and resources that are involved, using the entity relationship diagram by Chen (1976) (see Figure 4).

Each model has the attributes regarding the unique ID, the quantity to produce, the operations (refers to the production phases that the model requires) and their processing times, the group that executed the samples (Sampler in Figure 4) and the fineness. Fineness is a fundamental quantity in knitting and is defined as the number of needles that are present in one inch, i.e. 2.54 cm, on the gusset, a steel organ that has grooves in which the needles are positioned. Furthermore, each machine is set to process a single fineness during each collection. This means that each machine can process model of the same fineness. Each group is characterized by the identifier (ID) and the time available for production. The knitting groups are slightly different for the others, because each group has a set of machines available, each one with a certain fineness. This is relevant when considering the assignment of certain models to a knitting group and the available capacity for each fineness.

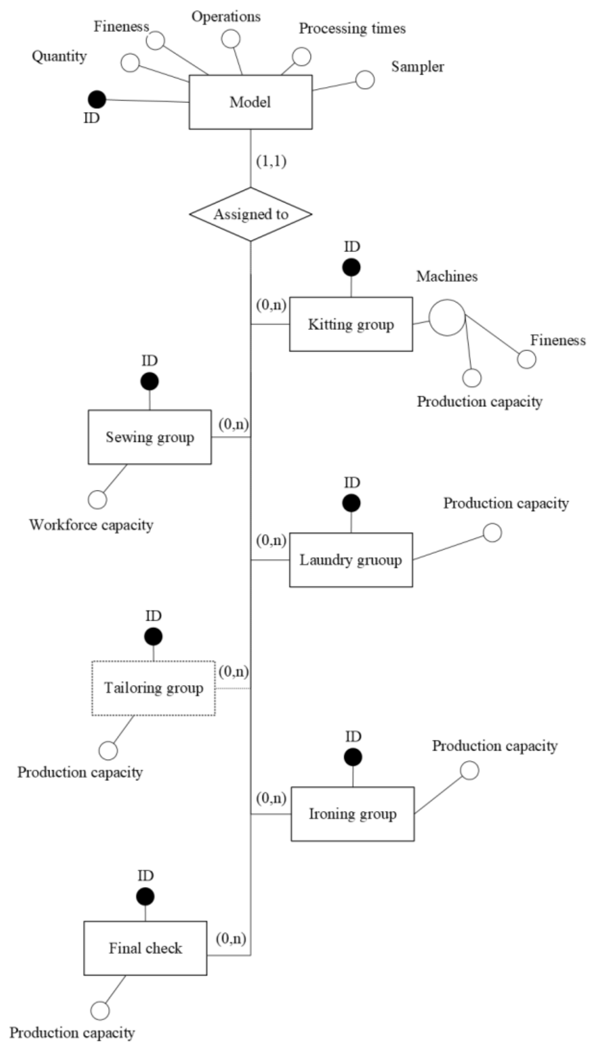

Figure 4: the entity relationship diagram

After the sales campaign the company receives the order about the quantity of each model of the collection to produce. The decisions are the quantity of each model in each period to assign for production to the different groups. The number of models to produce in each collection can be around 60-70, while the number of groups for the two critical phases is around 10-15. For each group the company knows everything about the available machines (only for knitting phase), the fineness that they can process and production capacity. Because of this the model can be viewed as multi-stage (sequence of multiple operations) and multi-site (different manufacturing sites).

The decision variables of the problem can be represented with the following nomenclature:

$x_{i,s,k}$ =the decision variable of the fraction of quantity of model i produced by the k-th group in s-th week

$\delta_{i,s,k}$ =the binary decision variable that is equal to 1 if the model i is produced by the k-th group in s-th week

$z_{i,s,r}$ =the decision variable of the fraction of quantity of model i produced by the r-th group in s-th week

$\gamma_{i,s,r}$ =the binary decision variable that is equal to 1 if the model i is produced by the r-th group in s-th week

Where:

i: index of model types

s: index of period number

k: index of knitting groups

r: index of sewing groups.

The presented model can be utilized as starting point for the optimization of the assignation and sequencing process considering all the steps, or it can be applied only to the first two steps of the process that are considered critical. In Figure 5 the framework for the application of the second option is depicted: the assignations for the first two steps are optimized by the model, while the assignations for the other steps are done "manually" by the operators.

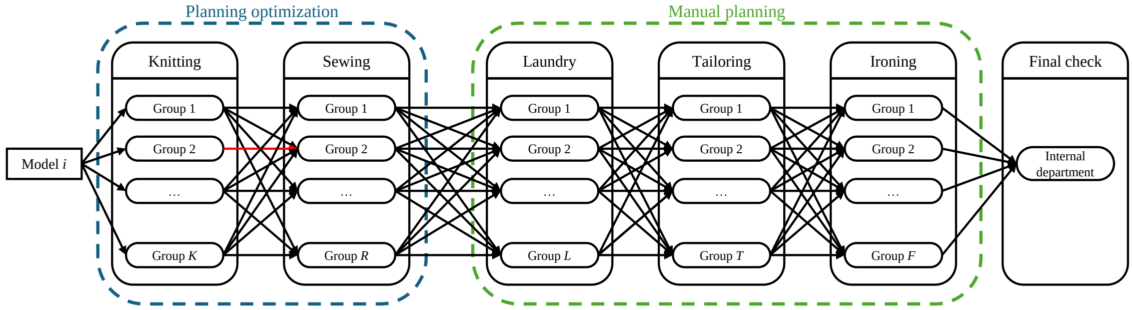

Figure 5: the assignations framework

4.1 Constraints

The planning horizon is divided in periods of the dimension of a week. During the knitting phase we consider the following constraints, that are characterized following the classification in Table 2:

(1) the demand of the model must be satisfied within the due date. (DS)

(2) a model can be assigned to only one group, because assigning to more than one would mean that more samples should have been realised. (CP)

(3) The production is organized in batches: each machine can produce only one type of model per week and no changes of models during the week are allowed. (CP)

(4) The quantity of the model produced during the week must be within the production capacity of the machines. (MC)

(5) A model can be produced only after the yarn which compose it is delivered and available: we suppose that a model can be produced starting from a week after the yarn arrival. (MA)

(6) The same model can be simultaneously processed in more than one compatible machine of the same knitting group and once the production of a model starts, it must be continuous until the completion and the quantity of the model produced must be constant over the production periods (except for the last period). This also means that the number of machines at a group processing a particular model is constant or decreasing during the production period. (ACC, CP)

Constraint (6) is peculiar of this problem, and it has not been previously addressed in the literature. Also, while it is easy to model this constraint using metaheuristics, the same cannot be applied when using a mathematical programming formulation. Even if the complete Mixed Integer Linear Programming (MILP) model is not presented within this work, we want to give a novel example of formulation for this constraint, that can be written with the following equations:

$$x_{i,s,k} = \min\left(x_{i,s-1,k}, 1-\sum_{j}^{s-1} x_{i,j,k}\right) \quad \forall i,k\ \forall s \in \left]A_i, D_i\right] \quad (1)$$

$$x_{i,s,k} - x_{i,s-1,k} - \left(1-\delta_{i,s-1,k}\right) \quad \forall i,k\ \forall s \in \left]A_i, D_i\right] \quad (2)$$

Where:

A_i =the week of arrival of the yarn needed to produce the model i

$D_{i,s,k}$ =the due date for the knitting phase of model i

Equation (1) in the current formulation is nonlinear because of the minimum function. However, it is possible to express the equation through a system of equations in order to make the constraint formulation linear and easy to solve. The linear system is detailed in the following.

$$\begin{cases} y_{i,s,k} \le x_{i,s-1,k} \\ y_{i,s,k} \le 1-\sum_{j=1}^{s-1} x_{i,s-1,k} \\ y_{i,s,k} \ge x_{i,s-1,k} - \left(1-d1_{i,s,k}\right) \\ y_{i,s,k} \ge \left(1-\sum_{j=1}^{s-1} x_{i,s-1,k}\right) - \left(1-d2_{i,s,k}\right) \\ d1_{i,s,k} + d2_{i,s,k} = 1 \\ x_{i,s,k} \ge y_{i,s,k} \end{cases}$$

Where $d1_{i,s,k}$, $d2_{i,s,k}$, and $y_{i,s,k}$ are local auxiliary variables.

For the sewing phase, we also divide the planning horizon in weeks, and we consider the following constraints:

(7) a model can be assigned to only one sewing group and that production must be continuous once it starts. (CP)

(8) Each group can produce simultaneously two types of models per week. (CP)

(9) The total quantity produced cannot exceed the capacity of the group capacity. (WC)

(10) The available quantity of each model that can be produced is strictly related to the quantity that has finished the knitting phase: in particular, we assume that a model is available for the sewing phase the week after it has been knitted. (MA)

(11) We consider that the quantity of the model sewed in the production weeks cannot decrease (except for the last week) to promote the learning rate effect of operators: the more garments of the same model that are sewn, shorter the standard processing time for sewing a garment become. (CP)

Another peculiar constraint that may happen in real scenarios, which falls into CC category due to the contracts established between the brand and the manufacturers, is that if a knitting group executes the knitting phase, it will also execute the sewing phase. This may happen for the manufacturers that have both the resources for knitting and sewing within their plant. This constraint introduces more complexity to the model, but on an operative level it could lead to benefits such as reduced transportation between different sites. In Figure 5, this constraint is highlighted for the knitting and sewing group number 2 (red arrow). Also, this constraint does not exclude that the sewing phase cannot also be carried out for models knitted from other groups.

The remaining phases can be modelled in a similar way to the sewing phase: the constraint to be considered are the production capacity constraint, the continuous production and the availability of garments depending on the previous phase.

To summarize, the model described has the characteristics of being :single period make-to-order, because the orders are collected in a single window prior the start of the production period, multi-stage because it considers the multiple steps of the production process, multi-site, because it considers multiple manufacturing groups for each state, that can alternatively process the model and considers also, and it also considers batch processing through the continuous production.

4.2 Objectives

The objective of the framework should align with the goal of the company. In most cases production costs are not a priority and also there are no obsolescence costs because the production is based only on the orders received, while the delivery within the due dates and the high level of quality are the main priorities. In our conceptual model the makespan is the main objective of the optimization, but also another relevant concern is the assignation of models to groups with respect to the ones realized the sampling phase. The minimization of the makespan may lead to several benefits, such as the non-overlapping of productions of two consecutive collections, the possibility of extending the order acquisition period and an overall increase in resource utilization that may help to identify possible improvement in the supply network. Furthermore, the correct assignations of models to the respective sampling group allows not to waste resources in doing other samples for the models, that need to be pre-emptively planned and may also cause problems related to the product quality, which lead to increase delivery times. Thus, the objective function may be the minimization of the makespan or it could consist in two components, the first one the makespan and the second one a penalization related to the misassignment of models to the sampling group. The choice of the objective function should be aligned with the brand goal. Also, the to understand the penalization related to the misassignment, it is important to understand the consequences that it has for the brand.

The conceptual model proposed can utilized as a starting point for a mathematical programming formulation (that is currently working in process) or for metaheuristics. The final goal is to obtain a decision support tool that can help the brand in the production planning phase, in order to reach the desired objectives, that can reduce the production planning window, while minimizing samples realization and granting high level of quality to customers.

As mentioned earlier, a mathematical formulation of the model is currently in progress. The main challenge encountered was to consider simultaneously many different constraints. Furthermore, one of the most challenging parts was modelling the constraint of continuous production under constant resources, while also considering the aggregate capacity constraint for models of the same fineness.

5 Conclusions

In this work we tackled the production planning problem for the luxury textile industry. This is a dynamic and complex environment subject to short windows for production and to the changing of products approximately every six months. Also, the supply chain typical of this sector is composed by many manufacturers, so the problem can be formalized as a multi-stage, multi-site scheduling orders.

In this work we propose a conceptual model for the operation planning in the luxury textile industry production planning that follows the fully fashioned knitwear production process, that respect the ones in the literature can consider simultaneously many different constraints, not only strictly related to production aspects but also related to contractual, or company policy aspects.

The aim of this model is to function as starting point for the development of mathematical model or heuristics that can find solutions to optimize the planning by obtaining a shorter makespan. While in this work we give the structure of the conceptual model, by defining the constraints that may be considered simultaneously, the mathematical formulation of for solving the problem is already in progress.

While many different constraints are considered simultaneously by the reference model, the transportation one is currently not taken into account. While it could be easily neglected in a supply chain located in a regional or national production site, typical of brands called "quality Davids", as the one who inspired the present work, but it should be included in international supply chains.

The mathematical model that considers that consider all the constraints introduced for the conceptual model, is currently under development. Furthermore, if needed also the formulation of metaheuristics will be considered

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