

Schuck, Katharina A.; Perret, Jens K.

Article

Optimizing Production of Fashion Goods as Means to a More Sustainable Garment Industry – An Assessment of the Literature

Research Journal for Applied Management (RJAM)

Provided in Cooperation with:

International School of Management (ISM), Dortmund

Suggested Citation: Schuck, Katharina A.; Perret, Jens K. (2023) : Optimizing Production of Fashion Goods as Means to a More Sustainable Garment Industry – An Assessment of the Literature, Research Journal for Applied Management (RJAM), ISSN 2701-6633, BoD – Books on Demand GmbH, Norderstedt, Vol. 4, Iss. 1, pp. 17-41

This Version is available at:

<https://hdl.handle.net/10419/324729>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

Schuck, Katharina A.; Perret, Jens K.

Optimizing Production of Fashion Goods as Means to a More Sustainable Garment Industry – An Assessment of the Literature

Abstract

Objectives:

The overall objective is to create awareness that production scheduling methods represent highly valuable tools in contributing to a more sustainable garment manufacturing. Further, a structured illustration of existing objectives of production scheduling is provided by grouping them according to their influence on the production runs. Based on this, it is demonstrated how each of the six groups would entail beneficial sustainability effects.

Theoretical Framework:

The theoretical framework is based on six decades of research, which produced a broad range of contributions to production scheduling for different production layouts and designs (flow-shop, job-shop, assembly lines), covering the full range of fashion production designs.

Method:

Methodologically, a literature review and an accompanied analysis are provided.

Results/Implications:

While the economic advantages of production planning are obvious, the discussion revealed that literature already contains considerable potentials for optimizing garment production, which, however, need to be applied to the fashion context, especially when it comes to enhanced sustainable business practices. As the link between optimization and holistic sustainability has received limited attention, this article presents a comprehensive conceptual view on the topic and provides decision makers and researchers with valuable inputs on which optimization approaches can support a company's sustainability efforts.

Keywords:

Sustainability, fashion, optimization, job-shop, flow-shop, assembly line

1 Introduction

The fashion market is a highly competitive, globally connected, diverse, and volatile market. It is estimated that around 40 million people are working in the fashion industry worldwide, with a large proportion probably remaining unaccounted for due to the complexity of the supply chain and a lack of international control mechanisms. Approximately 43 % of sales are generated with so-called 'entry-price' products, with large and internationally operating 'Giant Players' having the upper hand (BCG 2019). In the past, it was especially this low-priced and fast-moving part of the industry – also called 'fast fashion' which includes globally popular clothing brands such as Zara and H&M – that faced criticism due to a number of issues regarding environmental pollution and the socially questionable treatment of workers. According to the UN, the fashion industry is responsible for 20 % of water pollution, making it the second-largest water polluter and thus a very influential player (UNEP 2022).

Although being part of the fashion industry is extremely lucrative for numerous participants, the COVID-19 pandemic in particular revealed the industry's fragility to outside economic shocks. As consumers demanded less clothing, some clothing companies canceled orders and refused to pay for already ordered goods, while others tried to find new business fields and activities (Sumarliah et al. 2021). As the fashion industry is characterized by the fact that a number of supply chain partners – primarily the ones in the Southeast-Asian production locations – are dependent on the apparel companies, the situation was quite challenging for many of them (Brydges et al. 2020). Hence, the pandemic emphasized that the production of many fashion items is socially problematic (Kulsum 2020). At the same time, practitioners, researchers, and branch experts also brought the environmental issue of fashion production once again into the spotlight, catalyzed by consumers demanding security and durability in pandemic times, not only with regard to their daily lives, but also regarding their consumption (Kim 2021). Initially, the manufacturing process of garments was understood as a creative process characterized by craftsmanship and skill. Today, for many high-street fashion companies, it is especially the economic motive that is of primary concern (BoF & McKinsey 2021), and, only gradually, is the awareness that sustainable fashion can be economically advantageous while – at the same time – environmentally and socially friendly, taking ground in manufacturers' minds.

The economic motive is the one primarily targeted by applications of operations research in production planning, but economic goals do not necessarily need to be opposed to sustainability goals in general (Alberti & Varon Garrido 2017). Thus, a synthesis of both might be a solution for the apparel industry. Producing more efficiently can increase their profit margin while at the same time making the company more sustainable. Aside from operations research a number of other approaches exist to target the same problems, but as long as the relevant sources of information are certain to a degree mathematical optimization will provide the superior results.

Considering the supply chain of wearing apparel in full then the final production only accounts for a limited share and thus sustainability issues of fashion production can not be solved by optimization of the final production alone. Nevertheless, optimization of the final production is the part of the supply chain under the direct influence of the producing company itself and therefore it is the ideal starting point for sustainability-oriented changes in fashion production as such.

Taking a look at previous findings on the topic of garment manufacturing and optimization, there are different angles being taken. For some researchers, the place of manufacture as well as the materials used are of concern: Examples include the extent to which the production of clothing is compatible with the principles of social and environmental sustainability, highlighting the perspective of workers (Arvidsson et al. 2010; Perry & Towers 2013) as well as the resources and yarns used (Debnath 2016; Gwilt 2020; Niinimäki et al. 2020). While describing which business models could be conceivable for improving sustainable business activity, Pal and Gander (2018) provide one of the few contributions discussing environmentally sustainable fashion production from an economic perspective. Other studies are more concerned with the whole supply chain management: On a conceptual level, Bruce et al. (2004) address the issue of just-in-time delivery and argue that this might lead to achieving agility and flexibility in production, which – according to many authors – is mandatory for successful fashion production (Barnes & Lea-Greenwood 2006; de Oliveira Neto et al. 2019; Perry 2017). Further, Barnes and Lea-Greenwood (2006) emphasize the advantages of a vertical business model when it comes to enabling the most efficient supply chain management (and subsequently manufacturing). Ways to improve the actual manufacturing process are also provided: Liu et al. (2020) focused on the mass customization production format and delivered ideas that can contribute to efficiency improvement. Perret et al. (2022) concentrated on the same production format and delivered a cost-based optimization approach based on the concept of level scheduling. Further, Fani (2018) provides a scheduling approach similar to the one by Perret et al. (2022) but with a different array of objectives and not based on the level scheduling paradigm. Eira et al. (2015) conducted a case study of a clothing manufacturer and provided tailored waste elimination opportunities. Ait-Alla et al. (2014) present a mathematical model for fashion apparel suppliers to support them in achieving improvement regarding the allocation of production orders, whereas Choi et al. (2014) provide demand-focused forecasting tools for the fashion industry, i.e. mainly the manufacturer's side.

However, scientific studies dedicated to the optimization possibilities of garment manufacturers are limited in scope and often outdated regarding their methodology. It is the fact that fashion manufacturers changed little – despite years of drawing attention to the (social and environmental) problems in their production locations – shows that there is still room for improvement by integrating sustainability considerations into the discussion of the use of operations research in apparel manufacturing. Perret (2023) is among the few studies that take this aspect into consideration.

A look at other industries reveals that, in contrast to a plentiful breadth of literature, the set of objectives implemented in any of the major production layouts – job-shop, flow-shop and assembly line – is limited. While very few publications focus on applications of operations research in the fashion industry (Fani 2018; Perret et al. 2022), the existing studies and their accompanied methodologies, conducted for other industries, apply to the fashion industry nonetheless. The research objective of this paper therefore lies in delivering a summary of implemented objectives in job-shop, flow-shop and assembly line scheduling across literature and grouping them into sets with the same overarching goal. Each of the groups is discussed, not only in terms of its underlying objective, but also in respect of the benefits it offers to producers, i.e. particularly regarding social and ecological sustainability issues. Even though this study does not deliver a distinct optimization approach in itself, it provides a meta-study of objectives, offering both researchers and practitioners a toolbox to construct their own multi-objective optimization problems tailored to their particular needs and constraints. By referring to different production layouts, it presents easily applicable improvement options that not only lead to an economically more lucrative production process but also to a more environmentally and socially sustainable one. Hence, the problem as such might be well-known among practitioners in the fashion industry, it has not yet been considered in the academic literature. Thus, the present article contributes to the limited scientific literature base of fashion production planning and sequencing while incorporating practical relevance regarding sustainability issues.

2 Background on Garment Production

2.1 From an Industry Perspective

The manufacturing process of garments can happen in different formats, which require different production layouts. Overall, the production format chosen also has to do with the desired pricing of the product, as different formats demand different budgets, which is mainly due to the quantity that can be produced (Bevilacqua et al. 2013; Cachon & Swinney 2011). One of these possibilities is ‘custom tailoring’. It is largely carried out in a job-shop scheduling in which individual work tasks are done after one another without many processes being clearly defined in advance. In custom tailoring, manual work is also frequently used, as there is hardly any possibility of standardizing the processes due to the customized products and the individually designed tailor stores (Parveen & Ullah 2010). Hence, there are often qualified seamstresses working in this production format. The advantage of this method is that there is a high level of customer integration and, thus, a high probability of satisfaction and loyalty on the consumer side. In terms of production, the lack of standardization and the low production frequency result in considerable time and financial requirements, which are consequently also passed on to the products’ retail price. For this reason, tailored products tend to be in the premium or luxury price segment.

A very large proportion of companies focusing on low-priced and trend-oriented fashion items produce in 'mass productions'. Mass production is traditionally organized as a 'push-system'. The focus here is on a precise forecast, as the products and production quantities are planned on the basis of previous seasons' sales (Liu et al. 2020; Yeung et al. 2010). The production sites in this format are often located in low-wage countries, as most steps of the actual garment manufacture are carried out by workers on individual sewing machines (de Oliveira Neto et al. 2019; Niinimäki et al. 2020). In order to make the production as efficient as possible, there is usually a line of sewers strung together, all of whom have precisely defined jobs. By doing that, a highly beneficial standardized process is possible – beneficial as standardization favours speed. A possible scenario is that one sewer could only be responsible for the right arms of a shirt, whereas the next one in line is only putting the finished arms and middle parts together. Further, efficient inventory management is crucial for mass-producing fashion companies. Products manufactured in distant production facilities such as India, China, or Bangladesh are produced with a long lead time to their actual time of sale because otherwise, there would be problems due to the long transport distances (Camargo et al. 2020; Christopher et al. 2004). While this format has the advantage of standardized operations, it is error-prone and not very customer-centric: If a trend changes quickly (which is very often the case in high-street fashion) or a product does not arrive as planned, it accompanies the backlash that large quantities of goods remain unused and have to be destroyed, offered at large discounts, or be discarded (DW 2021). Alongside the spontaneously changing orders, there is enormous pressure on both the manufacturing sites and the sewers because there is only a very narrow timeframe where a trend (and with it, the product) is relevant for the consumers, i.e. for the fashion company (Christopher et al. 2004; Rafi-Ul-Shan et al. 2017).

In addition, there is also a kind of hybrid form of the two production formats described that is called 'mass customization'. In contrast to mass production, mass customization is oriented towards a 'pull-system' which requires a regular exchange of information between the various parties involved in the supply chain (Yeung et al. 2010). To respond to the fast-moving fashion industry, more and more companies have recently decided to produce in this specific format (Xu et al. 2020). As far as the production process is concerned, a final product is assembled only when a customer requests it. The choice of production layout is strongly related to the level of customization, meaning that more individuality and customizability also require more individually adapted production steps. Within this format, fashion producers greatly benefit from fewer customer returns because they influence the products' designs themselves. Since only the exact demand is produced, large overstocks can be eliminated, and storage costs as well as potential waste will be reduced. Nevertheless, this format also has a downside: It requires extreme flexibility and generates operational complexity, which is reflected in both financial expenditure and know-how requirements (Liu et al. 2020; Xu et al. 2020; Yang et al. 2015).

Note that the following study can be read as a literature review of the different objectives used in mathematical production planning and sequencing in the context of the three main production layouts

(Section 3.1). Second, it can be read as a first qualitative clustering of the objectives in use in this field of mathematical optimization (Section 3.2). Alternatively, it can also be read, and this is its main objective, as a discussion of the sustainability potentials inherent in the objectives, which primarily target output- or cost-related aspects (Section 3.3). While parts of this discussion are already known to practitioners or researchers, this study combines the insights into one comprehensive overview.

2.2 From an Operations Research Perspective

Regardless of the assumed objective, production scheduling in the fashion industry would usually take place in one of three possible layouts: flow-shop, job-shop or assembly line (Blazewicz et al. 2019). In all three situations, a number of tasks need to be performed to finish the manufacture of a pre-defined product, including different variants of the same product at this point. These tasks are assigned to different stations or workers involved in the production process, such as sewers in a sewing room. The assignment of tasks to stations is not made randomly but is determined by a given set of precedent constraints in addition to the assumed goals, i.e. certain tasks must be completed before others can be started (Scholl 1999). Without these precedence constraints, all three types could be subsumed as ‘open-shop problems’ (Blazewicz et al. 2019). The three approaches differ regarding the flow of goods through the production process, particularly resulting from whether each product requires all tasks to be performed and whether buffers or inventories are allowed between stations.

In a flow-shop environment, buffers are allowed to exist between stations, and each product is assumed to have the same operations done to it (Blazewicz et al. 2019). In this context, there are two main challenges arising: The first one emanates from the assignment of tasks to the stations (also referred to as balancing), and the second contains the order to process a series of orders at one of the stations at a specific system layout and station design (Scholl 1999).

Even though smart alternatives are possible with an assembly line, it is usually assumed that each product visits every station, even if no tasks are performed at that station. This case, however, would point to poor balancing in the balancing phase of the assembly line. Where flow-shop production allows for buffers or inventories to exist between stations in general, assembly lines (both in practical terms and mathematical theory) are constructed to avoid buffers and assure a continuous flow of goods via a continuously flowing line (Scholl 1999). Consequently, the main objectives of the two production types are quite similar. Job-shop production, in contrast, does not assume that each product has to visit each of the stations and that each task needs to be executed. Ultimately, it allows for the existence of buffers between stations or different stations in the product run (Blazewicz et al. 2019). A special case applies when there are a number of stations that all perform the same tasks, and the product is completed after all the required stations have been visited. In this case, the problem reduces to a scheduling problem on parallel machines Blazewicz et al. (2019). Generally, the particular

challenge in this situation is two-fold: On the one hand, there is the question of which order should be assigned to which station. On the other hand, however, it is also a matter of which order the jobs assigned to the stations are to be processed, if this option is permitted.

With regard to the fashion context, neither of the three approaches covers fully custom-made products like unique designer pieces. This area, however, can be excluded from this discussion without loss, as the creative and artistic dimension supersedes the planning aspect of the production anyway. For luxury fashion, it seems prudent to refer to a job-shop design, especially since job-shop production usually assumes that each station represents a specific area of expertise and cycle times across stations are not necessarily identical. The derived scheduling problem on parallel machines, where the same products are produced on a number of identical parallel stations, is reminiscent of the classical sweat-shop design, particularly used to generate mass-produced fast fashion goods or simple basic goods, like standard white t-shirts. Products at intermediate and affordable levels are usually mass-produced, but the trend is also continuously moving towards customization at these price levels (Liu et al. 2020). While other sectors, such as the automotive industry, have demonstrated that assembly lines are extremely effective in this environment (Scholl 1999), this has also been proven for the fashion segment (Perret et al. 2022).

Comparing classical flow-shop and assembly line problems in an environment where mass customization (pull production) persists, an assembly line-based approach provides better results (Scholl 1999), whereas in the classical mass production environment (push production), flow-shop approaches might fit better. With ever decreasing fashion cycle times (Choi et al. 2014) and the need to produce a new collection in less than a couple of weeks, it seems more and more critical that both objectives – balancing and sequencing – are jointly considered in a comprehensive approach. In the context of assembly lines, Battini et al. (2009), Defersha and Mohebalizadehgashti (2018) and Lopes et al. (2020) are among the recent studies to present such a joint approach. In the context of fashion production planning, this aspect has not yet been considered. However, since flow-shop and assembly line problems are closely linked, approaches that work in one of the two environments can oftentimes be modified to work in the other environment as well.

In summary, all three approaches to production planning find their application in the fashion industry. Therefore, the following section considers all three approaches, accompanied by a review of objectives used in the context of production sequencing. The focus on production sequencing is favored over production balancing since sequencing provides operative insights, whereas balancing provides strategic insights. Even if the trend is moving towards a decrease in fashion cycle times, the operative perspective is the one that offers the most approaches for making the whole production process more sustainable. The most important aspect of sustainability in the context of balancing is to set realistic task and cycle times that do not overburden workers. The determination of realistic times, however,

is not a question of the balancing approach per se but of the preceding data collection and measurements.

3 Optimization Approaches

3.1 Realized Objectives

Over the course of the last six decades, a broad range of articles on the scheduling of job-shops, flow-shops, or assembly lines were published. However, the implemented objectives – oftentimes propagated as a multi-objective version – remain mostly the same. The main objective in job-shop and flow-shop scheduling is minimizing the makespan, whereas in assembly line sequencing, it is balancing the part usage or workloads, i.e. minimizing work overloads. Table 1 summarizes the objectives used in relevant scheduling problems. For flow-shop scheduling, the objectives result from the recent and exhaustive literature reviews by Rossit et al. (2018) and Komaki et al. (2019), whereas the objectives for job-shop scheduling result from the literature reviews by Chaudhry and Khan (2016) and more recently the one by Zhang et al. (2019). Considering that no inherently new objectives have been introduced in assembly line sequencing in recent years, the literature reviews by Dhamala and Kubiak (2005) and Boysen et al. (2009) are still suitable summaries of the state-of-the-art in assembly line sequencing, particularly when considering the implemented objectives. In addition to each objective in table 1, an exemplary article is cited where the objective is implemented, even if it has only been part of an objective function consisting of multiple sub-objectives.

Table 1: *Implemented Objectives Across Literature*

Flow-Shops	Relating Articles
Makespan	Benavides/Ritt (2016)
Total Completion Time	Al-Anzi/Allahverdi (2013)
Lateness	Al-Anzi/Allahverdi (2007)
Tardiness	Ziaee (2013)
Holding Costs	Park/Kim (1999)
Lead Time	Blocher/Chhajed (2008)
Shipping Costs	Kazemi et al. (2017)
Flow Time	Pugazhendhi et al. (2004)
Changeover or Setup Costs	Grau et al. (1995)
Firm Income	Doganis et al. (2005)
Job-Shops	Relating Articles
Makespan	Sun et al. (2010)
Mean Completion Time	Nie et al. (2013)
Production Costs	Lan et al. (2010)
Balance Workload	Yuan/Xu (2013)
Resource Transition Costs	Lin et al. (2012)
Tardiness Costs	Chen et al. (2012)
Lateness Costs	Vilcot/Billaut (2011)
Mileage of Vehicles	Yan et al. (2022)
Machine Utilization Rate	Chen/Chen (2008)
Production Efficiency	Fattahi/Fallahi (2010)
Mean Flow Time	Nie et al. (2013)
Total Workload of Machines	Gen/Lin (2012)
Critical Workload of Machines	Yuan/Xu (2013)
Assembly Lines	Relating Articles
Work Overload	Tamura et al. (1999)
Line Stoppages / Duration of Stoppage	Xiaobo/Ohno (1994); Xiaobo/Ohno (1997)
Inventory Costs (Parts and Final Products)	Boysen et al. (2008); Wang/Sarker (2005)
Earliness and Tardiness Costs	Bolat (2003)
Balancing Part Usage	Tamura et al. (1999)
Set Up Costs	Rabbani et al. (2006)
Line Length	Bard et al. (1994)
Makespan / Throughput Time	McMullen (1998)
Worker Displacements	Bard et al. (1994)
Idle Time	Song et al. (2001)
Lead Times	Xiaobo/Ohno (1994)
Costs of Materials	Wang/Sarker (2005)

Source: *own table*

3.2 Grouping

Table 1 already groups the different objectives with regard to the type of production design. Nevertheless, this study is less concerned with production designs than with the effects that the implemen-

tation of specific objectives will have. Thus, groups are constructed according to the effects the contained objectives will have on the company, the involved workers, the products, and the customers. While the construction of the following six groups, plus a seventh group for the residual objectives, might seem arbitrary, their construction resulted from qualitative clustering. The grouping primarily serves to simplify the following discussion. These groups are not absolute, and in some cases, their borders might blur or overlap. The number of groups considered is kept as small as possible while trying to make them internally as homogenous as possible.

A limited number of groups will make it easier for practitioners to select the relevant top level group and, in a second step, consider the most relevant objective for their particular situation.

Group 1 – Makespan related

The first group consists of objectives aimed at minimizing the makespan, lead time, or throughput-times. It therefore also contains the minimization of the total, the mean completion, or the flow time (Benavides & Ritt 2016; McMullen 1998; Pugazhendhi et al. 2004; Sun et al. 2010). Since the length of an assembly line is linked to the lead time (Bard et al. 1994), it is also considered a part of this group. Another objective to be assigned to this group is the minimization of inventory costs for intermediate products (Park & Kim 1999), as the longer an intermediate product is kept in inventory or storage, the longer its lead time will be. Since more changeovers and setups automatically increase a product's lead time, minimizing changeover and setup costs (Grau et al. 1995; Rabbani et al. 2006) are also assigned to this first group. The absence of buffers and the design concept of assembly lines as a continuous flow of products preclude most assembly line objectives from this group. However, in cases where the continuous flow of products is interrupted, for example through the use of line stoppages (Xiaobo & Ohno 1994, 1997), the lead times of the products are impacted. Finally, the total and critical workload of the machines as well as the utilization rate can be assigned to this group if they allow for the accrual of backlogs, which – in consequence – lead to longer lead times.

Group 2 – Workload related

In contrast to the assembly line literature with an inherent focus on Japan (Xiaobo & Ohno 1997), which mainly concentrated on minimizing line stoppages, the US-focused articles were mainly concerned with minimizing work overloads of various types (Bard et al. 1994; Tamura et al. 1999). Worker displacements can be considered a slightly different take on work overloads covered via floater use or line stoppages. The only difference lies in the rigidity of station borders. With rigid station borders, workers cannot leave their station and no displacements occur; the work overloads, however, still need to be covered.

The flip-side to work overloads is idle time (Xiaobo & Ohno 1997), because too much idle time (similar to too much work overload) points to a poorly balanced production run and will put unnecessary stress on the workers. Within job-shop-related literature, the same problem is covered by approaches focusing on the critical workload of the machines (Yuan & Xu 2013). The total workload of the machines can also be assigned to this group if it allows for overutilization and, thus, production backlogs and increasing inventories.

Group 3 – Balanced Production Schedule

Achieving a balanced production schedule (variant-wise or regarding part usage) is one of the major objectives in assembly line scheduling (Boysen et al. 2009), following the assumption that a balanced production schedule will avoid work overloads (Tamura et al. 1999) while the order frequency for parts and intermediate products remains constant. In this regard, it follows the same goal as directly balancing part usage rates. Minimizing parts delivery costs is reflected in the flow store literature by shipping costs when they focus on inputs (Kazemi et al. 2017) and when the assumption is maintained that a machine uses the same parts for each processing of a product, by realizing the average workload of a machine. Focusing on minimizing shipments of parts and intermediate products between plants (Lin et al. 2012), the same idea is present in the resource transition costs or the mileage of vehicles if their focus is on the delivery of parts and not the delivery of final products.

Group 4 – Due date-oriented Goals

This group is similar to the first, but while the first group focused on production time per se, this one focuses on whether the set schedule or an increase in the production makespan results in a delay (Bolat 2003; Chen et al. 2012; Ziaee 2013). For products to become tardy, upper limits for the delivery date need to be set. Thus, minimizing tardiness or lateness costs belongs to this group of objectives. Furthermore, if lower bounds for the delivery date exist, as in an earliest date of delivery, the minimization of the resulting costs can also be assigned to this group. If the focus is on keeping the respective products in stock, the objective belongs to the succeeding group 5. Hence, group 4's objectives relate to group 1's objectives.

Group 5 – Inventory Costs

As discussed in the previous groups that already considered inventory-oriented goals, there are three main types of inventories: inventories of parts (Boysen et al. 2008), inventories of intermediate products, and inventories of final products (Park & Kim 1999; Perret et al. 2022). At this point, intermediate products only refer to those intermediate products produced in the plant itself and stored in buffers

or inventories between stations. The first type of inventory is unavoidable but depends on the use of the parts and the space available on the machines, assembly lines, or in the plant in general. The second type of inventory is null for assembly line designs (Scholl 1999), but can become relevant for flow- and job-shop production. Lastly, inventories of final products only become relevant when push production is implemented or products are processed in orders or batches rather than individually.

Group 6 – Delivery and Shipping Costs

Delivery and shipping costs are the counterpoint to group 3, which focused on parts shipments, whereas this group concentrates on the final products. As such, the minimization of the mileage of vehicles is considered an additional objective that falls into this group (Yan et al. 2022), if the vehicles considered are transporting finished goods.

Group 7 – Other objectives

The objective of maximizing firm income (Doganis et al. 2005) can be seen as an overreaching objective, similar to production efficiency (Fattahi & Fallahi 2010). Thus, both objectives are too broad to be evaluated from a particular sustainability point of view and are excluded from the following analysis.

Having described the six main groups and the seventh residual one, the qualitative clustering as a preliminary step in achieving the objective of this study has been realized. The inherent overarching goal of all objectives, and thus all groups, lies in realizing an increase in output levels or a decrease in costs. Still, they inadvertently target other secondary objectives as well. In the following section, these secondary objectives are discussed for each group with regard to the three pillars of sustainability.

3.3 Sustainability

In the context of the following discussion, the study assumes a definition of sustainability following the three-pillar model as adopted by Basiago (1998) or Purvis et al. (2019), differentiating between ecological, social, and economic sustainability.

Ecological sustainability, herein, is primarily understood as a decrease in resource utilization and harmful emissions. Social sustainability is understood as the living and working conditions of the population in particular and societal well-being in general. Finally, economic sustainability is understood as a positive, stable long-term economic development or, in the production context, as cost reduction in the long term.

In order to find out which sustainability aspects each of the groups addresses in addition to economic sustainability, the groups are discussed individually in turn. As part of this, side effects of implementing certain goals, such as increasing customer satisfaction, are also addressed.

Group 1 – Makespan related

Being able to finish a product earlier translates into an earlier delivery to the customer. The advantage in this regard is reflected in the waiting time for the customers and, thus, in more satisfied customers. Although this does not per se translate into more sustainability, it is not a negligible aspect. Realizing short makespans, however, allows for a shift to pull production, avoiding unnecessary production runs and thus less waste of materials and intermediate products. While pull production may not solve the ‘problem’ of fast fashion, it will at least avoid unnecessary output on the producer’s side (Kiran 2019).

Another advantage related to sustainability in this context is that products are usually paid once they are delivered. While they are kept in stock, they represent bound capital that cannot be used otherwise and is therefore unnecessarily taking up excess inventory space. Combining these aspects, shorter makespans or lead times can at least partially help to avoid or reduce situations like the Chilean Atacama Desert (DW 2021) by reducing overproduction by the manufacturers. In the long run, this would be ecologically beneficial. First and foremost, a focus on smaller inventories will save costs for the companies involved and free up capital that can be invested otherwise. If waste itself is considered an ecological issue, it will again be ecologically sustainable.

It needs to be noted that the proposed objectives, if realized, will lead to developments that carry slight social burdens as well. With less waste occurring and fewer garments dumped into sites like the Atacama Desert, the local population would be deprived of a free source of clothing. Additionally, realizing a leaner production might also reduce the workforce, leading to workers losing their jobs. Even though this is a negative social effect, the higher qualification level of the remaining workers would balance the lost jobs out, and it would therefore still be possible to reach higher ecological sustainability, further evolve the company, and achieve other social goals.

Group 2 – Workload related

A balanced production schedule will have the added benefit of being less stressful not only for the workers involved but also for the implemented machinery. If a machine has to continuously work at maximum capacity, it might result in outages or additional faults in the production runs, which, in turn, would increase the makespan and reduce the quality and, thus, the life-span of products. Aside from consumer preferences, this will play right into the throw-away mentality surrounding fast fashion items. Similarly, stressed workers will be more likely to make mistakes and tend to get sick faster. This effect occurs regardless of whether the overload is achieved through actual or theoretical floater employment or through line stoppages, both of which mean the employee has failed to meet his or her allotted time.

At first glance, idle times, the opposite of work overloads, seem to be beneficial to the workers since they can enjoy some free time. This holds true as long as the idle times are within reasonable bounds and do not alternate with significant work overloads. In the second case, the workers will be stressed by idle times as well, knowing that they will face a work overload. If idle time becomes commonplace, workers may begin to question their necessity or become bored, which will adversely affect their productivity and product quality in the long run. Thus, realizing balanced workloads will directly lead to a socially more sustainable production, indirectly to fewer faults, and consequently to both longer product lifetimes and positive ecological effects.

Group 3 – Balanced Production Schedule

A balanced production sequence helps in realizing two main goals. First, a balanced production sequence will balance workloads at the stations, and all the positive effects mentioned in the previous part will also occur. Second, a balanced production schedule results in even or at least predictable requirements for raw materials and intermediate products (Scholl 1999), realizing a basic requirement for just-in-time production. Sustainability-wise, this will result in better planning of order policies through easier requirement forecasts, translating into better supplier relations. As a result, this can both have a monetary advantage and be considered socially advantageous, especially for the employees involved in contractual work. This means that supply runs of operating materials can be better planned and thus also bundled, which ultimately leads to fewer required runs. In turn, fewer deliveries will mean lower transportation costs but – more importantly – lower fuel and energy requirements and therefore higher ecological sustainability.

Group 4 – Due date-oriented Goals

Due date-oriented goals do not primarily target ecological or social aspects of sustainability, and even economical aspects only matter because of fees related to violations of delivery horizons. Without these fees, the due date-oriented objectives ostensibly result in more satisfied customers.

From a secondary perspective, a production run that avoids tardiness will result in less stressed workers because if workers know they are working on an order that is already late, it will cause significant stress for them (Otten et al. 2019). Consequently, the same effects (even on a smaller scale) might occur as in the case of work overloads. Additionally, considering the delivery of the final product, a production schedule that avoids tardiness, i.e. finishes products as early as possible, will give the company more potential to batch deliveries and save on transportation costs as well as fuel or energy usage. Nevertheless, this advantage comes at the cost of requiring larger inventories for the final products.

Group 5 – Inventory Costs

Realizing a schedule that reduces inventory costs works like the flip side of Group 1's objectives. Minimizing inventory costs will reduce inventory and save inventory space. Due to shorter storage times, it will also lead to reduced lead times.

Depending on the type of product and the duration of storage, the product may deteriorate or, given the short cycle times in the fashion industry, simply go out of style, creating avoidable waste. In particular, if final inventories are kept small, more frequent delivery trips are required, consuming more fuel and energy. Considering that, a reduction in inventories will also free up physical space. Even if these spaces cannot be sold off or repurposed, less energy is required to maintain them, so powering and lighting unnecessary areas would be avoided.

Group 6 – Delivery and Shipping Costs

Minimizing shipment and delivery costs will lead to stronger batching and fewer transports. This will result in lower fuel and energy consumption and a reduction in fixed delivery costs as the company's delivery fleet is downsized. On the downside, realizing fewer shipments and deliveries will force the company to operate larger inventories for parts, intermediate goods, and finished products. Therefore, these objectives operate in opposition to those of Group 5.

Group 7 – Other Objectives

Since the two objectives in this group address overarching aspects, that impact the company as a whole, determining particular sustainability effects does not seem prudent.

Summarizing, it can be seen that a significant inherent potential for more sustainable production lies within most of the objectives currently known and used in mathematical production planning and sequencing. Even though, practitioners might already have realized parts of these inherent potentials, the overview generated in the preceding paragraphs delivers a first comprehensive discussion of the potentials for the three main types of production layouts.

The overview also illustrates that significant goal conflicts exist (groups 1, 5 and 6) which can not be solved in kind. Nevertheless, an optimization approach implementing multiple objectives can find Pareto-optimal solutions from which the decision maker can select the ones that best fit the company's strategy.

Additional practical and theoretical insights to be derived from this study are detailed in the following section.

4 Discussion of Added Values and Implications

Linking scheduling to fashion production and treating it as a possible improvement approach has not been something that has been frequently discussed in recent fashion literature (Perret 2023; Perret et al. 2022). However, it provides great opportunities. Considering the different aspects addressed in the literature and elaborated in the previous chapter, a number of relevant objectives for the improvement of fashion production were presented. The discussion in the second section of this article displayed that the optimization of fashion manufacturing is also possible without the imperative use of high investments in technology or in new machines – thus, a resource-saving improvement approach is definitely feasible. In addition, the advantage of the offered overview lies in its applicability: With the overview presented, manufacturers are equipped with a comprehensive instruction for action that merely needs to be put into a practical setting, i.e. selecting a suitable set of constraints reflecting the concrete production environment. By focusing on reducing sources of waste and working with existing resources, one also has a very company- and operation-oriented improvement methodology at hand. Further, all relevant production steps are included since both employees in manufacturing and logistics as well as possible auxiliary workers (floaters) are considered.

In the past, sustainability in fashion production was widely perceived from the perspective of ecologically and socially questionable conditions and with a lot of criticism (Niinimäki et al. 2020). As a result, previous work has focused less on the potential in terms of sustainable business practices that can originate from the actual production process. Due to savings in working time, liberated employee energy, saved materials (less waste and waste that is harmful to nature), and space that is either returned to nature or at least no longer wasted ‘superfluously’, as well as an optimization of transport routes and logistics (less fuel and energy consumed), the objectives described can enable resource efficiency.

As argued in the previous section, the relationship with customers can probably also be improved by optimizing the production process: In terms of sustainability, this means that increased satisfaction due to shorter waiting times, more flexibility, and most likely better product quality, pay off in the long term because it increases loyalty and thus, secures future sales and jobs. All of these aspects, consequently, result in both ecological and social sustainability as can be seen from discussions concerning ESG criteria (Câmara & Morais 2022). Further, since financial savings and reductions in fixed costs are highly conceivable, the application of the objectives discussed can also lead to economic sustainability, which – in turn – can be used for advanced sustainability projects, aligned with the corporate strategy and orientation. Examples of these include, but are not limited to, training and education opportunities for employees, charity projects, infrastructural projects for the local population, or environmental protection projects with regard to the areas negatively affected by the clothing industry.

Based on the above, there are also some aspects that are required from the management side when it comes to successfully implementing optimization projects in fashion productions and achieving the described objectives: Firstly, a corporate culture that is open-minded when it comes to change processes is strongly required. Any change process in companies rarely goes along without resistance from the employees' side, so transparent communication and the involvement of the workers are absolutely imperative if the changes are to be lastingly successful (Hines & Bruce 2007). In addition, regular analyses and an efficient information exchange system are essential, as this is the only way to regularly identify waste sources, improvement potentials, and actual time and resource allocations. Furthermore, optimization projects can only be managed efficiently if responsibilities and action plans are clearly defined, including targets and key performance indicators (Towers & McLoughlin 2005). Regular checks are also mandatory, as otherwise there is no long-term improvement that is both measurable and visible. But dealing with optimization also requires a responsible course of action: Reducing the number of employees, which might come along with some optimization objectives, could pose a new problem itself as many of the workers in fashion are highly dependent on their jobs, especially in the low-wage countries where fashion is often produced. Therefore, in addition to assistance in finding other positions, the manufacturer could offer training or educational programs as well as coaching for different manufacturing steps in order to keep the employees in the company. Further, at some production sites, some employees have generated their income from either free clothing or from the further processing of the respective textile waste. While optimizing production and rationalizing these income sources, production companies would need to take responsibility and offer alternatives.

Considering fashion manufacturing beyond the mere production process, it becomes evident that flexibility and an efficient supply chain partnership network would be necessary in order to optimize production above the limits of the company's own capabilities. This comes with the managerial challenge of long-term thinking, the commitment to suppliers, and their support in their own optimization. But, at the same time, it is also about being prepared and entering into new partnerships, expanding the existing network (Rafi-Ul-Shan et al. 2018). Realizing a more optimal production process frees resources and saves money that can finance these endeavors. Although this was not the explicit focus of this paper, it is nevertheless worth mentioning in this context.

5 Outlook and Limitations

In summary, it can be concluded that the garment industry is an extremely relevant industry that has a great influence on the environment – from an economic, but above all, from an ecological and social perspective (Niinimäki et al. 2020). Since garments are a basic necessity, the industry also holds a great deal of responsibility which (in many cases) is not born as such. Although the COVID-19 pandemic has triggered some changes and raised important issues for the industry, such as seasonless fashion or the inclusion of more sustainable pieces, as of 2022 and 2023, it has already become apparent that some

brands are falling back into former habits. For this reason, it is more relevant than ever to make sustainability lucrative and therefore interesting to apply to an industry as financially motivated as the fashion industry. Ultimately, optimizing production towards a more sustainable way of working is also about questioning established business models. For the fashion sector, this means a switch from fast to slow fashion, i.e. slow the cycles down and produce fewer collections in order to both reduce the pressure on production workers and cause less damage to the environment. But at the same time, it also means improving the already existing business models. Therefore, the meta-study in this paper delivered different objectives and accompanied optimization ideas that are applicable to various production formats for garment manufacturing while assuming the resources already available. It also introduced a different approach to thinking about production optimization because it displayed to what extent production optimization might also lead to more sustainable business activities (social and ecological) and how it can release potentials for sustainability activities and projects, beyond the bounds of material use, recycling, and cycle slowdown.

But it is not without limitations: The aspects described only cover one part of the value chain, namely the manufacturing process. However, depending on the production, distribution, and sales locations, a value chain in the garment industry can consist of various internationally connected and multi-layered stages, making it very complex (Backs et al. 2021). The process mostly starts with the cultivation of raw materials such as cotton or the manufacture of artificial or synthetic fibers and proceeds with the subsequent production of yarn and textile fabrics. These steps are usually processed in Southeast Asia. After the garments have been produced, they are transported to distribution centers or warehouses, followed by the retail steps (Backs et al. 2021; Niinimäki et al. 2020). The actual garment production is therefore only one small part of a whole chain, which is why further research should address other parts of the value chain in order to consider a more holistic optimization approach. In addition, aspects such as minimum and maximum order quantities, delivery times, and specific regulations (e.g. import and export constraints) should be included in further research. Moreover, the article does not offer a specialization on a specific case and does not apply the proposed optimization ideas to a 'real' company, including an evaluation of the employees. On the one hand, this gave the possibility of obtaining generalizable findings but, on the other hand, severely limited the accuracy of the results. Hence, it is suggested that researchers and practitioners apply the proposed ideas, i.e. put a distinct price tag on the proposed ideas, and also investigate the company's staff perspective as they play a crucial role in implementing new approaches.

Furthermore, only limited attention was paid to the changes that the pandemic has already brought or will bring to the production process (but also to the entire supply chain) of fashion companies in the future. In this context, researchers discussed the topic of 'near and re-shoring', which is the relocation of production to a site that is close to the respective company location. The ideas described strive to provide easy-to-implement options that do not necessarily require high investments. However, this

only provides companies with limited optimization options that can be beneficially extended with other approaches: For example, Bertola and Teunissen (2018) present ideas on how the use of technology (data analysis, 3D printers, and smart factory appliances) can help to optimize fashion production. Researchers are therefore reminded to consider various dimensions and approaches from different industries when it comes to achieving optimization in garment manufacturing. Moreover, while COVID-19 has had a negative impact on fashion companies, some practitioners believe at the same time that it might have a particularly positive impact on the garment industry as it strongly encouraged the use of robots and the associated automation in China, for example. Perhaps this will soon become the case in the global garment industry because, where people still work manually, the demand to always become faster and better can no longer be sustained at some point.

Finally, the article intentionally does not focus on any particular optimization method, use case or case study. As in the past decades, optimization techniques will improve in the coming years, not only methodologically but also with regard to computational power; e.g., due to the availability of quantum computing or the increased use of artificial intelligence to solve even complex optimization problems. While the techniques and methods will change, and even production layouts may vary over time, asking the right and most relevant questions will remain at the core of all practical applications of optimization.

While a practical use case might illustrate the theoretical aspects discussed herein, it needs to be considered that actual data, but even more so the implemented optimization approaches, are usually treated as strictly proprietary. With regard to the optimization of the production of automobiles, the sector most prominently featured in the literature, the competition by PSA launched in the 2000s, where they made their algorithm public, has been the only instance where a company shared this type of knowledge.

Another solution to this conundrum might be an in-depth qualitative interview-based study, using the opinions of experts to evaluate the ideas put forth in this study.

Summarizing, this article provides not just a solution to a single current problem but an overview of the major questions that might rightfully be asked and evaluates their relevance with regard to sustainability, making it more timeless than focusing on a single use case could ever be.

References

- Ait-Alla, A.; Teucke, M.; Lütjen, M.; Beheshti-Kashi, S.; Karimi, H. R. (2014): Robust production planning in fashion apparel industry under demand uncertainty via conditional value at risk. In: *Mathematical Problems in Engineering* (2014).
- Al-Anzi, F. S.; Allahverdi, A. (2007): A Self-Adaptive Differential Evolution Heuristic for Two-Stage Assembly Scheduling Problem to Minimize Maximum Lateness with Setup Times. In: *European Journal of Operational Research*, 182. (2007), No. 1, pp. 80–94.

- Al-Anzi, F. S.; Allahverdi, A. (2013): An Artificial Immune System Heuristic for Two-Stage Multi-Machine Assembly Scheduling Problem to Minimize Total Completion Time. In: *Journal of Manufacturing Systems*, 32. (2013), No. 4, pp. 825–830.
- Arvidsson, A.; Malossi, G.; Naro, S. (2010): Passionate work? Labor conditions in the Milan fashion industry. In: *Journal for Cultural Research*, 14. (2010), No. 3, pp. 295–309.
- Backs, S.; Jahnke, H.; Lüpke, L.; Stücken, M.; Stummer, C. (2021): Traditional versus fast fashion supply chains in the apparel industry: an agent-based simulation approach. In: *Annals of Operations Research*, 305. (2021), pp. 487–512.
- Bard, J. F.; Shtub, A.; Joshi, S. B. (1994): Sequencing mixed-model assembly lines to level parts usage and minimize line length. In: *The International Journal of Production Research*, 32. (1994), No. 10, pp. 2431–2454.
- Barnes, L.; Lea-Greenwood, G. (2006): Fast fashioning the supply chain: Shaping the research agenda. In: *Journal of Fashion Marketing and Management: An International Journal*, 10. (2006), No. 3, pp. 259–271.
- Basiago, A. D. (1998): Economic, social, and environmental sustainability in development theory and urban planning practice. In: *Environmentalist*, 19. (1998), pp. 145–161.
- Battini, D.; Faccio, M.; Persona, A.; Sgarbossa, F. (2009): Balancing–sequencing procedure for a mixed model assembly system in case of finite buffer capacity. In: *The International Journal of Advanced Manufacturing Technology*, 44. (2009), pp. 345–359.
- BCG (2019): Pulse of the Fashion Industry (https://web-assets.bcg.com/img-src/Pulse-of-the-Fashion-Industry2019_tcm9-237791.pdf). Accessed on 01.02.2022.
- Benavides, A. J.; Ritt, M. (2016): Two simple and effective heuristics for minimizing the makespan in non-permutation flow shops. In: *Computers & Operations Research*, 66. (2016), pp. 160–169.
- Bertola, P.; Teunissen, J. (2018): Fashion 4.0. Innovating fashion industry through digital transformation. In: *Research Journal of Textile and Apparel*, 22. (2018), No. 4, pp. 352–369.
- Bevilacqua, M.; Ciarapica, F. E.; Crosta, A.; Mazzuto, G.; Paciarotti, C. (2013): Designing an efficient production system: A case study of a clothing company. In: *International Journal of Engineering Business Management*, 5. (2013).
- Blazewicz, J.; Ecker, K. H.; Pesch, E.; Schmidt, G.; Sterna, M.; Weglarz, J. (2019): *Handbook on Scheduling. From Theory to Practice*. 2.th ed., Wiesbaden: Springer.
- Blocher, J. D.; Chhajer, D. (2008): Minimizing Customer Order Lead-Time in a Two-Stage Assembly Supply Chain. In: *Annals of Operations Research*, 161. (2008), No. 1, pp. 25–52.
- BoF & McKinsey (2021): The State of Fashion 2020 (<https://www.mckinsey.com/~media/mckinsey/industries/retail/our%20insights/the%20state%20of%20fashion%202020%20navigating%20uncertainty/the-state-of-fashion-2020-final.pdf>). Accessed on 01.02.2022.
- Bolat, A. (2003): A mathematical model for selecting mixed models with due dates. In: *International Journal of Production Research*, 41. (2003), No. 5, pp. 897–918.
- Boysen, N.; Fliedner, M.; Scholl, A. (2008): Sequencing mixed-model assembly lines to minimize part inventory cost. In: *OR Spectrum*, 30. (2008), No. 3, pp. 611–633.

- Boysen, N.; Fliedner, M.; Scholl, A. (2009): Sequencing mixed-model assembly lines: Survey, classification and model critique. In: *European Journal of Operational Research*, 192. (2009), No. 2, pp. 349–373.
- Bruce, M.; Daly, L.; Towers, N. (2004): Lean or agile: A solution for supply chain management in the textiles and clothing industry? In: *International Journal of Operations & Production Management*, 24. (2004), No. 2, pp. 151–170.
- Brydges, T.; Retamal, M.; Hanlon, M. (2020): Will COVID-19 support the transition to a more sustainable fashion industry? In: *Sustainability: Science, Practice and Policy*, 16. (2020), No. 1, pp. 298–308.
- Cachon, G. P.; Swinney, R. (2011): The value of fast fashion: Quick response, enhanced design, and strategic consumer behavior. In: *Management Science*, 57. (2011), No. 4, pp. 778–795.
- Câmara, P.; Morais, F. (eds.) (2022): *The Palgrave Handbook of ESG and Corporate Governance*. London: Palgrave Macmillan.
- Camargo, L. R.; Farias Pereira, S. C.; Santiago, Scarpin, M.R. (2020): Fast and ultra-fast fashion supply chain management: An exploratory research. In: *International Journal of Retail & Distribution Management*, 48. (2020), No. 6, pp. 537–553.
- Chaudhry, I. A.; Khan, A. A. (2016): A research survey: review of flexible job shop scheduling techniques. In: *International Transactions in Operational Research*, 23. (2016), No. 3, pp. 551–591.
- Chen, J.; Chen, F. (2008): Adaptive scheduling and tool flow control in flexible job shops. In: *International Journal of Production Research*, 46. (2008), No. 15, pp. 4035–4059.
- Chen, J. C.; Wu, C.-C.; Chen, C.-W.; Chen, K.-H. (2012): Flexible job shop scheduling with parallel machines using genetic algorithm and grouping genetic algorithm. In: *Expert Systems with Applications*, 39. (2012), No. 11, pp. 10016–10021.
- Choi, T.-M.; Hui, C.-L.; Yu, Y. (2014): *Intelligent Fashion Forecasting Systems: Models and Applications*. Wiesbaden: Springer.
- Christopher, M.; Lowson, R.; Peck, H. (2004): Creating agile supply chains in the fashion industry. In: *International Journal of Retail & Distribution Management*, 32. (2004), No. 8, pp. 367–376.
- de Oliveira Neto, G. C.; Ferreira Correia, J. M.; Silva, P. C.; de Oliveira Sanches, A. G.; Lucato, W. C. (2019): Cleaner Production in the Textile Industry and its Relationship to Sustainable Development Goals. In: *Journal of Cleaner Production*, 228. (2019), pp. 1514–1525.
- Debnath, S. (2016): Pineapple Lead Fibre – A Sustainable Luxury and Industrial Textiles. In: Gardetti, M. A.; Muthu, S. S. (eds.): *Handbook of Sustainable Luxury Textiles and Fashion*. Volume 2. Heidelberg: Springer, pp. 35–50.
- Defersha, F. M.; Mohebalizadehgashti (2018): Simultaneous balancing, sequencing, and workstation planning for a mixed model manual assembly line using hybrid genetic algorithm. In: *Computers & Industrial Engineering*, 119. (2018), pp. 370–387.
- Dhamala, T. N.; Kubiak, W. (2005): A brief survey of just-in-time sequencing for mixed-model systems. In: *International Journal of Operational Research*, 2. (2005), No. 2, pp. 38–47.

- Doganis, P.; Sarimveis, H.; Bafas, G.; Koufos, D. (2005): An MILP model for optimal scheduling of the lubricant production plant. In: *Chemical Engineering Communications*, 192. (2005), No. 8, pp. 1067–1084.
- DW (2021): Fast fashion on one-way trip to Atacama Desert dump (<https://www.dw.com/en/fast-fashion-on-one-way-trip-to-atacama-desert-dump/av-60133560>). Accessed on 01.02.2022.
- Eira, R.; Maia, L. C.; Alves, A. C.; Leao, C. P. (2015): An Initiation of a lean Journey in a Clothing Company. In: Gomes, J.; Meguid, S. A. (eds.): *M2D2015: Proceedings of the 6th International Conference on Mechanics and Materials in Design*. Porto: INEGI-FEUP, pp. 1349–1358.
- Fani, V. (2018): *A Simulation Optimization Framework for Production Planning and Control in the Fashion Industry*; Università degli studi Firenze (ed.), Florence.
- Fattahi, P.; Fallahi, A. (2010): Dynamic scheduling in flexible job shop systems by considering simultaneously efficiency and stability. In: *CIRP Journal of Manufacturing Science and Technology*, 2. (2010), No. 2, pp. 114–123.
- Gen, M.; Lin, L. (2012): Multiobjective genetic algorithm for scheduling problems in manufacturing systems. In: *Industrial Engineering & Management Systems*, 11. (2012), No. 4, pp. 310–330.
- Grau, R.; Espuna, A.; Puigjaner, L. (1995): Environmental considerations in batch production scheduling. In: *Computers & Chemical Engineering*, 19. (1995), pp. 651–656.
- Gwilt, A. (2020): *A Practical Guide to Sustainable Fashion*. 2nd ed., London: Bloomsbury Publishing.
- Hines, T.; Bruce, M. (2007): *Fashion Marketing. Contemporary Issues*. 2nd ed., Oxford: Butterworth-Heinemann.
- Kazemi, H.; Mazdeh, M. M.; Rostami, M. (2017): The Two Stage Assembly Flow-Shop Scheduling Problem with Batching and Delivery. In: *Engineering Applications of Artificial Intelligence*, 63. (2017), pp. 98–107.
- Kim, M. (2021): Green is the New Black: The Effects of COVID-19 on the Fashion Industry's Need for Sustainability (Joseph Wharton Scholars) (https://repository.upenn.edu/joseph_wharton_scholars/108). Accessed on 01.02.2022.
- Kiran, D. R. (2019): *Production Planning and Control*. Oxford: Butterworth-Heinemann.
- Komaki, G. M.; Sheikh, S.; Malakooti, B. (2019): Flow shop scheduling problems with assembly operations: A review and new trends. In: *International Journal of Production Research*, 57. (2019), No. 10, pp. 2926–2955.
- Kulsum, U. (2020): Sustainable Fashion as The Early Awakening of the Clothing Industry Post Corona Pandemic. In: *International Journal of Social Science and Business*, 4. (2020), No. 3, pp. 422–429.
- Lan, M.; Xu, T.-R.; Peng, L. (2010): Solving flexible multi-objective JSP problem using a improved genetic algorithm. In: *Journal of Software*, 5. (2010), No. 10, pp. 1107–1113.
- Lin, L.; Hao, X. C.; Gen, M.; Jo, J. B. (2012): Network modeling and evolutionary optimization for scheduling in manufacturing. In: *Journal of Intelligent Manufacturing*, 26. (2012), No. 6, pp. 2237–2253.
- Liu, N.; Chow, P.-S.; Zhao, H. (2020): Challenges and Critical Successful Factors for Apparel Mass Customization Operations: Recent Development and Case Study. In: *Annals of Operations Research*, 291. (2020), No. 1, pp. 531–563.

- Lopes, T. C.; Sikora, C.; Michels, A. S.; Magatao, L. (2020): An iterative decomposition for asynchronous mixed-model assembly lines: combining balancing, sequencing, and buffer allocation. In: *International Journal of Production Research*, 58. (2020), No. 2, pp. 615–630.
- McMullen, P. R. (1998): JIT sequencing for mixed-model assembly lines with setups using tabu search. In: *Production Planning & Control*, 5. (1998), No. 5, pp. 504–510.
- Nie, L.; Gao, L.; Li, P.; Li, X. (2013): A GEP-based reactive scheduling policies constructing approach for dynamic flexible job shop scheduling problem with job release dates. In: *Journal of Intelligent Manufacturing*, 24. (2013), No. 4, pp. 763–774.
- Niinimäki, K.; Peters, G.; Dahlbo, H.; Perry, P.; Rissanen, T.; Gwilt, A. (2020): The environmental price of fast fashion. In: *Nature Reviews Earth & Environment*, 1. (2020), No. 4, pp. 189–200.
- Otten, M.; Braaksma, A.; Boucherie, R. J. (2019): Minimizing Earliness/Tardiness costs on multiple machines with an application to surgery scheduling. In: *Operations Research for Health Care*, 22. (2019), p. 100194.
- Pal, R.; Gander, J. (2018): Modelling environmental value: An examination of sustainable business models within the fashion industry. In: *Journal of Cleaner Production*, 184. (2018), pp. 251–263.
- Park, M. W.; Kim, Y. D. (1999): A Heuristic Algorithm for a Production Planning Problem in an Assembly System. In: *Journal of Operational Research Society*, 50. (1999), No. 2, pp. 132–143.
- Parveen, S.; Ullah, H. (2010): Review on job-shop and flow-shop scheduling using multi criteria decision making. In: *Journal of Mechanical Engineering*, 41. (2010), No. 2, pp. 130–146.
- Perret, J. K. (2022): A simultaneous balancing and sequencing algorithm to plan assembly lines in the fashion industry. In: *Research Journal of Textile and Apparel*, vol. Online First (2022).
- Perret, J. K.; Schuck, K. A.; Hitzegrad, C. (2022): Production Scheduling of Personalized Fashion Goods in a Mass Customization Environment. In: *Sustainability*, 14. (2022), No. 1, p. 538.
- Perry, P. (2017): Garments without guilt? In: Gardetti, M. A.; Torres, A. L. (eds.): *Sustainability in Fashion and Textiles*. London: Routledge, pp. 294–307.
- Perry, P.; Towers, N. (2013): Conceptual framework development: CSR implementation in fashion supply chains. In: *International Journal of Physical Distribution & Logistics Management*, 43. (2013), No. 5/6, pp. 478–500.
- Pugazhendhi, S.; Thiagarajan, S.; Rajendran, C. (2004): Relative performance evaluation of permutation and non-permutation schedules in flowline-based manufacturing systems with flowtime objective. In: *The International Journal of Advanced Manufacturing Technology*, 23. (2004), No. 11–12, pp. 820–830.
- Purvis, B.; Mao, Y.; Robinson, D. (2019): Three pillars of sustainability: In search of conceptual origins. In: *Sustainability Science*, 14. (2019), pp. 681–695.
- Rabbani, M.; Rahimi-Vahed, A.; Javadi, B.; Tavakkoli-Moghaddam, R. (2006): A New Approach for Mixed-Model Assembly Line Sequencing. In: Waldmann, K.-H.; Stocker, U. M. (eds.): *Operations Research Proceedings 2006*. Wiesbaden: Springer, pp. 169–174.
- Rafi-Ul-Shan, P. M.; Grant, D. B.; Perry, P. (2017): Coopetition in Fashion Supply Chains. In: *Global Fashion Management Conference*, (2017), pp. 176–180.

- Rafi-Ul-Shan, P. M.; Grant, D. B.; Perry, P.; Ahmed, S. (2018): Relationship between sustainability and risk management in fashion supply chains: A systematic literature review. In: *International Journal of Retail & Distribution Management*, 46. (2018), No. 5, pp. 466–486.
- Rossit, D. A.; Tohmé, F.; Frutos, M. (2018): The non-permutation flow-shop scheduling problem: A literature review. In: *Omega*, 77. (2018), pp. 143–153.
- Scholl, A. (1999): *Balancing and Sequencing of Assembly Lines*. Heidelberg: Springer.
- Song, D. P.; Earl, C. F.; Hicks, C. (2001): Stage due date planning for multistage assembly systems. In: *International Journal of Production Research*, 39. (2001), No. 9, pp. 1943–1954.
- Sumarlia, E.; Usmanova, K.; Fauziyah, F.; Mousa, K. (2021): Managing the risks in the clothing supply chain considering the coronavirus pandemic. In: *Operations and Supply Chain Management: An International Journal*, 14. (2021), No. 4, pp. 576–587.
- Sun, W.; Pan, Y.; Lu, X.; Ma, Q. (2010): Research on flexible job-shop scheduling problem based on a modified genetic algorithm. In: *Journal of Mechanical Science and Technology*, 24. (2010), No. 10, pp. 2119–2125.
- Tamura, T.; Long, H.; Ohno, K. (1999): A sequencing problem to level part usage rates and work loads for a mixed-model assembly line with a bypass subline. In: *International Journal of Production Economics*, 60. (1999), pp. 557–564.
- Towers, N.; McLoughlin, J. (2005): Effective Total Quality Management in the textile fashion retail supply chain: A pilot survey of the UK textile manufacturers. In: *The Journal of the Textile Institute*, 96. (2005), No. 2, pp. 87–92.
- UNEP (2022): Putting the brakes on fast fashion (<https://www.unep.org/news-and-stories/story/putting-brakes-fast-fashion>). Accessed on 01.02.2022.
- Vilcot, G.; Billaut, J.-C. (2011): A tabu search algorithm for solving a multicriteria flexible job shop scheduling problem. In: *International Journal of Production Research*, 49. (2011), No. 23, pp. 6963–6980.
- Wang, S.; Sarker, B. R. (2005): An assembly-type supply chain system controlled by kanbans under a just-in-time delivery policy. In: *European Journal of Operational Research*, 162. (2005), No. 1, pp. 153–172.
- Xiaobo, Z.; Ohno, K. (1994): A sequencing problem for a mixed-model assembly line in a JIT production system. In: *Computers & Industrial Engineering*, 27. (1994), No. 1-4, pp. 71–74.
- Xiaobo, Z.; Ohno, K. (1997): Algorithms for sequencing mixed models on an assembly line in a JIT production system. In: *Computers & Industrial Engineering*, 32. (1997), No. 1, pp. 47–56.
- Xu, Y.; Thomassey, S.; Zeng, X. (2020): Garment mass customization methods for the cutting-related processes. In: *Textile Research Journal*, 9. (2020), No. 7-8, pp. 802–819.
- Yan, H.; Du, X.; Xu, L.; Xu, S.; Zhang, Y. et al. (2022): Toward intelligent clothes manufacturing: a systematic method for static and dynamic task allocation by genetic optimization. In: *Neural Computing and Applications*, 34. (2022), No. 10, pp. 7881–7897.
- Yang, J.-H.; Kincade, D. H.; Chen-Yu, J.H. (2015): Type of Apparel Mass Customization and Levels of Modularity and Variety: Application of the Theory of Inventive Problem Solving. In: *Clothing and Textiles Research Journal*, 33. (2015), No. 3, pp. 199–212.

- Yeung, H.-T.; Choi, T.-M.; Chiu, C.-H. (2010): Innovative Mass Customization in the Fashion Industry. In: Cheng, T.; Choi, T.-M. (eds.): Innovative Quick Response Programs in Logistics and Supply Chain Management. Heidelberg: Springer (International Handbooks on Information Systems), pp. 423–454.
- Yuan, Y.; Xu, H. (2013): Multiobjective flexible job shop scheduling using memetic algorithms. In: IEEE Transactions on Automation Science and Engineering, 12. (2013), No. 1, pp. 1–18.
- Zhang, J.; Ding, G.; Zou, Y.; Qin, S.; Fu, J. (2019): Review of job shop scheduling research and its new perspectives under Industry 4.0. In: Journal of Intelligent Manufacturing, 30. (2019), No. 4, pp. 1809–1830.
- Ziaee, M. (2013): General flowshop scheduling problem with the sequence dependent setup times: A heuristic approach. In: Information Sciences, 25. (2013), No. 126–135.

Authors

Katharina A. **Schuck**, M.A. finished her post-graduate studies in Luxury, Fashion and Sales Management at the International School of Management, German University of Applied Sciences. She holds a Bachelor in Business Administration from the Hochschule Fresenius in Düsseldorf. Her research interests include the luxury and the fashion industry with a focus on general marketing in particular brand management and consumer behaviour as well as topics of manufacturing and change management.



Prof. Dr. Jens K. **Perret** studied business mathematics and economics and received his PhD in economics from the Bergische Universität Wuppertal. Mr. Perret worked at the European Institute for International Economic Relations in Wuppertal. Since 2016, he holds a professorship in Economics and Statistics at the International School of Management, German University of Applied Sciences. His research interests include the use of data analytics in marketing and aspects of the knowledge society.

