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Simulation-based optimization of production flows in a job shop department

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Chapter 1

Introduction

In today’s highly competitive business environment, final consumers desire to buy various products that respect high quality standards at a lower cost. Every year, the companies that have to buy semi-finished products from other companies require shorter lead time to their supplier, due to the enhancing difficulty of forecasting the final clients’ demand because of its increasing variability and due to the willing of responding to this producing following the just in time logic. Thus, if five years ago the delivery date was set to ninety days, now most of the clients demand the products in sixty days. [1]

Therefore, every company has to focus on rapidity to respond to its customers’ requirements, while producing many different products that are often processed in small manufacturing lot sizes due to the increasing variability in clients’ orders. High-mix low-volume manufacturing systems are the focus of many studies and the job shop manufacturing system, in particular, is the one present in the factories in which there is the necessity of responding to customers’ demand for diverse and individual goods. [2]

In order to maintain competitiveness in a highly competitive environment, the main issue addressed by many companies is to develop and handle the productivity in small batches. But it is also fundamental to provide a good coordination and planning of production and logistics activities on the floor in order to match today’s market requirements. [3]

The ultimate goal of most of the companies remains to optimize costs and reduce delivery lead times in order to provide a high service level to the clients and increase the customers' satisfaction.

Therefore, the aim of this thesis is to analyze Loro Piana's finishing department, that is organized as a complex Job Shop manufacturing system, to understand if improvements regarding transportation activities between operations would be necessary, in order to assure a better service level to their customers, and convenient for the company. In particular, what we want to find out is if one worker per working shift allocated to the transportation's activities is enough or not, and thus if it would be necessary to hire more transporters to assure that all the possible transportation's activities are performed.

To do this, first of all, a mathematical programming model is proposed, in which the system's behavior is expressed with a series of inequalities, which represent the constraints of the process.

Then a discrete event simulation model of the department built with Arena simulation software is described. Nowadays, Discrete Event Simulation is used in many fields, like logistics and manufacturing, when it is necessary to represent complex systems that would be difficult to describe with equalities or inequalities. Thanks to simulation models it is easier to evaluate their performance measure such as the resource utilization, the flowtime of the entities to process, the throughput and many others.

Afterward, this simulation model is integrated with an optimization model in order to find the optimal number of transporters required to minimize the cost of the delays. For this purpose, the optimization tool OptQuest for Arena is used.

The thesis is organized as follows. In the second chapter the company in which this case study was implemented is described. In the third chapter the mixed integer linear programming model representing the problem under study is proposed and then it is explained how the optimization procedure was implemented using

OptQuest for Arena. Finally, in the fourth chapter the results of the optimization process are presented.

Chapter 2
The company

In this chapter, it will be given a brief description of the company with the aim of ensuring a better understanding of the analysis it will be done in the next chapters.

In the first section, it will be quickly introduced the history and the strategy of the company.

In the second section, Loro Piana's production facilities and the most important manufacturing process done in each of them will be explained. Then the production plant located in Quarona will be briefly described to introduce the criticalities that characterize the manufacturing process that takes place in this department.

2.1 Presentation of the company

Loro Piana is a company that operates in the luxury goods industry and one of the world’s most exclusive brands for high quality clothes and accessories. With its products it represents a benchmark in high-quality ready-to-wear garments and accessories.

It is based in Piedmont, in the north of Italy and produces top quality textiles. Its fabrics are made from the very finest and rarest raw materials the world has to offer, above all cashmere and baby cashmere form northern China and Mongolia, vicuña from the Andes, extra-fine Merino wool from Australia and New Zealand and lotus flower fiber from Myanmar. It is one of the world’s largest producers of cashmere and the biggest supplier of vicuña.

Loro Piana family started as a merchants of wool fabrics at the beginning of the 19th century in Trivero. In 1924, Pietro Loro Piana opened a wool mill in Quarona Sesia and officially founded the current company, Ing. Loro Piana & C.

In the late 1940s, with Franco Loro Piana, the firm began to export fine fabrics into international markets. In this way it started to create its reputation as a supplier of wool and cashmere textiles of the highest quality for the haute couture industry, that was growing in those years.

When Sergio and Pier Luigi took the reins of the company, they introduced the luxury good division and they started to develop a global retail network.

Thanks to this the firm became more and more renowned for its premium cashmere and fine wool.

Loro Piana was a family-owned enterprise until July 2013, when it became part of Louis Vuitton Moët Hennessy (LVMH), a French luxury goods group, which acquired 80 percent stake in Loro Piana for €2 billion ($2.6 billion). The rest of shareholding remained in Loro Piana family's hands and the company’s heads, Sergio and Pier Luigi Loro Piana, remained in their roles. The enterprise had a value of €2,685 million euros after the acquisition. Loro Piana joined the LVMH group with the aim of benefiting from powerful synergies that can derive from being part of one of the most powerful multinational luxury goods conglomerates while staying true to its value, like craftsmanship, uncompromising search for quality, authenticity and innovation. [4]

In 2017, Pier Luigi Loro Piana sold half of his shares to LVMH and reduced his participation in the company by 5%. With this operation the family reduced their 20% ownership holdings to 15%. [5]

Future prospects comprehend extending Loro Piana’s product range and selectively increasing its worldwide network of boutiques, affirming its global renown for supreme quality.

2.2 Loro Piana's production plants

Loro Piana owns nine production sites, all located in Italy, and 167 flag-ship stores, in the most prestigious locations of the world.

Every plant is specialized in one of the phases of the production process. The most important are:

- spinning, the process of transforming wool, cashmere and vicuna fibres into yarns
- weaving, the process used to form a fabric by interlacing long yarns passing in one direction with others at a right angle to them:
- dyeing
- finishing, the process required to impart the necessary functional properties to the fabric.

The know-how acquired with six generations of experience can guarantee the vertical integration of each stage, from sourcing to production to the delivery of the finished products to the stores. Because of this complete control over manufacturing processes at every stage, the quality standards required can be assured and 100% made in Italy can be guaranteed to the final clients.

In the weaving mill 5 million meters of fabrics are produced each year. A consistent part of the company's revenue derives from supplying textiles to other brands.

2.2.1 The finishing department

The fabric's finishing takes place in the plant located in Quarona. It can be said it is the most complex and critical phase of the production cycle since it comprehends many little processes, each with a different purpose.

In this floor more than one thousand different articles need to be handled and this leads to a wide range of production cycles. The same operations can be done in a different sequence and with different technical specifications in order to obtain a different result on the end product. If there are quality issues fabrics are reworked starting from a different point of the production cycles depending on the type of problem. Fabrics have to be worked in batch of different numerousness, depending on the machine, to assure the saturation of the capacity. The batch size depends also on the type of fabric, heavy textiles are grouped in smaller batches because otherwise it would be impossible to transport them from a machinery to another. New prototypes are continuously released, and they have to be monitored on every step of the production process.

All these factors make the scheduling of the production and the management of the plant quite complex. They can lead to a lot of problems, like bottleneck and consequently delays in deliveries, if they are not properly and quickly solved.

Chapter 3
Problem definition

In the first section of this chapter, the general features of the job shop will be discussed in detail to understand what are, in general, the strengths and the weaknesses of these kind of manufacturing systems.

It will be then provided a description of how these criticalities have an impact on the production process in Loro Piana’s finishing department to understand why improvements are needed, in particular in the transportation process, in paragraph 3.1.1.

In section 3.2 is proposed a literature survey of previous studies that introduced a mathematical model and different solution methods of job shop scheduling problems with various critical issues.

The problem, focus of this study, is afterward formalized with a mathematical model in paragraph 3.3.

In section 3.4 is described the simulation-optimization approach used to provide a solution to the problem, and it is proposed a literature survey of previous studies in which real complex systems were simulated with Arena and then optimized using OptQuest.

In section 3.5 the discrete event simulation model built to represent Loro Piana’s finishing department is described.

3.1 Job Shop manufacturing systems

A job shop is a kind of manufacturing system designed to achieve maximum flexibility in the production process. Flexibility is becoming essential to handle the increasing variability in customers' demand and a varying mix of products.

This type of systems were therefore introduced to produce a wide variety of articles with different production cycles and small lot sizes on the same machines. Every product manufactured in a job shop can have its own operation sequence and therefore its own routing in the system. The operating time for each operation could vary significantly, even if it is performed on the same machine, depending on the type of item. Since, in a job shop, there are a lot of transports to be handled, machines are usually disposed in the department on the basis of technological processes involved to limit the time wasted to deliver a batch from an operation to the following one.

One of the most complex activities in this kind of systems is the production planning and scheduling since usually there isn't a unique production cycle to manage and it can be really problematic to combine all of them together maintaining the production flow constant on every machine.

Most of the weaknesses of this kind of systems are also related to the fact that the material must be moved from a machine to another one. Every product may have to travel through the entire department to fulfil all the required operations. The status and the location of the items might be difficult to track and control especially if there aren't appropriate and specific area to store the articles. In the departments in which the production is organized in batches, if the lot size is big, each part has to wait for a long time for all the remaining ones in the batch to complete processing before it can be moved to the next stage; this might cause high production lead times and high level of work in progress inventory. Consequently, transportation and handling costs might be very high in this kind of manufacturing systems. [2]

3.1.1 Loro Piana's finishing department

The manufacturing system of Loro Piana's finishing department is a job shop.

As said in the previous chapter, in the finishing department, there are many factors that contribute to make very complex the planning of the production and the management of all the activities necessary to assure that every manufacturing process can be properly completed:

- more than one thousand different articles are finished in this woolen mill. They can be divided in two main families, worsted and woolen fabrics. The first ones are typically used to make coats, while the second ones to produce suits. The pieces of fabrics are often grouped in small lot sizes due to the high demand variety;
- even if the final product is always a piece of fabric, the sequence of the operations can vary from item to item. For example, at the beginning of the process, worsted fabrics have to do an operation, called singeing, to obtain an even surface by burning off projecting fibres; while woolen fabrics have to do another operation, called carbonizing, to remove vegetable fibres from wool in an acidic treatment;
- even when the operation seems the same there could be a lot of differences, every piece of fabric could be washed and fulled in many different ways depending on the final aspect and "hand" the product must have; even the same article could react every time in a different way to the washing process and this could lead to fluctuations in the process time;
- the production cycles are often very long, and they comprehend operations typical both of the wet and dry finishing;
- a lot of transports are necessary to move every batch from a machine to the next one, and, especially when operations of the wet and dry finishing are done alternatively, they could take a lot of time. They become even more problematic in high demand periods, when the buffers allocated to the

deposit of the batches of fabrics in front of the machines are all full and the workers have to waste a lot of time to find an available space buffer for the products that they are transporting.

At the moment, in many cases, when the worker finishes to process a batch, he has to stop the machine he is working on and transport the fabrics to the machine where they will do the following operation. There is a resource for working shift allocated to transportation's operations, but he has to do only some specific transports and in particular the ones related to the bottleneck machines. This obviously causes inefficiencies because some machines are often idle even if there would be batches to work. This might lead to a risky deterioration of system's performance, especially during high demand's periods when some machines already constitute a bottleneck without considering the efficiencies losses due to the necessity of transporting the batches. In this situation "wasting" time, which could be spent to produce, on doing transports could be one of the causes of delays in deliveries and, consequently, of the worsening of the service level. To have an idea of why transportation activities can have a big impact on the global performances of the system in this mill, the average number of transports executed every year in Loro Piana's finishing department is summarized in Table 9 in the appendix. According to the data of last year's production, more than one million pieces of fabrics where transported last year in Loro Piana's finishing department.

In today's highly competitive environment, in which delivery times become every year shorter and in which the rapidity and punctuality in responding to customers' demand is one of the most important factors for customer' satisfaction, manufacturers need to reduce response time to customer orders and increase their flexibility. New solutions must be found and implemented to achieve this result and to assure that every piece of fabric will be delivered on time to the clients.

For this reason, as already specified in the introduction, the purpose of this study is to find out if it would advantageous to achieve the desired service level and economically convenient for the company to hire more than one transporter for every work shift.

3.2 Literature review

The problem analyzed in this thesis concerns a job shop scheduling with transport resource routing problem. By the above literature review emerges that many studies were presented that address the classical Job shop scheduling problem (JSSP), while Job Shop scheduling Problem with Transportation resources was treated in a limited number of studies.

The Job shop scheduling problem (JSSP) is one of most complex optimization problems in the planning and managing of manufacturing processes that belongs to the class of (non-deterministic polynomial time) known as NP hard problems [6].

There are many approaches have been used to the JSSP, however, most of them are not efficient to solve large scale problems due to the computational time required. Branch and bound and dynamic programming, for example, are only applicable to modest scale problems [7].

Concerning the JSSP, most of the researchers are interested in optimizing two types of objective functions, known as minimizing the makespan, which is the maximum completion time of all jobs, and minimizing the total weighted tardiness that is the measure of the delay.

Zhang, Rao and Li [8] proposed, considering the minimization of makespan as the objective function, a hybrid algorithm combining a genetic algorithm with local search for the JSSP. Always considering makespan as the objective function, Wang, Xiao, Yin, Hu, Zhao, Jiang [9] introduced a two-stage genetic algorithm for JSSP. Eswaramurthy and Tamilarasi [10] presented, for the classical job shop scheduling problem, a hybrid tabu search and ant colony algorithms. Li and Pan [11] proposed a hybrid algorithm combining particle swarm optimization and tabu search to solve the job shop scheduling problem where the objective is to minimize the maximum fuzzy completion time.

To solve the job shop scheduling problem considering the minimization of the total weighted tardiness, Tamilarasi and Anantha Kumar [12] proposed an enhanced genetic algorithm with simulated annealing.

Kuo and Cheng [13] proposed a study that intends to solve the job shop scheduling problem with both due date time window and release date, where the objective is to minimize the sum of earliness time and tardiness time in order to reduce the storage cost and improve the customer satisfaction. To solve this problem, they introduced a novel hybrid meta-heuristic, called ant colony-particle swarm optimization, that combined ant colony optimization and particle swarm optimization.

Jamili [14], introduced a new variant JSSP, where for every job and/or machine an operator is assigned, all the operations can start only if there is the operator and the workers must have some resting times during the daily working hours and, therefore, it is required to schedule the operations contemplating the obligatory resting times. To solve the problem a branch and bound algorithm and two heuristic algorithms based on the Beam Search and Particle Swarm Optimization are employed. Then the efficiency of the suggested algorithms is validated comparing the obtained solution with optimum solution found using simulated annealing algorithm.

Zhang and Chiong [15] described a job shop scheduling problem with the objective of minimizing energy consumption. To solve this optimization problem, a multi-objective genetic algorithm, incorporated with two problem-specific local improvement methods, is suggested, which aims to improve the quality of the solution by exploiting the mathematical models of two restricted subproblems derived from the original problem.

Tang and Dai [16] extended the classical job shop scheduling problem, where usually the objective is to minimize the makespan, incorporating energy consumption into the objective function. With this approach they tried to vary the total idle time of the given schedule in order to minimize energy consumption while keeping the optimal solution of the makespan.

Shen, Dauzère-Pérès and Neufeld [17] described a mathematical model for the flexible job shop scheduling problem with sequence-dependent setup times and where the objective is to minimize the makespan.

Fu, Aloulou and Triki [18] studied a production scheduling and vehicle routing problem to integrate production programming and outbound distribution scheduling. In this problem a set of jobs has to be processed on distinct parallel machines with job splitting and sequence-dependent setup times and, afterwards, the finished products have to be delivered in batches to several customers with various vehicles, considering that there are delivery time windows. They proposed mathematical models where a production schedule and a distribution plan are built consecutively and in which the objective of the first problem is to minimize the total set up cost and the objective of the second problem is to minimize the transportation cost. To solve the integrated scheduling problem, they developed a two-phase iterative heuristic.

Even if the classical Job Shop scheduling problem is the most treated, some authors focused their studies on a generalization of the classical Job Shop scheduling Problem, the Job Shop scheduling Problem with Transportation resources. Two sub-problems constitute the JSPT: the job shop scheduling problem and the vehicle scheduling problem.

Deliktas, Torkul and Ustun [1] proposed a novel mathematical model that deal with a flexible job shop scheduling problem in a cellular manufacturing environment by taking into consideration intercellular transportation times, sequence-dependent family setup times and recirculation, but without considering empty transportation times.

Bilge and Ulusoy [19] introduced the problem of simultaneous scheduling of machines and AGVs in a flexible manufacturing system. They formulated a nonlinear mixed integer programming model with the objective of minimizing the makespan, in which they considered that the automated guided vehicles don’t have to return to the load/unload station after each delivery. To find a solution to the problem they developed an iterative procedure in which admissible time windows for the trip are constructed solving the machine scheduling problem, which generates the completion times of each operation with a heuristic procedure.

Zhang and Manier [20] proposed a nonlinear model to solve a Flexible Job Shop Scheduling Problem with transportation constraints, with the objective of minimizing the makespan and the the total waiting time before and after each machine during production. They considered that there is a set of identical transport resources responsible for transportation tasks, that all jobs can be transported by any of them, and that empty transportation times are job-independent but machine-dependent. In order to find a solution to the problem of the assignment of resources and of the sequencing of the jobs on each resource, they proposed a tabu search procedure.

El Khoukhi, Lamoudan, Boukachour and El Hilali Alaoui [3] proposed a mathematical model for a problem in which they considered the constraints of the classical JSSP to which they added some additional constraints concerning the operations of transports. In their formulation the transporter vehicles can carry more than one task at a time. The objective of their study is to minimize tardiness and earliness penalties on delays and advances together with the number of empty moves of transporter vehicles. To find a solution to the problem they introduced a resolution algorithm based on ant colony optimization that they denoted ant colony optimization for job shop with transportation times, which can generate the starting times of operations, as well as their starting transportation times.

Caumond, Lacomme, Moukrim, Tchernev [21] proposed a mathematical formulation for the Flexible Manufacturing Systems Scheduling Problem (FMSSP) with only one vehicle available to perform the transportation between operations.

By the above literature survey, there is no research that proposed a linear programming model for the Job Shop scheduling Problem with Transportation resources, where an optimal schedule for each transporter has to be found considering that there are many transporters, each of them can carry only one task at a time and taking into account empty travel times. Furthermore, it must be highlighted that the problem under study tries to replicate a real existing department with a lot of complexities starting from the fact that more than 600 pieces of fabrics are delivered to the clients every day, most of them with a very long production cycle that in most of the cases comprehend almost 30 different processes each of then performed on a different machine. Considering the number of fabrics produced every year and the number of manufacturing process that every article has to do millions of transports are performed every year.

A linear programming model of this problem is proposed in the following section.

3.3 Problem description and mathematical model

Consider a job shop environment with i jobs that have to be processed on a set of machines. Each job i consists of a sequence of n_i consecutive operations, each of which has to be processed on a given machine and has its own route to follow through the shop. Every processing route could be partially or entirely different from the ones of the other jobs. All jobs also have a due date dd_i, representing a desired completion time; they have to be delivered to the client before or at due date to avoid tardiness penalties. Furthermore, they all have a release date rd_i, after which the first operation of the sequence can be performed.

The processing time p_{ij} for operations of each job are known and fixed. Each operation can start only when the previous task, on the associated machine, is concluded and when the job is transported from that machinery to the next one. Preemption is not permitted and therefore each operation has to be finished without interruption once started. Moreover, every machine can process at most one operation at the same time. Each machinery is ready at time zero. A job is completed when all of its operations are entirely done.

The objective of the problem is to sequence the assigned operations on all machines and the transports on the resources allocated to this activity, in order to obtain a feasible schedule minimizing the total cost of the tardiness.

The indices, parameters and decision variables considered in the model are summarized in the following tables.

INDICES		
i	Index for jobs	$i = \{1, \dots, N\}$
j	Index for operations of job i	$j = \{1, \dots, n_i\}$
t	Index for transporters	$t = \{1, \dots, T\}$

PARAMETERS	
CTA	Daily cost of tardiness
rd_i	Release date of job i
p_{ij}	Processing time of $\boldsymbol{j}$-th operation of job i
$d_{iji'j'}$	Distance, expressed in units of time, from the position of job ij to the position of job $i'j'$
dd_i	Due date of job i
M	Large positive number

DECISION VARIABLES	
$\boldsymbol{C_{ij}}$	Completion time of operation j of job i
$WT_{iji'j't}$	Time at which transporter t is available to transport job i' at operation j'
TA_i	Tardiness of job i
$\beta_{iji'j'}$	1, if operation ij is scheduled before $i'j'$; 0, otherwise
α_{ijt}	1 if job ij is assigned to transporter t; 0, otherwise
$\gamma_{iji'j't}$	1, if job ij is assigned to transporter t before $i'j'$; 0, otherwise

The mathematical model of the problem is presented below:

$$\min \sum_{i=1}^{N} TA_i \, CTA \tag{3.1}$$

s.t.

$$C_{i1} \geq rd_i + p_{i1} + d_{i1i2} \qquad \forall\, i \tag{3.2}$$

$$C_{ij} \geq C_{i(j-1)} + p_{ij} + d_{iji(j+1)} \qquad \forall\, i, j = 2, \dots, n_i \tag{3.3}$$

$$C_{ij} \geq WT_{i'j'ijt} + d_{iji(j+1)} \qquad \forall\, t, i \neq i', j = 1, \dots, n_i, j' = 1, \dots, n_{i'} \tag{3.4}$$

$$C_{ij} \geq C_{i'j'} + p_{ij} - M\beta_{iji'j'} \qquad \forall\, i \neq i', j = 1, \dots, n_i, j' = 1, \dots, n_{i'} \tag{3.5}$$

$$C_{i\prime j\prime} \geq C_{ij} + p_{i'j'} - \left(1 - \beta_{iji'j'}\right)M \qquad \forall\, i \neq i', j = 1, \dots, n_i, j' = 1, \dots, n_{i'} \tag{3.6}$$

$$\begin{gathered} WT_{i'j'ijt} \geq C_{i'j'} - p_{i'j'} + d_{i'j'ij} - M\left(2 - \alpha_{ijt} - \alpha_{i'j't} + \gamma_{iji'j't}\right) \\ \forall\, t, i \neq i', j = 1, \dots, n_i, j' = 1, \dots, n_{i'} \end{gathered} \tag{3.7}$$

$$\begin{gathered} WT_{iji'j't} \geq C_{ij} - p_{ij} + d_{iji'j'} - M\left(3 - \alpha_{ijt} - \alpha_{i'j't} - \gamma_{iji'j't}\right) \\ \forall\, t, i \neq i', j = 1, \dots, n_i, j' = 1, \dots, n_{i'} \end{gathered} \tag{3.8}$$

$$\sum_{t=1}^{T} \alpha_{ijt} = 1 \qquad \forall\, i, j = 1, \dots, n_i \tag{3.9}$$

$$C_i \geq C_{ij} \qquad \forall\, i\,, j = 1 \dots n_i \tag{3.10}$$

$$TA_i \geq C_i \; - dd_i \qquad \forall\, i \tag{3.11}$$

$$\gamma_{iji\prime j\prime t} \leq \frac{\alpha_{ijt} + \alpha_{i'j't}}{2} \qquad \forall\, t, i \neq i', j = 1, \dots, n_i, j' = 1, \dots, n_{i'} \tag{3.12}$$

$$C_{ij} \geq 0 \qquad \forall\, i, j = \; 1 \dots n_i \tag{3.13}$$

$$C_i \geq 0 \qquad \forall\, i \tag{3.14}$$

$$WT_{iji\prime j\prime t} \geq 0 \qquad \forall\, t, i \neq i', j = 1, \dots, n_i, j' = 1, \dots, n_{i'} \tag{3.15}$$

$$TA_i \geq 0 \qquad \forall\, i \tag{3.16}$$

$$\beta_{iji\prime j\prime} \,\epsilon\, \{0, 1\} \qquad \forall\, i, i', j = 1, \dots, n_i, j' = 1, \dots, n_{i\prime} \tag{3.17}$$

$$\alpha_{ijt} \,\epsilon\, \{0, 1\} \qquad \forall\, t, i, j = 1, \dots, n_i \tag{3.18}$$

$$\gamma_{iji\prime j\prime t} \,\epsilon\, \{0, 1\} \qquad \forall\, t, i, i', j = 1, \dots, n_i, j' = 1, \dots, n_{i\prime} \tag{3.19}$$

The objective of the problem is to minimize the total tardiness penalties (3.1). In the objective function, the tardiness of every job i has to be multiplied by the daily cost of the delay CTA.

Constraints (3.2) state that the first operation of every job can't be considered completed before its release date rd_i plus its first operation's processing time and the time necessary to move the job to the next machine. Constraints (3.3) and (3.4) ensure the precedence relations between consecutive operations of the same job, considering that jobs are not always transferred to the next operation as soon as they are ready to be transported because at that time all the transporters could be busy in other transports. Constraints (3.5) and (3.6) guarantee that at most one part is processed by each machine at a time; the first one ensures that operation ij starts after the completion of $i'j'$ if ij is scheduled after $i'j'$, while constraints (3.6) are bounding when operation ij is scheduled before $i'j'$. In the other cases these constraints are automatically satisfied, since the right side of the inequalities becomes negative. Constraints (3.7) and (3.8) have the same purpose of prevent overlapping and schedule the jobs, but on the resources allocated to transportations. These constraints are only relevant when jobs ij and $i'j'$ are both assigned to the same transporter t, i.e., $\alpha_{ijt} = \alpha_{i'j't} = 1$.

As stated in constraints (3.9) only one transporter t can be chosen to perform a specific transport. Constraints (3.10) define the completion time of the last operation of job i and constraints (3.11) are used to determine the tardiness of each job. Constraints (3.12) link the binary variable used to assign each job to a transporter with the one used to schedule the transports assigned to every transporter. Finally, binary and non-negativity conditions are set by constraints (3.13), (3.14), (3.15), (3.16), (3.17), (3.18) and (3.19).

3.3.1 Model decomposition

The model described can't be solved in an efficient way with an optimization algorithm that would provide an optimal solution to the problem, principally because of the large number of binary variables used to formulate the constraints of the problem.

A metaheuristic, like the ones proposed in the studies analyzed in the literature review that are capable of solving big and complex problems, such as tabu search, simulated annealing or a genetic algorithm, might provide a sufficiently good solution to the problem. Metaheuristics explore the search space in order to find near optimal solutions, but they don't guarantee that a globally optimal solution will be found [22].

In this section, an approach to reduce the complexity of the model is proposed. The original model has been decomposed into two subproblems to make the problem easier to solve.

The first one is basically the classical job shop scheduling problem while the second one is a vehicle routing problem. The two problems are linked and there is an exchange of information between the two of them that will be described in detail in the following pages.

JOB SHOP

The mathematical model of the job shop scheduling problem is presented below:

$$\min \sum_{i=1}^{N} TA_i \, CTA \tag{3.20}$$

s.t.

$$C_{i1} \geq rd_i + p_{i1} + d_{i1i2} \qquad \forall\, i \tag{3.21}$$

$$C_{ij} \geq C_{i(j-1)} + p_{ij} + d_{iji(j+1)} \qquad \forall\, i, j = 2, \dots, n_i \tag{3.22}$$

$$C_{ij} \geq WT_{i'j'ijt} + d_{iji(j+1)} \qquad \forall\, t, i \neq i', j = 1, \dots, n_i, j' = 1, \dots, n_{i'} \tag{3.23}$$

$$C_{ij} \geq C_{i'j'} + p_{ij} - M\beta_{iji'j'} \qquad \forall\, i \neq i', j = 1, \dots, n_i, j' = 1, \dots, n_{i'} \tag{3.24}$$

$$C_{i'j'} \geq C_{ij} + p_{i'j'} - \left(1 - \beta_{iji'j'}\right)M \qquad \forall\, i \neq i', j = 1, \dots, n_i, j' = 1, \dots, n_{i'} \tag{3.25}$$

$$C_i \geq C_{ij} \qquad \forall\, i\,, j = 1 \dots n_i \tag{3.26}$$

$$TA_i \geq C_i - dd_i \qquad \forall\, i \tag{3.27}$$

$$C_{ij} \geq 0 \qquad \forall\, i, j = 1 \dots n_i \tag{3.28}$$

$$C_i \geq 0 \qquad \forall\, i \tag{3.29}$$

$$TA_i \geq 0 \qquad \forall\, i \tag{3.30}$$

$$\beta_{iji'j'} \in \{0, 1\} \qquad \forall\, i, i', j = 1, \dots, n_i, j' = 1, \dots, n_{i'} \tag{3.31}$$

In this model, the constraints are the ones of the classical job shop scheduling problem. All the constraints are the same presented in the previous model. The only difference is that, while in the previous model $WT_{iji'j't}$ is a variable, in the current model is a parameter. It is the obtained solving a vehicle routing problem and, as previously said, represents the time at which transporter t is available to transport job i' at operation j' to the machine where it will do the following operation.

Solving for the first time this problem, initially considering $WT_{iji'j't}$ equal to zero, an initial sequence of the completion time of each job's operation can be found. Once a first schedule of the operation is defined, the time at which every job i is available to be transported can be used as an input to the vehicle routing problem.

In this model, knowing the moment in which every job finishes each operation and that every job can be moved to the next task only when it completes the previous one, an optimal route for each transporter can be found. Knowing the route of every transporter the parameter $WT_{iji'j't}$ can be updated in the first model. This would probably change the solution given by the job shop scheduling problem and so also the second model should be updated with the new information obtained, solved again to find the new values of the parameter $WT_{iji'j't}$ to update the other model, and so on.

VEHICLE ROUTING

For the second model the formulation of Yang, Jaillet and Mahmassani of the multivehicle pickup and delivery problem is used (23). This problem evaluates the costs related to the distance covered, but also the ones associated with transporters' empty travel distances. It also takes into consideration the operational problem related to the continuous arrival of new transportations' request.

In this problem T transporters work in the job shop, they have to serve a sequence of known job requests. Initially, all T transporters are empty and idle at their initial position. Each transporter can carry on only one job at a time and can't serve another job until the current one is delivered to its final destination. It is assumed that each transporter moves at the same constant unit speed and its available at time zero.

It is assumed that there are K known job to be transported. Each job is characterized by a time at which it is available to be carried to the next operation, AT_k, a pickup location and a delivery location, which is the next machine where it will have to be processed. The corresponding distance between the pickup and delivery locations of each job is denoted l_k.

It has to be specified that for notational simplicity it has been decided to replace the double index ij, used in the job shop scheduling problem and representing operation j of job i, with the single index k. It is now clearer that the variable defined in this model, PT_k, which is the time in which job k can start to be transported to its delivery position, corresponds to the parameter that has to be given as an input to the job shop scheduling problem $WT_{iji'j't}$.

The distance from the transporter t's original position to job k's pickup location, expressed in units of time, is represented by d_{tk}, while the distance between job k's delivery location and the pickup location of job k' is denoted with $d_{kk'}$.

In the model, a set of nodes (1, ..., T, T+1, …, T+K) are considered, where the node t for t =1,…,T corresponds to transporter t and node T+ k for k =1, …,K corresponds to the job k that has to be transported.

In the problem, a binary variable θ_{uv} for u, v = 1,…,T+K is used to indicate if an arc (u, v) is selected in one of the cycles. Using this terminology, $\theta_{t,T+k}$ specifies if transporter t first transports job k, $\theta_{T+k,T+k'}$ identifies whether there is a transporter t that serves job k and k' consecutively. If $\theta_{t,t}$ is equal to 1 it means that there is a transporter t who doesn't carry any job, while if $\theta_{T+k,T+k}$ is equal to 1 it means that job k is not served.

The variable PT_k is used to indicate the pick-up time of job k.

The indices, parameters and decision variables considered in the model are summarized in the following tables.

INDICES		
k	Index for jobs	$k = \{1, \dots, K\}$
t	Index for transporters	$t = \{1, \dots, T\}$
u, v	Indices for the nodes	$u, v = \{1, \dots, T, T+1, \dots, T+K\}$

PARAMETERS	
AT_k	Time at which job k is available to be transported to its delivery destination
d_{tk}	Distance, expressed in units of time, from the transporter t's original position to job k's pickup location
$d_{kk'}$	Distance, expressed in units of time, from the delivery location of job k and the pickup location of job k'
l_k	Distance, expressed in units of time, between the pickup and the delivery locations of each job k
M	Large positive number

DECISION VARIABLES	
PT_k	Time at which job k can start to be transported from its pickup position to its delivery position
θ_{uv}	1, if arc (u, v) is selected in one of the cycles; 0, otherwise

The problem is modeled as an assignment problem, which consists of finding a set of cycles going through all the nodes (1, ..., T, T+1, …, T+K) minimizing the travelled distance.

The mixed-integer programming formulation is proposed below:

$$\min \quad \sum_{t=1}^{T}\sum_{k=1}^{K} d_{tk}\,\theta_{t,T+k} + \sum_{k=1}^{K}\sum_{k'=1,k\neq k'}^{K} d_{kk'}\,\theta_{T+k,T+k'} \tag{3.32}$$

s.t.

$$\sum_{v=1}^{T+K} \theta_{uv} = 1 \qquad \forall \;\; u = 1, \dots, T+K \tag{3.33}$$

$$\sum_{v=1}^{T+K} \theta_{vu} = 1 \qquad \forall \;\; u = 1, \dots, T+K \tag{3.34}$$

$$PT_k \geq \sum_{t=1}^{T} d_{tk}\,\theta_{t,T+k} \qquad \forall \;\; k = 1, \dots, K \tag{3.35}$$

$$PT_{k'} \geq PT_k + l_k + d_{kk'} + M\big(\theta_{t+k,t+k'} - 1\big) \qquad \forall\, k, k' = 1, \dots, K, \quad k \neq k' \tag{3.36}$$

$$PT_k \geq AT_k \qquad \forall \;\; k = 1, \dots, K \tag{3.37}$$

$$\theta_{T+k,T+k} = 0 \qquad \forall\, k = 1, \dots, K \tag{3.38}$$

$$PT_k \geq 0 \qquad \forall \;\; i = 1, \dots, K \tag{3.39}$$

$$\theta_{uv} = \{0, 1\} \qquad \forall\, u, v = 1, \dots, T+K \tag{3.40}$$

Equations (3.33) indicate that each node must be visited only once, meaning that it has to be assigned to only one route. With equations (3.34) the same reasoning is done to the number of departures from each node. Constraints (3.35) impose that, if job k is the first to be transported, the transporter arrives at job k's pickup location after d_{tk} units of time. Constraints (3.36) state that, if k' is served after k, the transporter t arrives at the pickup location of job k' after an amount of time that considers the moment in which he arrives to k's pick up location plus the time necessary to reach the delivery location of this job, l_k, and the time required to get to the pickup position of k', $d_{kk'}$. Since the big M is a large number, when $\theta_{t+k,t+k'} = 0$, and so the two jobs are not served consecutively, the constraints are nonrestrictive. The last two constraints also avoid the creation of cycles without a transporter. Constraints (3.37) assure that each job is picked up after the time in which it becomes available for transport. Constraints (3.38) guarantee that each job is served. Finally, constraints (3.39) and (3.40) set binary and non-negativity conditions.

Despite the decomposition of the original model into two subproblems it still remains quite complex to efficiently solve the optimization problem of the finishing department using an optimization algorithm in order to find the optimal solution of the problem, due to the amount of jobs processed every day by the system, the high number of machines on which every job has to be worked and the transports required. Further studies would be necessary to propose an appropriate optimization method to solve this complex problem in an efficient way.

Metaheuristics like the ones already cited could be used to find a near optimal solution to the mathematical model described. For the purpose of this study and due to the fact that the objective of this work is also to provide a tool usable day by day by the company to constantly evaluates the performances of the systems and understand if some kind of improvements could be implemented in the department, it was decided to propose a preliminary solution using a commercial optimization software, OptQuest.

Moreover, the real problem comprehends elements that are difficult to include in a linear programming model. These are for example the stochastic nature of some parameters like the processing times and the interarrival times between batches or the necessity of varying the numerousness of fabrics included in every batch, depending on the machinery in which it has to do a certain operation, in order to assure the saturation of that machine. While these features are very difficult to handle in a mathematical model, it is quite easy to model them in a discrete event simulation environment.

This software is compatible with Arena Simulation Software, in which a discrete event simulation model of the system under study has to be built. This software uses tabu search, the already cited metaheuristic, and scatter search to try to find the optimal solution to the problem modelled in Arena.

Using this approach, and providing a validated simulation model of the department, it is presented to the company a tool that could be easily used and further modified, depending on the problem that will have to be analyzed, even by the people that don’t have deep programming competencies.

Furthermore, the aim of this thesis is also to propose to Loro Piana a pilot study to show the effectiveness of simulation-optimization approach to analyze, manage and find a convenient solution to the problems of the production plants of the company in order to minimize the costs while maximizing the service level offered to the customers. Thus, the purpose of this study is also to provide to the company the required results necessary to justify further investments in this kind of studies, which would finance the studies needed for the formulation of a more complex simulation-optimization approach to this and other problems of Loro Piana’s facilities.

3.4 Simulation-optimization approach

The studies done in the area of optimization have permitted the formulation of intelligent search method with which it is possible to estimate optimal or near optimal solutions to complex problems that comprehend elements of uncertainty and variability. OptQuest combines these search technologies with simulation models built for Arena. It enriches the analysis competencies of Arena by allowing to search for optimal solutions within a simulation model [24] using an efficient search method, which combines scatter search and tabu search to guide the search for the best combination of input variables, performing a predetermined number of simulation’s runs. OptQuest’s optimization algorithm evaluates the responses from the last simulation run performed and determines a new set of values for the input variables by analyzing and integrating them with responses of previous simulation runs.

Many studies present complex operational problems solved using discrete event simulation with Arena and optimization with OptQuest.

Netto and Botter [25] presented a simulation model to dimension the number of containers necessary to operate with a ship fleet that covers determined route, and at the same time considers the loading operations of empty containers with customers on land, that is to say the empty containers can be repositioned between ports to allow the company to have smaller container fleets. They tried to find a solution that minimize the container fleet using, as a support to the simulation model built, the tool OptQuest of Arena.

Pawlewski and Hoffa [26] tried to solve some designing and organizational problems related to cross-docking terminals, where typically products are received and staged on the dock, then they are reconfigured for shipment and reloaded in outbound trucks. They presented a mathematical model and they introduced a simulation approach to solve these problems. They showed how a problem, difficult to solve by analytical methods, is relatively easy to solve with simulation methods using commercially available simulation and optimization tools like OptQuest.

Bataineh, Al-Aomar, Abu-Shakra [27] proposed an approach for enhancing the performance of a real-world system, the citizen affairs and passports department in Jordan. The proposed approach utilizes discrete-event simulation, and in particular Arena simulation software, to develop the simulation model of the public service office. Afterwards, OptQuest is used for the optimization of the current department.

Neeraj, Pranav Nithin, Niranjhan, Sumeshb, Thenarasu [28] tried to model a manufacturing industry to detect the bottlenecks of the factory and also to compute the productivity and the workforce required. In their paper they focused on discrete event simulation using Arena simulation software and then two tools available with

Arena, Process Analyzer (PAN) and OptQuest, were used to find the optimal results for the system under study.

Pierreval, Daures, Both, Szimczak, Gonzalez and Framinan [29] presented an approach based on simulation optimization developed on Arena and OptQuest to reduce the work in process and maintain a required level of customer satisfaction in a ConWIP system.

Yun, Lee and Choi [30] tried to study an inventory control problem of empty containers in a hub area, in which more empty containers were needed because the demand of empty containers was greater than the supply. To fulfill the request of empty containers, it became necessary to move empty containers from other hubs based on the (s, S) inventory policy or to lease empty containers with zero lead time. They developed this study using simulation with Arena, to evaluate an estimation of the expected cost rate, and OptQuest for Arena to obtain the near optimal (s, S) inventory policy.

Feng, Qing-hua, San-tao and Wei [31] introduced how to simulate the scheduling of flight logistic vehicle support by using the discrete event simulation software Arena and afterward, they tried to find the optimal number of resources of support vehicle using the OptQuest toolbox integrated in the Arena.

Ilgin and Gupta [32] proposed an optimization model using OptQuest for Arena to handle the disassembly, transportation of spare parts and their inventory policies in a reverse logistics network designed for End of Life products' recycling. The discrete event simulation model was developed in detail using Arena simulation software. Afterward, in order to minimize the total inventory, recovery, operating costs and the truck amortization, the optimal number and the optimal capacity of trucks together with the optimum reorder level and order quantity for the spare parts was estimated with OptQuest.

Malopolski [33] studied an automated manufacturing system in which transports were handled with automated guided vehicles (AGV). Arena simulation software and OptQuest were used to model the problem and perform the optimization, in which the objective was to find the optimal number of resources in the factory and the optimal number of locations for the AGVs to maximize the profit of the manufacturing system.

3.5 Preparing the discrete event simulation model

Before running OptQuest, an appropriate Arena model for the problem, which comprehends all the elements that have to be optimized, must be developed.

The discrete event simulation model proposed describes Loro Piana's finishing department introducing a change to the current allocation of transport's operations to the workers. While, at the moment, in many cases the workers assigned to the machines are the same that perform the transport's operations of the batches they finish to work to the next machinery, in this formulation of the department all the transportations are performed only by the transporters.

In the considered Job Shop more than one thousand different types of articles and more than 100.000 pieces of fabric are produced every year, which could be divided into twelve main different families: worsted yarn-dyed, worsted yarn-dyed Tasmanian, worsted piece-dyed Tasmanian, woolen yarn-dyed, woolen yarn-dyed double, woolen piece-dyed, scarves yarn-dyed, scarves piece-dyed, flannels, pile, nylon, linen. Since every piece of fabrics is characterized by a type, a length and a due date and due to the fact that the production is affected by seasonality, it was necessary to estimate the distributions of the monthly interarrival times, the monthly production mix, the length of each different type of fabric and the distribution of the due dates of every job.

To provide an example of the method used to estimate these distributions, the estimation's process of the distribution of the due dates will be presented.

Since, to create the simulation model of the finishing department twelve categories of fabrics, which grouped all the articles with a similar production cycle, were identified, it became necessary to estimate a distribution of the due dates of all the pieces of fabric belonging to every classification.

To obtain all the needed information related to the due date of each type of article the data provided by the company were investigated and reorganized to estimate their statistical distribution.

The data were analyzed using Matlab (presented in appendix) to determine the probability distributions that provide the best fit to the real data. Frequency histograms were used to identify the shape and the correct family of the data's distributions and afterward the parameters of the distributions that guaranteed the best fit were estimated using Maximum likelihood estimators' method (MLEs). However, since the shape of the histogram could have been associated to different families, a goodness-of-fit test was performed to evaluate how well the distribution and the parameters represented the analyzed data. In this case in particular, Kolmogorov-Smirnov test was performed. None of the fitted distribution was exactly correct, but the objective was to determine a distribution accurate enough for the purposes of the model. [34]

The following figures show the histograms and the representation of the distributions that provide a good fit to the data.

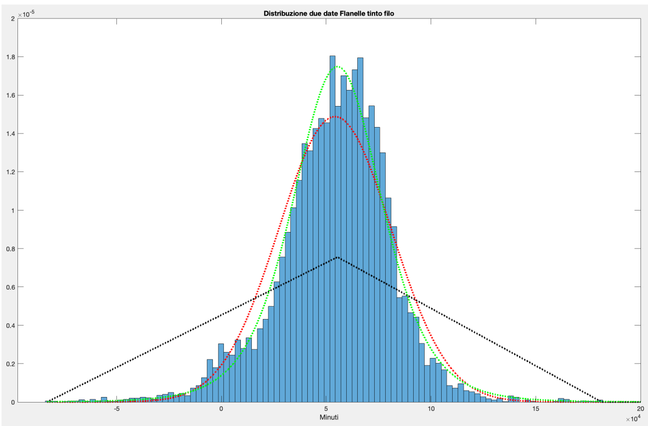

Figure 1: Due Date flannel yarn-dyed

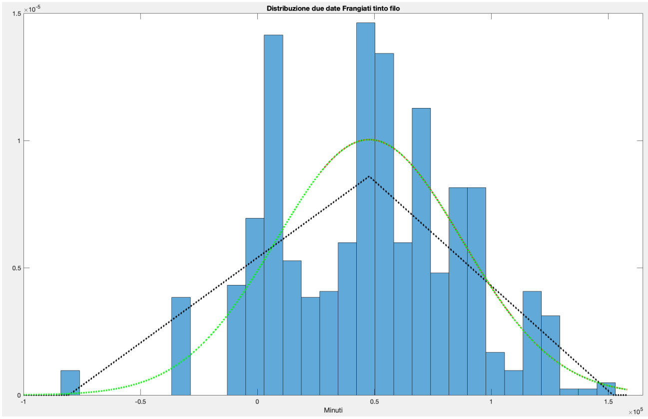

Figure 2: Due Date scarves yarn-dyed

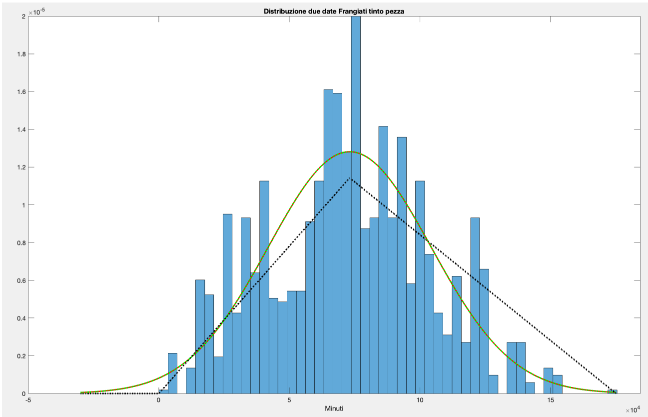

Figure 3: Due Date scarves piece-dyed

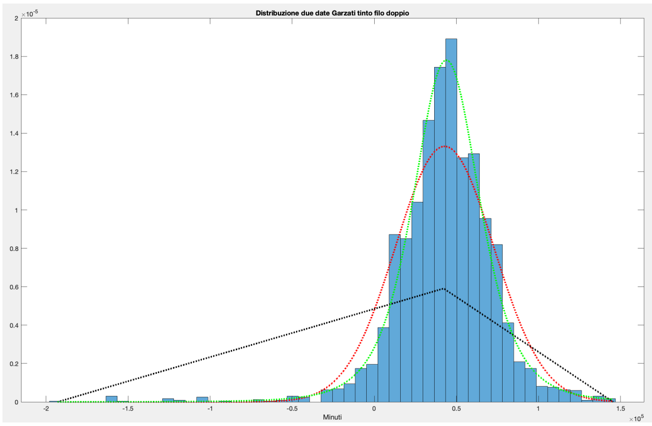

Figure 4: Due Date woolen yarn-dyed double

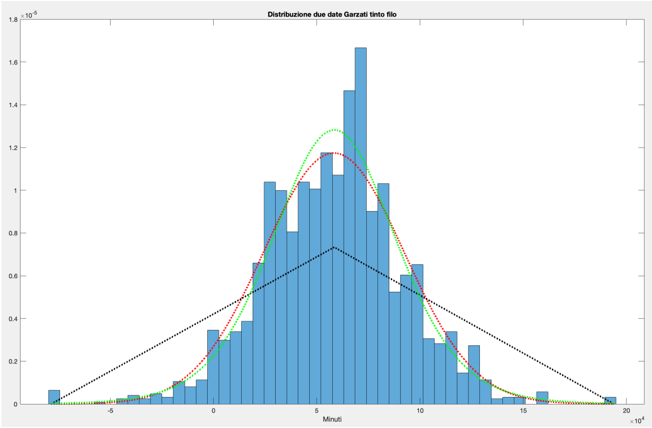

Figure 5: Due Date woolen yarn-dyed

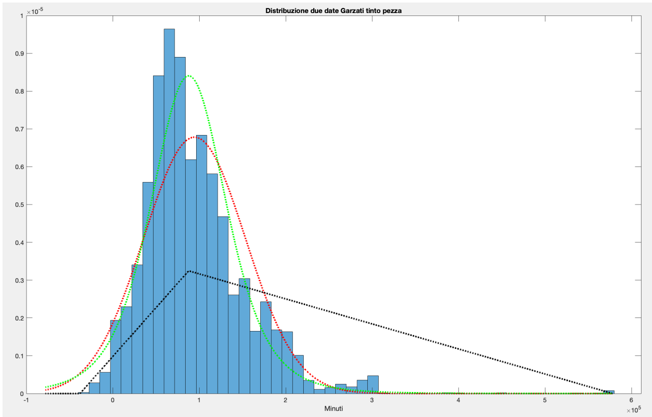

Figure 6: Due Date woolen piece-dyed

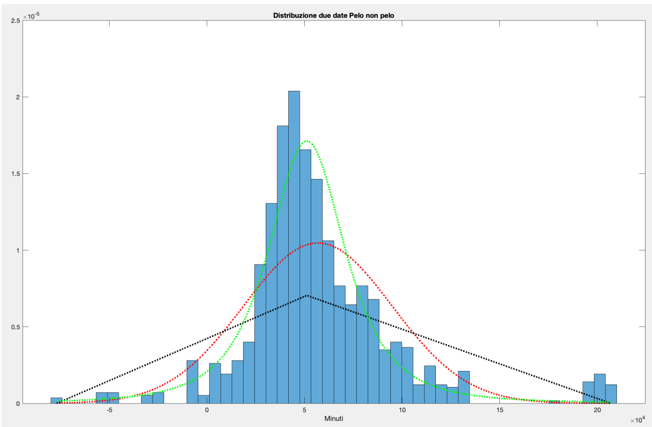

Figure 7: Due Date pile

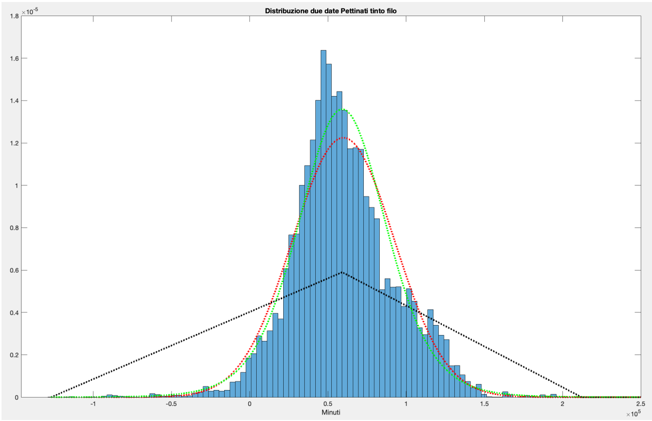

Figure 8: Due Date worsted yarn-dyed

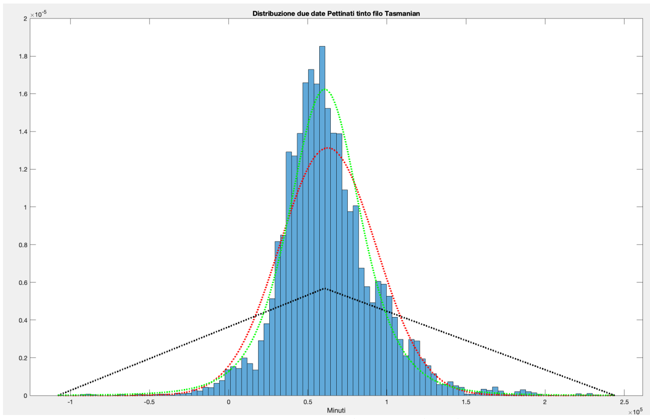

Figure 9. Due Date worsted yarn-dyed Tasmanian

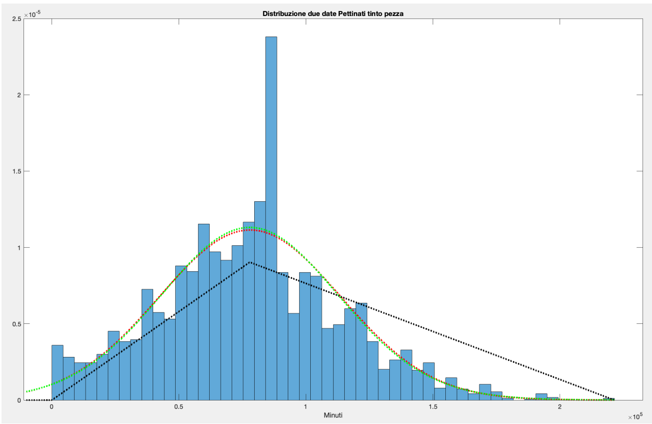

Figure 10: Due Date worsted piece-dyed

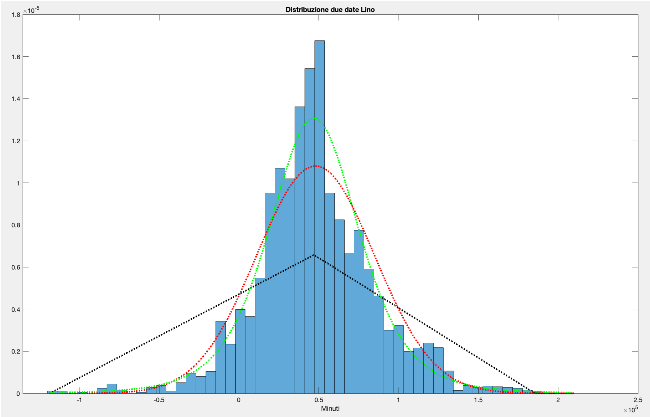

Figure 11: Due Date worsted Linen

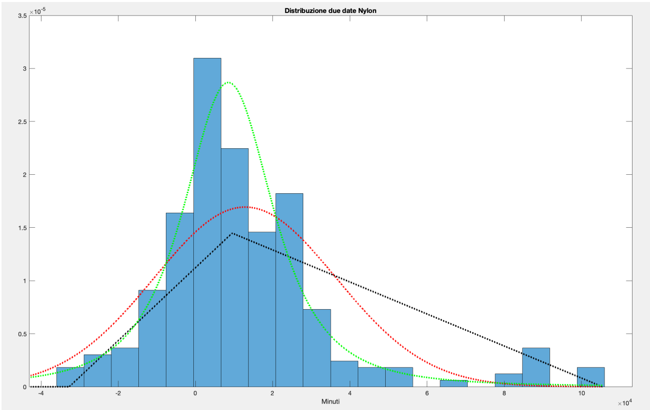

Figure 12: Due Date Nylon

It must be mentioned, as illustrated in the histograms of the due date's distribution of the various families of product, that sometimes happens that the fabrics, considering their expected delivery date, already arrive at their first operation of the finishing process with a delay. This is mainly due to delays that occur in the weaving process, which in their turn may be caused by an unavailability of the raw material of this phase, the yarn.

These fabrics have maximum priority on every machine during the finishing process.

It has to be specified that, for this reason, only the distribution that can assume also negative values were tried to be fitted to the data.

The estimated distributions are summarized in the following table. Even if, for certain product Student's t-distribution provided a better fit, it was decided to select the

Normal Distribution because the previous one cannot be supported by Arena simulation software.

TYPES	*DISTRIBUTION*
Nylon	NORM (12856 , 23559)
Woolen YDD	NORM (42826 , 29971)
Scarves YD	NORM (46807 , 41606)
Linen	NORM (48219 , 38204)
Flanells YD	NORM (54217 , 27133)
Pile	NORM (56792 , 38117)
Woolen YD	NORM (58264 , 33978)
Worsted YD	NORM (60052 , 33357)
Worsted YDT	NORM (62671 , 30638)
Worsted PD	NORM (78915 , 40196)
Scarves PD	NORM (79000 , 58111)
Woolen PD	NORM (94518 , 58823)

Table 1: Due Date distributions

The same method was used to estimate the distributions of the interarrival times and the ones of the product mix. Both the interarrivals times and the product mix have a different distribution for each month of the year, it was necessary to do that since the fabrics produced are affected by seasonality, due to the presence of a winter and summer collection. (Table 11 in appendix)

It was then required to find the distribution of the length of each type of fabric, since it is not always the same and the length of each product significantly affects the processing times. (Table 12 in appendix)

Furthermore, each entity, depending on its type, has a different production cycle. A lot of different operations are needed to give to the final product the desired aspect and "hand". Even if the final product is always a piece of fabric, the sequence of the operations can vary a lot from item to item. As previously said, twelve different production cycles are considered. Thirty-nine different types of machines form the job shop and each machinery is necessary to perform a different operation required to have the end products. To have an idea of the complexity of the process and of the number of operations needed to have a high-quality final product, the production cycle of a worsted piece-dyed Tasmanian is presented in the flow diagram in figure 21 in appendix.

Each fabric has a different processing time calculated considering the length of that specific fabric and the speed at which that machine works. Even when the operation seems the same there could be a lot of differences, for example, every piece of fabric could do what might seem the same process in many different ways depending on the final aspect and "hand" the product must have and even the same article could react every time in a different way to the same operation and this could lead to variability in the process time. For this reason, it was necessary to carefully evaluates the distribution of the speed of each machine considering the specific operation it is performing and the kind of fabric worked, in order to be able to calculate the processing time of each type of fabric.

Furthermore, in the model it was considered that the fabrics are grouped in batches of different numerousness and that the batch size could vary during the process depending on the lot size required to perform each operation in order to assure the saturation of the machineries.

From each station, after being processed, every entity has to be transported to the next operation according to its specified sequence. In this model all the transports are performed by the specific resources allocated to this kind of activities.

Since the objective of the optimization is to find the optimal number of transporters in order to minimize the delay of each job and consequently the related costs, it was necessary to assure that the job with the earliest due date, or the one that already has a delay, in the queue of each machine is processed before the others.

Furthermore, since the number of transporters required in the department is one of the decision variables of the problem, it was necessary to record the number of transporters that are not necessary to perform the required transport's operations.

Moreover, the tardiness of each fabric and the number of entities that are not delivered to the client on time have to be estimated by the discrete event simulation model.

The optimal configuration of the model was then found using OptQuest. The company's main objective is to minimize the annual cost of tardiness, while minimizing the number of resources required to perform transportations between machines. Thus, the objective of the optimization process is to find the optimal number of transporters in order to simultaneously minimize both the costs related to these resources and the ones related to the delays in the deliveries of the final product to the customers.

In order to obtain a consistent value for the statistics used to build the objective function and for the ones necessary to evaluate the job shop's performances, 15 replications for each simulation are performed. The method used to estimate the required number of replications is explained in detail in the next section.

The implementation of the model in OptQuest is described in detail in appendix.

Chapter 4

Evaluated scenarios and results

This chapter proposes a preliminary solution to the job shop scheduling with transport resource routing problem described in the previous chapter. The solution provided is obtained using OptQuest for Arena.

In section 4.1 the two different scenarios considered in the optimization process are described.

In section 4.2 it is described how the required number of replications for each simulation run was estimated in order to achieve a required confidence level for the performance measures of the problem.

Finally, in section 4.3 the results of the optimization procedure are presented and analyzed.

4.1 Evaluated scenarios

In the optimization process two scenarios were considered in order to provide a comparison and understand that is always recommendable to continuously control the process and its performance because with a different configuration of the department the results could significantly change.

As previously said, the objective function evaluates both the cost of the transporters and the cost of the delays.

The hourly cost of the transporter comprehends all the training course constantly done, the medical assurance provided by the company, the subsidy for the meal in the canteen, the medical examinations each worker has to periodically do and all their necessary equipment.

It is really complex to evaluate the cost of the tardiness, mainly due to the fact that in a few cases in zero, in many cases depends on the length of the delay and sometimes might even cause the cancellation of the order and might contribute to the loss of a client. For this reason, different levels of cost were considered for the value assigned to the daily unitary cost of tardiness.

In the first scenario the transporter's speed is set to 60 mt/min, which is the velocity directly evaluated from the analysis of Loro Piana's finishing department.

One more scenario was analyzed to see how the results would change considering that the efficiency of the transporter and the speed of the forklift truck could be different from the current one. It was decided to simulate a more restrictive scenario to evaluate the impact of transporters' productivity on production flows.

4.2 Number of replications and interval estimation

As introduced in the previous chapter, in order to obtain a reliable value of every performance measure necessary to evaluate the global performance of the system under study, many replications for each simulation run are needed to evaluate the mean value, the variance and the interval estimation of each statistic.

Thus, the number of replications, necessary to achieve a required confidence level, has to be established.

To estimate the number of replications to run for each scenario the two-steps method was applied [34]. With this technique n is calculated in using the following formula, where $t_{n_1-1,1-\frac{\alpha}{2}}$ is the value of Student's t-distribution with $n_1 - 1$ degrees of freedom, c^* is the desired half-width we would like to obtain from the simulation experiment and $S(n_1)^2$ is the sample variance:

$$n = \left(\frac{t_{n_1-1,1-\frac{\alpha}{2}}}{c^*}\right)^2 * S(n_1)^2$$

To evaluate the sample variance, fifteen pilot replications were executed.

As can be seen in table 7 in the appendix for the statistic representing the monthly throughput of scarves yarn-dyed, the number of replications required to achieve the predefined confidence interval is really high, in particular for the statistic concerning the throughput for this kind of fabrics in January when more than 3000 replications would be necessary. This is mainly due to the small number this type of entities created each month that have to be grouped in batches of eight piece of fabrics to be processed. In January in particular, a number of entities large enough to create one batch is generated only in two of the fifteen replications and consequently this causes an elevated variability. Therefore, the value of the sample variance appears really high compared to the mean value of this performance measure and this leads to an enormous increase in the number of needed replications.

Thus, since it would have been really time consuming and non-value added to run 3204 replications, it was decided not to consider this exception and to consider the others performance measures to estimate this value.

The resulting number turned out to be fifteen. Since fifteen was the number of pilot replications performed it was not necessary to run further replications to correctly evaluate the performance measures and their interval estimation.

In the optimization procedure 15 replications were done for each simulation.

4.3 Results

The results obtained optimizing the existing model in order to minimize the total cost, which comprehend the the yearly cost of transporters and the annual cost of tardiness, are summarized in figure 18 and table 10 in the appendix.

Figure 18 and table 2 show that only when the daily unitary cost of the tardiness is equal to or higher than 125 €/(u*dd) it results convenient to hire two transporters per working shift. Even increasing the tardiness penalty and assigning to it an unreal value, it never results convenient to hire more than two transporter per working shift.

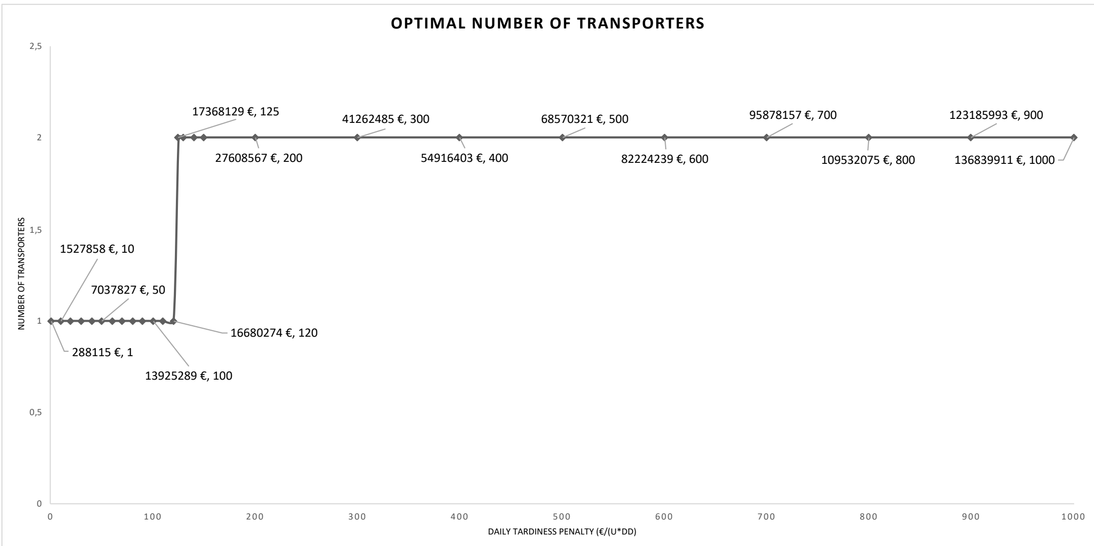

Figure 13: Optimal number of transporters required

As highlighted in the table 2, with two transporters per working shift instead of one, only one hundred more entities can be delivered to the client on time. With three transporters per working shift the number of fabrics completed after their due date remains approximately the same, meaning that the transporters are not the bottleneck of the process.

NUMBER OF TRANSPORTERS	*MEAN NUMBER OF ENTITIES WITH A DELAY*	*MEAN DAYS OF DELAY*
1	10725	13
2	10662	13
3	10669	13

Table 2: Analysis of delays

Even if only one transporter per shift would be hired, considering that more than 120.000 piece of fabrics are produced every year, the resource allocated to transport can't be considered the most critical bottleneck of the process and, in most of the cases, one transporter for working shift should be able to perform all the required operations.

Since the articles produced and sold by Loro Piana are affected by seasonality and the product mix as well as the production volumes change every month, as highlighted in figure 19, it might be recommended to hire a second seasonal worker only for the months characterized by the highest levels of demand. In fact, these are the months in which it would be more risky to not have all the necessary transportations' resources required to assure a continuous and fast supply of every machine and to guarantee that the batches are moved to the next operation as soon as they finish the previous one, since in these months every kind of delay should be prevented due to the high saturation of the machines.

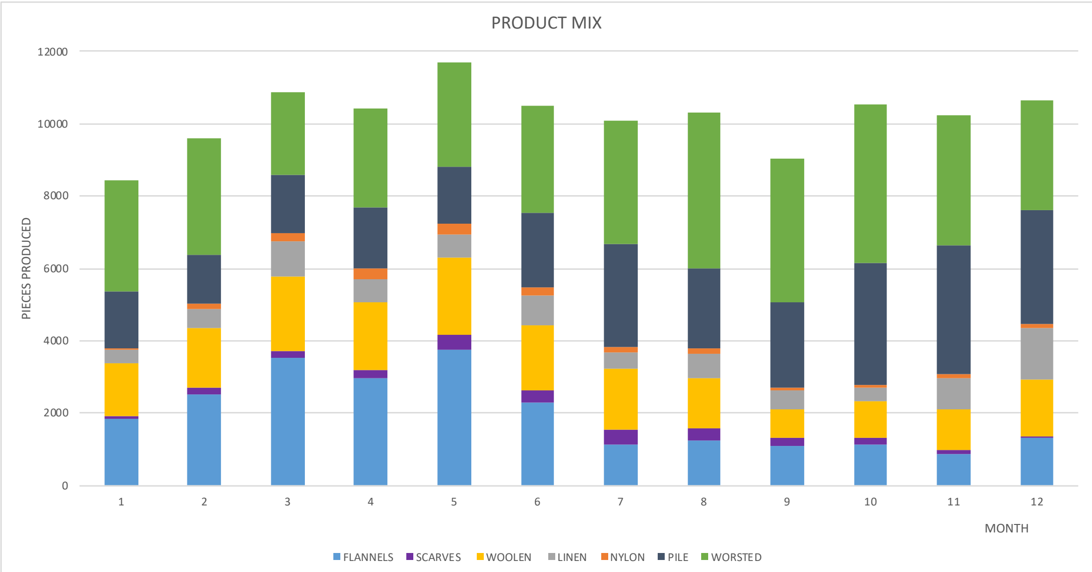

Figure 14: Annual product mix

As stated in table 4, the months in which the production volumes are higher correspond to the months in which the mean days of delay and the number of pieces delivered after their due date are higher.

MONTH	*MEAN DAYS OF DELAY*	*NUMBER OF ENTITY WITH A DELAY*
January	12	595
February	13	778
March	13	1012
April	14	1097
May	14	1215
June	13	1008
July	13	849
August	13	816
September	12	698
October	12	841
November	12	871
December	13	945

Table 3

To understand if it would be recommendable to hire a second transporter during peak periods, the same analysis was done considering two resources. As highlighted in table 5, the improvements are not so significant to justify the engagement of one more worker. In May, the month characterized by the highest number of delays, only two more units on average are delivered on time. An investment in another resource would be justified only if the tardiness cost is very high compared to the cost of the worker.

MONTH	*MEAN DAYS OF DELAY*	*NUMBER OF ENTITY WITH A DELAY*
January	12	600
February	13	753
March	13	1008
April	14	1089
May	14	1213
June	13	1004
July	13	852
August	12	816
September	12	699
October	12	850
November	12	845
December	13	932

Table 4

These two examples clearly show that the transports are not the bottleneck of the process. Analyzing the results in table 8 in the appendix it is evident that some machinery, like the stenter machine, are critical because their utilization, especially during peak-periods, is closer to 100%. The cause of the delays in the deliveries, with this configuration of the department, mainly reside in the high saturation of these machineries. Eliminating these bottlenecks first, the schedule of every operation on each machine would surely change, the required supply of every machine would be different and, consequently, the production flows would increase. This could lead to the necessity to hire more than one transporter per working shift to process all the needed transport's operations.

As previously introduced, a second scenario was analyzed to evaluate the impact of transporters' productivity on production flows.

Figure 20 shows how the results would change assigning a value of 40 mt/min, instead of 60 mt/min, to the speed of the transporter.

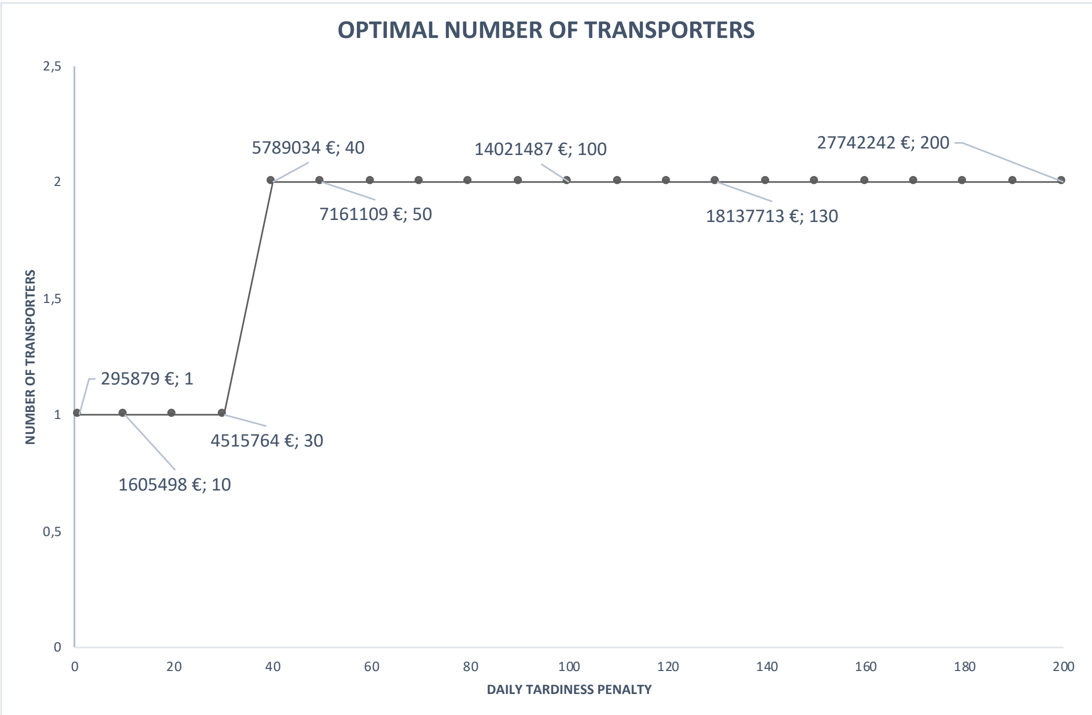

Figure 15: Optimal number of transporters required with a speed of 40 mt/min

In this scenario, it would be highly recommended to have two transporters, at least for the first two working shift that are the ones in which all the machineries work and, consequently, in which there are more transportations to handle. It can be seen that, in this case, with a daily cost for the tardiness of 40 € per piece of fabric it becomes convenient to hire a second worker, while, in the previous case, it started to become cheaper to have two transporters when the cost was equal to 125 € per piece of fabric.

Comparing table 5 and table 6, it can be highlighted that with a transporter's speed of 40 mt/min, on average during the months characterized by the highest tardiness it would be possible, having two transporters, to deliver approximately one hundred more pieces to the clients on time every month. In the previous scenario, with two transporters, one hundred more pieces were completed on time in one year.

Thus, it results really fundamental to constantly monitor the performances of the transporters in order to evaluate if they remain the same or if they change, because, as shown with these two examples, they can have an important impact on the global performances of the system and on the service level assured to the client.

MONTH	*MEAN DAYS OF DELAY*	*NUMBER OF ENTITY WITH A DELAY*
January	12	614
February	13	806
March	14	1035
April	14	1163
May	14	1356
June	13	1110
July	13	902
August	13	844
September	12	694
October	12	867
November	12	872
December	12	934

Table 5

MONTH	*MEAN DAYS OF DELAY*	*NUMBER OF ENTITY WITH A DELAY*
January	12	588
February	13	749
March	14	1018
April	14	1096
May	14	1213
June	13	1012
July	13	832
August	13	808
September	12	701
October	12	845
November	12	854
December	12	928

Table 6

Chapter 6
Conclusion

Due to the complexity and variability that, nowadays, characterize customers' demand, the company are facing an increasing necessity to respond as fast as possible to clients' orders. One of the main issues of the firms is to avoid delays in the delivery of their products to the clients, in order to maintain a high service level and consequently a high customer's satisfaction, despite the fact that the delivery lead time required by the clients of every company is becoming every year shorter.

This is also the main concern of Loro Piana. In the finishing department of this company more than one thousand articles are handled every year, they all have a very complex and articulated production cycle and the main issue addressed by the company still remains to distribute fabrics of the finest quality to their clients. But despite that, the increasing demand, the continue creation of new prototypes that will then become new articles to produce to add to the old ones and the necessity to have a high service level in order not to lose any clients and maintain competitiveness, are pushing Loro Piana to focus its attention to find an optimal exploitation of all its resources.

In particular, the problem addressed by this study is to understand if one transporter per working shift was enough to fulfill all the transportation's request and to assure a regular supply to every machine of the job shop department under study, or instead if it would be better to hire more worker to allocate to this activity. The ultimate objective is to minimize the total cost associated to the delay together with the cost of the transporters

To provide a solution to this problem, the first approach proposed is to optimize the process solving a mixed integer linear programming model. Due to the high complexity of this problem it resulted impossible to efficiently solve it using an optimization algorithm.

A second approach is proposed, and the problem was modelled in Arena and successively, OptQuest for Arena is used to provide an analysis to the company. From the optimization process it resulted that one transporter per working shift is sufficient to handle all the transport operation and that, considering the actual configuration of the department, the bottlenecks of the process are constituted by some of the machinery.

A second scenario, with a lower efficiency of the transporters, was simulated to understand if the transporter's productivity could have an impact on the global performances, and in this it resulted convenient to have two transporter per shift in order to deliver one hundred more piece of fabrics on time to the clients, especially during peak periods.

It is then recommended to constantly monitor the efficiency of this activity in order to evaluate if it is necessary to vary the number of resources allocated to this activity in the department.

It must be specified new machineries have been recently installed in the department, thus it will be necessary to revisit this analysis adding all the new constraints to evaluate if more transporters would be necessary to handle the increasing number of transportation's request due to the rising of the production flows consequent to the presence of new machines.

Appendix

DETAILED DESCRIPTION OF THE OPTIMIZATION PROCEDURE

The objective of this section is to provide a detailed description of how the model was implemented in OptQuest for Arena in order to obtain the desired results.

As described in the thesis, the company's main objective is to minimize the annual cost of tardiness, while minimizing the number of resources required to perform transportations between machines.

For this reason, the variable InactiveTransporters, introduced in the Arena model to record the number of transporters that are not used in a specific simulation run, had to be selected as a control as shown in figure 13. Controls can be selected among variables or resources defined in the Arena model. Their values are changed before the starting of each new simulation to find the combination that assures the best performance of the simulated system. Lower and upper bounds had to be specified to limit the value of capacity that the transporter can have.

It is important to specify that, for the way in which the Arena Simulation model was built, when the control InactiveTransporters assumes the value 10 it means that there is only one active transporter for each working shift in the system, when the optimal value of the control is 9 it means that there are two transporters for working shift operating in the department and so on.

Controls

Included	Category	Name	Element Type	Type	Low Bound	Suggested Value	High Bound	Step	Description
☑	User Specified	InactiveTransporters	Variable	Discrete	1	2	10	1	
☐	Resources	Bruciapelo	Resource	Discrete	0	0	1	1	
☐	Resources	Carbonizzo	Resource	Discrete	0	0	1	1	
☐	Resources	ChemisetFissatex	Resource	Discrete	0	0	1	1	
☐	Resources	CimatricePettinati	Resource	Discrete	0	0	1	1	
☐	Resources	CimatriceScuri	Resource	Discrete	0	0	1	1	
☐	Resources	Cimi	Resource	Discrete	0	0	1	1	
☐	Resources	ControlloFinito	Resource	Discrete	0	0	1	1	
☐	Resources	ControlloIntermedio	Resource	Discrete	0	0	1	1	
☐	Resources	ControlloLunato	Resource	Discrete	0	0	1	1	
☐	Resources	ControlloTintoria	Resource	Discrete	0	0	1	1	
☐	Resources	Decatizzo	Resource	Discrete	0	0	1	1	
☐	Resources	Ecosystem	Resource	Discrete	0	0	1	1	
☐	Resources	Formula1	Resource	Discrete	0	0	1	1	
☐	Resources	Garza	Resource	Discrete	0	0	1	1	
☐	Resources	GarzaPiccola	Resource	Discrete	0	0	1	1	
☐	Resources	GX	Resource	Discrete	0	0	1	1	
☐	Resources	KD	Resource	Discrete	0	0	1	1	
☐	Resources	Lavanova	Resource	Discrete	0	0	1	1	
☐	User Specified	MaxTrasloelevatore	Variable	Continuous	0.9	1	1.1	N/A	
☐	Resources	Multicrab	Resource	Discrete	0	0	1	1	
☐	Resources	Multipla	Resource	Discrete	0	0	1	1	
☐	Resources	Pentek	Resource	Discrete	0	0	1	1	
☐	Resources	Preparazione	Resource	Discrete	0	0	1	1	
☐	Resources	RamaAlea	Resource	Discrete	0	0	1	1	
☐	Resources	RamaF2	Resource	Discrete	0	0	1	1	
☐	Resources	RamaUnitech	Resource	Discrete	0	0	1	1	
☐	Resources	Rotormat	Resource	Discrete	0	0	1	1	
☐	Resources	Soliatura	Resource	Discrete	0	0	1	1	

Figure 16: Constrols summary in OptQuest

Then the responses had to be selected. The value of the responses is an output of the Arena model and can't be modified. However, the tardiness had to be minimized and thus it was necessary to select the statistic that calculates the mean tardiness and the one that counts the number of products that are completed after their due date in order to be able to insert these values in the objective function.

Using OptQuest, it is not required to specify all the constraints relative to the dynamic of the system since all of them are implicitly considered during the construction of the Arena simulation model.

Responses

	Included	Category	Data Type	Name	Response Type
	☑	User Specified	Count	Pezze in ritardo	Counter Value
	☑	User Specified	Count	PezzeProdotte	Counter Value
	☑	User Specified	Interval	Record Tardiness	Tally Value
	☐	Entity	Number In	Controllo.NumberIn	Output Value
	☐	Entity	Number Out	Controllo.NumberOut	Output Value
	☐	Entity	NVA Cost	Controllo.NVACost	Tally Value
	☐	Entity	NVA Time	Controllo.NVATime	Tally Value
	☐	Entity	Other Cost	Controllo.OtherCost	Tally Value
	☐	Entity	Other Time	Controllo.OtherTime	Tally Value
	☐	Entity	Total Cost	Controllo.TotalCost	Tally Value
	☐	Entity	Total Time	Controllo.TotalTime	Tally Value
	☐	Entity	Tran Cost	Controllo.TranCost	Tally Value
	☐	Entity	Tran Time	Controllo.TranTime	Tally Value
	☐	Entity	VA Cost	Controllo.VACost	Tally Value
	☐	Entity	VA Time	Controllo.VATime	Tally Value
	☐	Entity	Wait Cost	Controllo.WaitCost	Tally Value
	☐	Entity	Wait Time	Controllo.WaitTime	Tally Value
	☐	Entity	WIP	Controllo.WIP	DStat Average
	☐	Entity	Number In	Entity 1.NumberIn	Output Value
	☐	Entity	Number Out	Entity 1.NumberOut	Output Value
	☐	Entity	NVA Cost	Entity 1.NVACost	Tally Value
	☐	Entity	NVA Time	Entity 1.NVATime	Tally Value
	☐	Entity	Other Cost	Entity 1.OtherCost	Tally Value
	☐	Entity	Other Time	Entity 1.OtherTime	Tally Value
	☐	Entity	Total Cost	Entity 1.TotalCost	Tally Value
	☐	Entity	Total Time	Entity 1.TotalTime	Tally Value
	☐	Entity	Tran Cost	Entity 1.TranCost	Tally Value
	☐	Entity	Tran Time	Entity 1.TranTime	Tally Value
	☐	Entity	VA Cost	Entity 1.VACost	Tally Value

Figure 17: Responses Summary in OptQuest

Next, the objective function had to be defined as shown in figure 15. As previously said the company wants to minimize the annual cost of tardiness, while finding the optimal number of resources necessary to perform all the required transports among machines. Thus, the objective function is composed by the summation of the total annual cost of the tardiness and the annual cost of the transporters. The first term is calculated multiplying the average days of delay of each entity by the number of fabrics that are delivered after their due date. In the second one, the number of transporters used in that specific simulation is multiplied by their annual cost. It has already been specified that when the variable InactiveTransporters takes the value 10 it means that there is one active transporter for each working shift in the system, and for this reason to find the number of resources that are occupied in transports it is necessary to subtract the value of the control InactiveTransporters from 11.

The value assigned to the annual cost of the transporters was found starting from the hourly cost of each transporter, which was then multiplied by the yearly working hours.

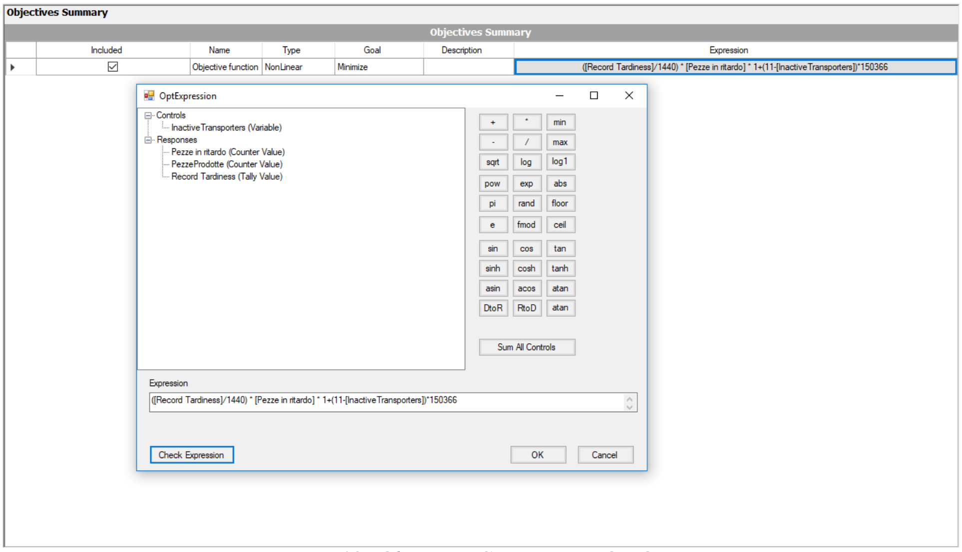

Figure 18: Objectuve Summary in OptQuest

The model is then simulated. During each simulation the number of resources allocated to transports changes. In order to obtain a consistent value for the statistics used to build the objective function and for the ones necessary to evaluate the job shop's performance, 15 replications for each simulation are performed. The method used to estimate the required number of replications is explained in detail in the next section.

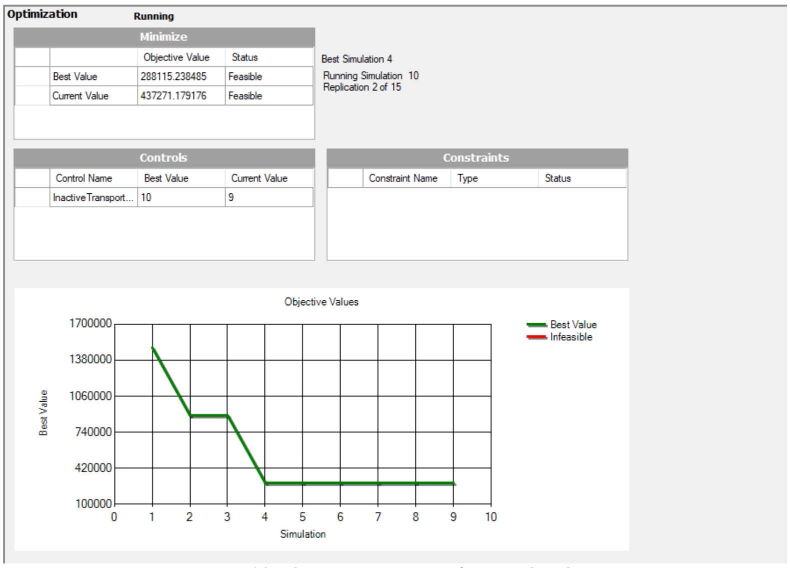

Figure 19: Optimization window in OptQuest

Several simulations are done to find the value of transporters that makes the objective function converge to a minimum possible value, as shown in the graph in figure 16. It can be seen that at each iteration the objective is minimized at it reaches the minimum value at the fourth simulation, in which there is one active transporter per working shift. When the minimum value is obtained the graph forms a straight line.

Once the solution is completed the best solutions for the number of iterations performed can be viewed as shown in figure 17.

Best Solutions **Optimal solution found.**

Best Solutions

Included	Simulation	Objective Value	Status	InactiveTransporters
☐	4	288115.238485	Feasible	10
☐	9	437271.179176	Feasible	9
☐	5	588127.213213	Feasible	8
☐	8	739689.579751	Feasible	7
☐	2	888486.034239	Feasible	6
☐	10	1038841.922727	Feasible	5
☐	6	1188710.913475	Feasible	4
☐	7	1339725.967174	Feasible	3
☐	1	1491933.246663	Feasible	2
☐	3	1640013.371177	Feasible	1

Figure 20: Best solutions window in OptQuest

Matlab code

```
clc
clear all
close all
% Lettura da file
MIN = xlsread('DeltaMatlabCanali.xlsx', 'Flanelle','a4:a18087');
% Stima parametri distribuzione normale
phat1=mle(MIN,'distribution','Normal');
Mean=phat1(1);
Stdev=phat1(2);
% Stima parametri distribuzione triangolare
minimo=min(MIN);
massimo=max(MIN);
M= mode(MIN);
% Stima parametri distribuzione tstudent
phat2=mle(MIN,'distribution','tlocationscale');
MeanTStudent=phat2(1);
StdevTStudent=phat2(2);
DOF=phat2(3);
% Istogramma
nbins=100;
x = -minimo:massimo;
pd1 = makedist('normal','mu', Mean,'sigma',Stdev);
pd2 = makedist('Triangular','a', minimo,'b',M , 'c', massimo);
pd3 = makedist('tLocationScale','mu', MeanTStudent, 'sigma',
StdevTStudent, 'nu', DOF);
pdf1 = pdf(pd1,x);
pdf2 = pdf(pd2,x);
pdf3 = pdf(pd3,x);
figure(1);
histogram(MIN, nbins,'Normalization','pdf');
hold on;
plot(x,pdf1,'r:','LineWidth',2);
plot(x,pdf2,'k:','LineWidth',2);
plot(x,pdf3,'g:','LineWidth',2);
hold off;
xlabel('Minuti');
title('Distribuzione due date Flanelle tinto filo');
% Test KS per distribuzione normale
[h2,p2]= kstest(MIN, 'CDF', pd1, 'Alpha', .05);
% Test KS per distribuzione triangolare
[h3,p3]= kstest(MIN,'CDF', pd2,'Alpha', .05);
% Test KS per distribuzione Tstudent
[h6,p6]= kstest(MIN, 'CDF', pd3, 'Alpha', .05);
```

STATISTIC	*MEAN VALUE*	*SAMPLE VARIANCE*	*NUMBER OF REPLICATIONS*
January Flannels Yarn-Dyed	1.846,93	5082,21	0,69
January Scarves Piece-Dyed	81,07	163,35	11,43
January Scarves Yarn-Dyed	1,07	7,92	3203,69
January Woolen Yarn-Dyed	228,27	163,35	1,44
January Woolen Yarn-Dyed Double	498,67	408,38	0,76
January Woolen Piece-Dyed	732,27	1013,64	0,87
January Linen	352,00	457,14	1,70
January Nylon	45,87	68,27	14,93
January Worsted Yarn-Dyed	1.594,67	3315,81	0,60
January Worsted Yarn-Dyed Tasmanian	2.710,40	3101,26	0,19
January Worsted Piece-Dyed	76,80	190,17	14,83
January Pile	259,20	336,46	2,30
February Flannels Yarn-Dyed	2.529,07	4743,92	0,34
February Scarves Piece-Dyed	101,33	97,52	4,37
February Scarves Yarn-Dyed	74,67	60,95	5,03
February Woolen Yarn-Dyed	186,13	187,12	2,48
February Woolen Yarn-Dyed Double	349,87	177,98	0,67
February Woolen Piece-Dyed	1.107,20	2594,74	0,97
February Linen	515,73	410,21	0,71
February Nylon	148,27	53,64	1,12
February Worsted Yarn-Dyed	1.373,87	2628,27	0,64
February Worsted Yarn-Dyed Tasmanian	2.851,20	10613,03	0,60
February Worsted Piece-Dyed	265,60	1162,97	7,58
February Pile	93,87	296,84	15,45
March Flannels Yarn-Dyed	3.539,20	3262,17	0,12
March Scarves Piece-Dyed	123,73	126,78	3,81
March Scarves Yarn-Dyed	68,27	90,21	8,90
March Woolen Yarn-Dyed	309,33	490,67	2,36
March Woolen Yarn-Dyed Double	430,93	830,78	2,06
March Woolen Piece-Dyed	1.317,33	3617,52	0,96
March Linen	942,93	647,92	0,34
March Nylon	225,07	346,21	3,14
March Worsted Yarn-Dyed	1.625,60	4271,54	0,74
March Worsted Yarn-Dyed Tasmanian	1.994,67	25039,24	2,90
March Worsted Piece-Dyed	220,80	1104,46	10,42
March Pile	71,47	95,70	8,62

April Flannels Yarn-Dyed	2.953,07	3436,50	0,18
April Scarves Piece-Dyed	214,40	175,54	1,76
April Scarves Yarn-Dyed	30,40	20,11	10,01
April Woolen Yarn-Dyed	290,13	168,84	0,92
April Woolen Yarn-Dyed Double	543,47	717,41	1,12
April Woolen Piece-Dyed	1.044,80	2137,60	0,90
April Linen	637,87	543,70	0,61
April Nylon	301,87	653,41	3,30
April Worsted Yarn-Dyed	1.675,73	7185,07	1,18
April Worsted Yarn-Dyed Tasmanian	2.457,60	16596,11	1,26
April Worsted Piece-Dyed	172,80	958,17	14,76
April Pile	96,53	187,12	9,24
May Flannels Yarn-Dyed	3.769,07	7102,78	0,23
May Scarves Piece-Dyed	252,80	190,17	1,37
May Scarves Yarn-Dyed	149,33	179,81	3,71
May Woolen Yarn-Dyed	528,53	1073,98	1,77
May Woolen Yarn-Dyed Double	522,67	646,10	1,09
May Woolen Piece-Dyed	1.064,00	1353,14	0,55
May Linen	649,07	1050,21	1,15
May Nylon	307,20	153,60	0,75
May Worsted Yarn-Dyed	1.574,40	5295,54	0,98
May Worsted Yarn-Dyed Tasmanian	2.537,60	18168,69	1,30
May Worsted Piece-Dyed	225,07	1041,07	9,45
May Pile	131,73	154,21	4,09
June Flannels Yarn-Dyed	2.294,93	5027,35	0,44
June Scarves Piece-Dyed	242,13	324,27	2,54
June Scarves Yarn-Dyed	92,80	263,31	14,07
June Woolen Yarn-Dyed	490,67	1020,95	1,95
June Woolen Yarn-Dyed Double	413,33	518,10	1,40
June Woolen Piece-Dyed	904,00	1362,29	0,77
June Linen	808,53	470,55	0,33
June Nylon	245,33	499,81	3,82
June Worsted Yarn-Dyed	2.051,20	4981,03	0,54
June Worsted Yarn-Dyed Tasmanian	2.643,20	9150,17	0,60
June Worsted Piece-Dyed	206,93	1443,35	15,44
June Pile	96,00	73,14	3,65
July Flannels Yarn-Dyed	1.136,53	2427,12	0,86
July Scarves Piece-Dyed	281,07	501,64	2,92
July Scarves Yarn-Dyed	115,20	89,60	3,11
July Woolen Yarn-Dyed	259,73	291,35	1,99

July Woolen Yarn-Dyed Double	318,93	483,35	2,19
July Woolen Piece-Dyed	1.126,40	2954,97	1,07
July Linen	449,07	647,92	1,48
July Nylon	129,07	346,21	9,56
July Worsted Yarn-Dyed	2.868,27	6051,35	0,34
July Worsted Yarn-Dyed Tasmanian	2.867,20	13794,74	0,77
July Worsted Piece-Dyed	385,07	1626,21	5,05
July Pile	151,47	95,70	1,92
August Flannels Yarn-Dyed	1.245,87	1494,55	0,44
August Scarves Piece-Dyed	254,40	221,26	1,57
August Scarves Yarn-Dyed	60,27	53,64	6,79
August Woolen Yarn-Dyed	203,73	300,50	3,33
August Woolen Yarn-Dyed Double	254,40	248,69	1,77
August Woolen Piece-Dyed	958,93	15495,92	7,75
August Linen	656,00	274,29	0,29
August Nylon	142,93	382,78	8,62
August Worsted Yarn-Dyed	2.216,53	2262,55	0,21
August Worsted Yarn-Dyed Tasmanian	3.815,47	8443,12	0,27
August Worsted Piece-Dyed	404,27	1077,64	3,03
August Pile	93,33	134,10	7,08
September Flannels Yarn-Dyed	1.104,00	1938,29	0,73
September Scarves Piece-Dyed	147,20	190,17	4,04
September Scarves Yarn-Dyed	46,40	56,69	12,11
September Woolen Yarn-Dyed	124,80	117,03	3,46
September Woolen Yarn-Dyed Double	251,20	272,46	1,99
September Woolen Piece-Dyed	411,20	683,89	1,86
September Linen	533,87	616,84	1,00
September Nylon	93,87	214,55	11,20
September Worsted Yarn-Dyed	2.350,93	8245,64	0,69
September Worsted Yarn-Dyed Tasmanian	3.498,67	14396,95	0,54
September Worsted Piece-Dyed	378,67	1779,81	5,71
September Pile	80,53	159,70	11,33
October Flannels Yarn-Dyed	1.115,73	1223,92	0,45
October Scarves Piece-Dyed	168,53	141,41	2,29
October Scarves Yarn-Dyed	40,53	40,84	11,43
October Woolen Yarn-Dyed	94,93	71,92	3,67
October Woolen Yarn-Dyed Double	241,07	218,21	1,73
October Woolen Piece-Dyed	670,93	1598,78	1,63

October Linen	361,07	483,35	1,71
October Nylon	94,93	236,50	12,07
October Worsted Yarn-Dyed	3.344,00	11264,00	0,46
October Worsted Yarn-Dyed Tasmanian	3.805,87	12868,27	0,41
October Worsted Piece-Dyed	509,87	3579,12	6,33
October Pile	91,20	80,46	4,45
November Flannels Yarn-Dyed	854,93	1388,50	0,87
November Scarves Piece-Dyed	103,47	141,41	6,08
November Scarves Yarn-Dyed	20,27	44,50	49,83
November Woolen Yarn-Dyed	117,33	134,10	4,48
November Woolen Yarn-Dyed Double	232,00	118,86	1,02
November Woolen Piece-Dyed	755,73	1233,07	0,99
November Linen	875,20	894,17	0,54
November Nylon	99,20	190,17	8,89
November Worsted Yarn-Dyed	3.572,27	11939,35	0,43
November Worsted Yarn-Dyed Tasmanian	3.150,93	10001,07	0,46
November Worsted Piece-Dyed	410,67	2218,67	6,05
November Pile	60,80	53,03	6,60
December Flannels Yarn-Dyed	1.296,00	1938,29	0,53
December Scarves Piece-Dyed	65,60	56,69	6,06
December Scarves Yarn-Dyed	8,00	9,14	65,72
December Woolen Yarn-Dyed	118,93	236,50	7,69
December Woolen Yarn-Dyed Double	509,33	463,24	0,82
December Woolen Piece-Dyed	941,87	1750,55	0,91
December Linen	1.396,80	1479,31	0,35
December Nylon	109,87	287,70	10,96
December Worsted Yarn-Dyed	3.169,07	15633,07	0,72
December Worsted Yarn-Dyed Tasmanian	2.546,13	3981,41	0,28
December Worsted Piece-Dyed	384,00	1572,57	4,91
December Pile	97,07	53,64	2,62
Piece with a Delay	10.725,00	26180,57	0,10
Piece produced	122.359,47	10573,41	0,00
TH FlannelsYarn-Dyed	35.404,87	61969,98	0,02
TH ScarvesYarn-Dyed	795,00	690,43	0,50
TH ScarvesPiece-Dyed	3.190,67	5318,52	0,24
TH WoolenYarn-Dyed	3.321,60	3418,97	0,14
TH WoolenYarn-Dyed Double	5.136,60	3835,54	0,07

TH WoolenPiece-Dyed	12.414,00	10456,71	0,03
TH Linen	9.200,40	7133,40	0,04
TH Nylon	2.269,80	3023,17	0,27
TH PettinatoYarn-Dyed	35.539,00	30581,71	0,01
TH PettinatoYarn-Dyed Tasmanian	45.153,33	20323,67	0,00
TH PettinatoPiece-Dyed	5.118,33	6930,95	0,12
TH Pile	1.488,60	1120,11	0,23
Flowtime FlannelsYarn-Dyed	7.321,05	49423,21	0,42
Flowtime ScarvesYarn-Dyed	11.430,95	57860,65	0,20
Flowtime ScarvesPiece-Dyed	17.358,25	32396,52	0,05
Flowtime WoolenYarn-Dyed	10.163,50	547354,58	2,44
Flowtime WoolenYarn-Dyed Double	6.204,38	8934,04	0,11
Flowtime WoolenPiece-Dyed	31.314,88	4286629,38	2,01
Flowtime Linen	8.503,97	1206,85	0,01
Flowtime Nylon	22.694,34	39993,38	0,04
Flowtime PettinatoYarn-Dyed	12.845,78	68131,97	0,19
Flowtime PettinatoYarn-Dyed Tasmanian	14.309,48	147715,45	0,33
Flowtime PettinatoPiece-Dyed	33.639,53	490120,33	0,20
Flowtime Pile	7.304,85	12625,22	0,11
Record Tardiness	18.493,76	60568,17	0,08
January Number Delay	594,60	708,11	0,92
February Number Delay	778,27	458,78	0,35
March Number Delay	1.012,07	1243,92	0,56
April Number Delay	1.097,40	1421,97	0,54
May Number Delay	1.214,87	3011,55	0,94
June Number Delay	1.007,87	2311,55	1,05
July Number Delay	849,13	2361,41	1,51
August Number Delay	816,20	1441,74	1,00
September Number Delay	697,73	590,50	0,56
October Number Delay	840,67	894,67	0,58
November Number Delay	871,33	720,81	0,44
December Number Delay	944,87	414,27	0,21
January Tardiness	17.499,90	371658,10	0,56
February Tardiness	18.221,21	498935,23	0,69
March Tardiness	19.339,98	617857,60	0,76
April Tardiness	19.834,82	491561,45	0,57
May Tardiness	20.164,35	365591,70	0,41
June Tardiness	19.079,38	357824,62	0,45
July Tardiness	18.439,31	725965,10	0,98

August Tardiness	18.192,52	491623,74	0,68
September Tardiness	16.944,59	722259,13	1,16
October Tardiness	16.875,61	203052,88	0,33
November Tardiness	17.299,74	359313,96	0,55
December Tardiness	18.067,48	268867,93	0,38
Utilization Bruciapelo January	0,15	0,00	0,04
Utilization Bruciapelo October	0,16	0,00	0,00
Utilization Bruciapelo November	0,17	0,00	0,00
Utilization Bruciapelo December	0,17	0,00	0,00
Utilization Bruciapelo February	0,15	0,00	0,02
Utilization Bruciapelo March	0,15	0,00	0,01
Utilization Bruciapelo April	0,15	0,00	0,01
Utilization Bruciapelo May	0,14	0,00	0,01
Utilization Bruciapelo June	0,14	0,00	0,01
Utilization Bruciapelo July	0,15	0,00	0,00
Utilization Bruciapelo August	0,15	0,00	0,00
Utilization Bruciapelo September	0,16	0,00	0,00
Utilization Carbonizzo January	0,88	0,00	0,20
Utilization Carbonizzo October	0,60	0,00	0,03
Utilization Carbonizzo November	0,58	0,00	0,02
Utilization Carbonizzo December	0,59	0,00	0,02
Utilization Carbonizzo February	0,88	0,00	0,12
Utilization Carbonizzo March	0,88	0,00	0,11
Utilization Carbonizzo April	0,79	0,00	0,08
Utilization Carbonizzo May	0,74	0,00	0,05
Utilization Carbonizzo June	0,72	0,00	0,04
Utilization Carbonizzo July	0,71	0,00	0,04
Utilization Carbonizzo August	0,67	0,00	0,04
Utilization Carbonizzo September	0,62	0,00	0,04
Utilization ChemisetFissatex January	0,81	0,00	1,65
Utilization ChemisetFissatex October	0,73	0,00	0,13
Utilization ChemisetFissatex November	0,71	0,00	0,15
Utilization ChemisetFissatex December	0,72	0,00	0,10
Utilization ChemisetFissatex February	0,89	0,00	0,31
Utilization ChemisetFissatex March	0,90	0,00	0,59
Utilization ChemisetFissatex April	0,89	0,00	0,34
Utilization ChemisetFissatex May	0,86	0,00	0,24
Utilization ChemisetFissatex June	0,84	0,00	0,38

Utilization ChemisetFissatex July	0,86	0,00	0,41
Utilization ChemisetFissatex August	0,81	0,00	0,14
Utilization ChemisetFissatex September	0,75	0,00	0,15
Utilization CimatriceWorsted January	0,22	0,00	1,68
Utilization CimatriceWorsted October	0,25	0,00	0,03
Utilization CimatriceWorsted November	0,23	0,00	0,03
Utilization CimatriceWorsted December	0,22	0,00	0,04
Utilization CimatriceWorsted February	0,27	0,00	0,64
Utilization CimatriceWorsted March	0,31	0,00	0,24
Utilization CimatriceWorsted April	0,32	0,00	0,15
Utilization CimatriceWorsted May	0,34	0,00	0,12
Utilization CimatriceWorsted June	0,32	0,00	0,07
Utilization CimatriceWorsted July	0,30	0,00	0,05
Utilization CimatriceWorsted August	0,28	0,00	0,05
Utilization CimatriceWorsted September	0,26	0,00	0,04
Utilization CimatriceScuri January	0,14	0,00	0,36
Utilization CimatriceScuri October	0,15	0,00	0,05
Utilization CimatriceScuri November	0,15	0,00	0,03
Utilization CimatriceScuri December	0,15	0,00	0,03
Utilization CimatriceScuri February	0,16	0,00	0,09
Utilization CimatriceScuri March	0,17	0,00	0,10
Utilization CimatriceScuri April	0,17	0,00	0,07
Utilization CimatriceScuri May	0,17	0,00	0,06
Utilization CimatriceScuri June	0,18	0,00	0,05
Utilization CimatriceScuri July	0,17	0,00	0,04
Utilization CimatriceScuri August	0,17	0,00	0,05
Utilization CimatriceScuri September	0,16	0,00	0,05
Utilization Cimi January	0,34	0,00	7,07
Utilization Cimi October	0,65	0,00	0,19
Utilization Cimi November	0,63	0,00	0,21
Utilization Cimi December	0,60	0,00	0,22
Utilization Cimi February	0,43	0,00	1,87
Utilization Cimi March	0,45	0,00	0,59
Utilization Cimi April	0,51	0,00	0,53
Utilization Cimi May	0,56	0,00	0,60
Utilization Cimi June	0,60	0,00	0,30

Utilization Cimi July	0,64	0,00	0,21
Utilization Cimi August	0,66	0,00	0,25
Utilization Cimi September	0,65	0,00	0,22
Utilization Decatizzo January	0,55	0,00	0,19
Utilization Decatizzo October	0,73	0,00	0,01
Utilization Decatizzo November	0,74	0,00	0,01
Utilization Decatizzo December	0,74	0,00	0,01
Utilization Decatizzo February	0,66	0,00	0,06
Utilization Decatizzo March	0,69	0,00	0,06
Utilization Decatizzo April	0,71	0,00	0,04
Utilization Decatizzo May	0,73	0,00	0,03
Utilization Decatizzo June	0,74	0,00	0,03
Utilization Decatizzo July	0,74	0,00	0,01
Utilization Decatizzo August	0,74	0,00	0,01
Utilization Decatizzo September	0,73	0,00	0,01
Utilization Ecosystem January	0,49	0,00	0,06
Utilization Ecosystem October	0,53	0,00	0,01
Utilization Ecosystem November	0,53	0,00	0,00
Utilization Ecosystem December	0,53	0,00	0,00
Utilization Ecosystem February	0,51	0,00	0,03
Utilization Ecosystem March	0,53	0,00	0,02
Utilization Ecosystem April	0,53	0,00	0,02
Utilization Ecosystem May	0,54	0,00	0,01
Utilization Ecosystem June	0,53	0,00	0,01
Utilization Ecosystem July	0,52	0,00	0,01
Utilization Ecosystem August	0,52	0,00	0,01
Utilization Ecosystem September	0,53	0,00	0,01
Utilization Formula1 January	0,01	0,00	10,44
Utilization Formula1 October	0,03	0,00	0,58
Utilization Formula1 November	0,03	0,00	0,52
Utilization Formula1 December	0,02	0,00	0,53
Utilization Formula1 February	0,02	0,00	3,55
Utilization Formula1 March	0,02	0,00	3,48
Utilization Formula1 April	0,03	0,00	1,90
Utilization Formula1 May	0,03	0,00	1,24
Utilization Formula1 June	0,03	0,00	1,02
Utilization Formula1 July	0,03	0,00	0,79
Utilization Formula1 August	0,03	0,00	0,73
Utilization Formula1 September	0,03	0,00	0,63
Utilization GarzaPiccola January	0,27	0,00	8,67

Utilization GarzaPiccola October	0,25	0,00	0,90
Utilization GarzaPiccola November	0,24	0,00	0,94
Utilization GarzaPiccola December	0,23	0,00	0,81
Utilization GarzaPiccola February	0,23	0,00	2,68
Utilization GarzaPiccola March	0,23	0,00	2,99
Utilization GarzaPiccola April	0,24	0,00	2,62
Utilization GarzaPiccola May	0,27	0,00	1,61
Utilization GarzaPiccola June	0,29	0,00	1,30
Utilization GarzaPiccola July	0,29	0,00	1,14
Utilization GarzaPiccola August	0,28	0,00	1,11
Utilization GarzaPiccola September	0,27	0,00	1,04
Utilization Garza January	1,00	0,00	0,27
Utilization Garza October	0,92	0,00	0,09
Utilization Garza November	0,89	0,00	0,06
Utilization Garza December	0,90	0,00	0,05
Utilization Garza February	1,00	0,00	0,07
Utilization Garza March	1,00	0,00	0,04
Utilization Garza April	1,00	0,00	0,02
Utilization Garza May	1,00	0,00	0,02
Utilization Garza June	1,00	0,00	0,02
Utilization Garza July	1,00	0,00	0,01
Utilization Garza August	1,00	0,00	0,09
Utilization Garza September	0,96	0,00	0,09
Utilization GX January	0,33	0,00	11,70
Utilization GX October	0,50	0,00	0,67
Utilization GX November	0,50	0,00	0,58
Utilization GX December	0,50	0,00	0,50
Utilization GX February	0,44	0,00	3,09
Utilization GX March	0,47	0,00	2,19
Utilization GX April	0,49	0,00	1,62
Utilization GX May	0,50	0,00	1,33
Utilization GX June	0,51	0,00	1,40
Utilization GX July	0,51	0,00	1,16
Utilization GX August	0,50	0,00	1,10
Utilization GX September	0,50	0,00	0,95
Utilization KD January	0,41	0,00	0,64
Utilization KD October	0,50	0,00	0,03
Utilization KD November	0,50	0,00	0,03
Utilization KD December	0,50	0,00	0,03
Utilization KD February	0,49	0,00	0,28

Utilization KD March	0,50	0,00	0,21
Utilization KD April	0,50	0,00	0,09
Utilization KD May	0,52	0,00	0,07
Utilization KD June	0,51	0,00	0,04
Utilization KD July	0,50	0,00	0,04
Utilization KD August	0,50	0,00	0,04
Utilization KD September	0,50	0,00	0,04
Utilization Lavanova January	0,54	0,00	0,23
Utilization Lavanova October	0,44	0,00	0,03
Utilization Lavanova November	0,43	0,00	0,02
Utilization Lavanova December	0,43	0,00	0,02
Utilization Lavanova February	0,51	0,00	0,14
Utilization Lavanova March	0,52	0,00	0,10
Utilization Lavanova April	0,51	0,00	0,09
Utilization Lavanova May	0,52	0,00	0,08
Utilization Lavanova June	0,52	0,00	0,07
Utilization Lavanova July	0,51	0,00	0,04
Utilization Lavanova August	0,48	0,00	0,04
Utilization Lavanova September	0,46	0,00	0,04
Utilization Multicrab January	0,39	0,00	0,25
Utilization Multicrab October	0,35	0,00	0,05
Utilization Multicrab November	0,34	0,00	0,04
Utilization Multicrab December	0,34	0,00	0,04
Utilization Multicrab February	0,39	0,00	0,07
Utilization Multicrab March	0,40	0,00	0,12
Utilization Multicrab April	0,40	0,00	0,07
Utilization Multicrab May	0,40	0,00	0,07
Utilization Multicrab June	0,41	0,00	0,06
Utilization Multicrab July	0,40	0,00	0,04
Utilization Multicrab August	0,38	0,00	0,04
Utilization Multicrab September	0,36	0,00	0,05
Utilization Multipla January	0,43	0,00	0,13
Utilization Multipla October	0,44	0,00	0,01
Utilization Multipla November	0,44	0,00	0,01
Utilization Multipla December	0,44	0,00	0,01
Utilization Multipla February	0,43	0,00	0,07
Utilization Multipla March	0,44	0,00	0,06
Utilization Multipla April	0,44	0,00	0,04
Utilization Multipla May	0,45	0,00	0,03
Utilization Multipla June	0,45	0,00	0,02

Utilization Multipla July	0,44	0,00	0,02
Utilization Multipla August	0,44	0,00	0,02
Utilization Multipla September	0,44	0,00	0,01
Utilization Pentek January	0,23	0,00	2,16
Utilization Pentek October	0,35	0,00	0,05
Utilization Pentek November	0,36	0,00	0,05
Utilization Pentek December	0,40	0,00	0,04
Utilization Pentek February	0,29	0,00	0,53
Utilization Pentek March	0,38	0,00	0,18
Utilization Pentek April	0,37	0,00	0,14
Utilization Pentek May	0,37	0,00	0,14
Utilization Pentek June	0,39	0,00	0,08
Utilization Pentek July	0,37	0,00	0,07
Utilization Pentek August	0,37	0,00	0,04
Utilization Pentek September	0,36	0,00	0,05
Utilization Preparazione January	0,29	0,00	0,02
Utilization Preparazione October	0,32	0,00	0,00
Utilization Preparazione November	0,33	0,00	0,00
Utilization Preparazione December	0,33	0,00	0,00
Utilization Preparazione February	0,31	0,00	0,03
Utilization Preparazione March	0,32	0,00	0,03
Utilization Preparazione April	0,32	0,00	0,02
Utilization Preparazione May	0,32	0,00	0,01
Utilization Preparazione June	0,32	0,00	0,01
Utilization Preparazione July	0,32	0,00	0,01
Utilization Preparazione August	0,32	0,00	0,01
Utilization Preparazione September	0,32	0,00	0,01
Utilization RamaAlea January	0,49	0,00	0,60
Utilization RamaAlea October	0,47	0,00	0,05
Utilization RamaAlea November	0,46	0,00	0,04
Utilization RamaAlea December	0,46	0,00	0,05
Utilization RamaAlea February	0,53	0,00	0,16
Utilization RamaAlea March	0,54	0,00	0,15
Utilization RamaAlea April	0,54	0,00	0,11
Utilization RamaAlea May	0,54	0,00	0,10
Utilization RamaAlea June	0,54	0,00	0,11
Utilization RamaAlea July	0,54	0,00	0,08
Utilization RamaAlea August	0,52	0,00	0,05
Utilization RamaAlea September	0,49	0,00	0,05
Utilization RamaF2 January	0,44	0,00	1,61

Utilization RamaF2 October	0,55	0,00	0,25
Utilization RamaF2 November	0,53	0,00	0,27
Utilization RamaF2 December	0,52	0,00	0,29
Utilization RamaF2 February	0,52	0,00	0,64
Utilization RamaF2 March	0,56	0,00	0,45
Utilization RamaF2 April	0,60	0,00	0,50
Utilization RamaF2 May	0,63	0,00	0,39
Utilization RamaF2 June	0,63	0,00	0,33
Utilization RamaF2 July	0,62	0,00	0,28
Utilization RamaF2 August	0,60	0,00	0,29
Utilization RamaF2 September	0,57	0,00	0,29
Utilization RamaUnitech January	0,85	0,00	0,05
Utilization RamaUnitech October	0,96	0,00	0,01
Utilization RamaUnitech November	0,96	0,00	0,01
Utilization RamaUnitech December	0,96	0,00	0,01
Utilization RamaUnitech February	0,91	0,00	0,01
Utilization RamaUnitech March	0,93	0,00	0,03
Utilization RamaUnitech April	0,95	0,00	0,02
Utilization RamaUnitech May	0,96	0,00	0,01
Utilization RamaUnitech June	0,96	0,00	0,01
Utilization RamaUnitech July	0,95	0,00	0,01
Utilization RamaUnitech August	0,95	0,00	0,01
Utilization RamaUnitech September	0,95	0,00	0,01
Utilization Rotormat January	0,65	0,00	1,05
Utilization Rotormat October	0,69	0,00	0,07
Utilization Rotormat November	0,66	0,00	0,06
Utilization Rotormat December	0,64	0,00	0,07
Utilization Rotormat February	0,74	0,00	0,62
Utilization Rotormat March	0,81	0,00	0,36
Utilization Rotormat April	0,83	0,00	0,15
Utilization Rotormat May	0,86	0,00	0,10
Utilization Rotormat June	0,83	0,00	0,09
Utilization Rotormat July	0,77	0,00	0,07
Utilization Rotormat August	0,74	0,00	0,07
Utilization Rotormat September	0,71	0,00	0,08
Utilization Soliatrice January	0,08	0,00	7,44
Utilization Soliatrice October	0,19	0,00	0,20
Utilization Soliatrice November	0,18	0,00	0,16
Utilization Soliatrice December	0,17	0,00	0,17
Utilization Soliatrice February	0,11	0,00	1,79

Utilization Soliatrice March	0,12	0,00	1,02
Utilization Soliatrice April	0,14	0,00	0,70
Utilization Soliatrice May	0,17	0,00	0,72
Utilization Soliatrice June	0,18	0,00	0,34
Utilization Soliatrice July	0,19	0,00	0,20
Utilization Soliatrice August	0,20	0,00	0,22
Utilization Soliatrice September	0,20	0,00	0,22
Utilization StriccaGreggio January	0,46	0,00	0,57
Utilization StriccaGreggio October	0,41	0,00	0,05
Utilization StriccaGreggio November	0,40	0,00	0,04
Utilization StriccaGreggio December	0,40	0,00	0,04
Utilization StriccaGreggio February	0,47	0,00	0,21
Utilization StriccaGreggio March	0,47	0,00	0,20
Utilization StriccaGreggio April	0,48	0,00	0,11
Utilization StriccaGreggio May	0,48	0,00	0,08
Utilization StriccaGreggio June	0,48	0,00	0,05
Utilization StriccaGreggio July	0,48	0,00	0,06
Utilization StriccaGreggio August	0,46	0,00	0,06
Utilization StriccaGreggio September	0,43	0,00	0,05
Utilization StriccaTinto January	0,14	0,00	0,98
Utilization StriccaTinto October	0,17	0,00	0,05
Utilization StriccaTinto November	0,17	0,00	0,04
Utilization StriccaTinto December	0,17	0,00	0,03
Utilization StriccaTinto February	0,20	0,00	0,29
Utilization StriccaTinto March	0,21	0,00	0,14
Utilization StriccaTinto April	0,20	0,00	0,10
Utilization StriccaTinto May	0,20	0,00	0,10
Utilization StriccaTinto June	0,19	0,00	0,10
Utilization StriccaTinto July	0,20	0,00	0,06
Utilization StriccaTinto August	0,19	0,00	0,06
Utilization StriccaTinto September	0,18	0,00	0,06
Utilization VaporizzoPiano January	0,50	0,00	0,12
Utilization VaporizzoPiano October	0,65	0,00	0,00
Utilization VaporizzoPiano November	0,65	0,00	0,00
Utilization VaporizzoPiano December	0,65	0,00	0,00
Utilization VaporizzoPiano February	0,60	0,00	0,03
Utilization VaporizzoPiano March	0,63	0,00	0,04
Utilization VaporizzoPiano April	0,64	0,00	0,02
Utilization VaporizzoPiano May	0,66	0,00	0,01
Utilization VaporizzoPiano June	0,66	0,00	0,01

Utilization VaporizzoPiano July	0,65	0,00	0,00
Utilization VaporizzoPiano August	0,66	0,00	0,00
Utilization VaporizzoPiano September	0,65	0,00	0,00
Utilization VaporizzoSpazzolaScarves January	0,02	0,00	7,94
Utilization VaporizzoSpazzolaScarves October	0,06	0,00	0,21
Utilization VaporizzoSpazzolaScarves November	0,06	0,00	0,18
Utilization VaporizzoSpazzolaScarves December	0,06	0,00	0,18
Utilization VaporizzoSpazzolaScarves February	0,03	0,00	1,73
Utilization VaporizzoSpazzolaScarves March	0,04	0,00	0,84
Utilization VaporizzoSpazzolaScarves April	0,05	0,00	0,56
Utilization VaporizzoSpazzolaScarves May	0,05	0,00	0,57
Utilization VaporizzoSpazzolaScarves June	0,06	0,00	0,36
Utilization VaporizzoSpazzolaScarves July	0,06	0,00	0,23
Utilization VaporizzoSpazzolaScarves August	0,07	0,00	0,26
Utilization VaporizzoSpazzolaScarves September	0,06	0,00	0,25
Utilization VaporizzoSpazzola January	0,26	0,00	0,30
Utilization VaporizzoSpazzola October	0,29	0,00	0,03
Utilization VaporizzoSpazzola November	0,29	0,00	0,02
Utilization VaporizzoSpazzola December	0,29	0,00	0,01
Utilization VaporizzoSpazzola February	0,30	0,00	0,20
Utilization VaporizzoSpazzola March	0,32	0,00	0,12
Utilization VaporizzoSpazzola April	0,33	0,00	0,11
Utilization VaporizzoSpazzola May	0,34	0,00	0,07
Utilization VaporizzoSpazzola June	0,34	0,00	0,05
Utilization VaporizzoSpazzola July	0,34	0,00	0,04
Utilization VaporizzoSpazzola August	0,33	0,00	0,03
Utilization VaporizzoSpazzola September	0,31	0,00	0,03
Utilization WoolPower January	0,04	0,00	5,77
Utilization WoolPower October	0,06	0,00	0,29

Utilization WoolPower November	0,06	0,00	0,26
Utilization WoolPower December	0,06	0,00	0,18
Utilization WoolPower February	0,05	0,00	1,99
Utilization WoolPower March	0,05	0,00	1,72
Utilization WoolPower April	0,05	0,00	0,94
Utilization WoolPower May	0,05	0,00	1,62
Utilization WoolPower June	0,05	0,00	0,81
Utilization WoolPower July	0,05	0,00	0,32
Utilization WoolPower August	0,05	0,00	0,26
Utilization WoolPower September	0,06	0,00	0,32
Utilization Zonco January	0,96	0,00	0,10
Utilization Zonco October	0,67	0,00	0,08
Utilization Zonco November	0,64	0,00	0,07
Utilization Zonco December	0,66	0,00	0,04
Utilization Zonco February	0,93	0,00	0,32
Utilization Zonco March	0,92	0,00	0,23
Utilization Zonco April	0,86	0,00	0,17
Utilization Zonco May	0,82	0,00	0,16
Utilization Zonco June	0,80	0,00	0,17
Utilization Zonco July	0,78	0,00	0,16
Utilization Zonco August	0,74	0,00	0,15
Utilization Zonco September	0,69	0,00	0,13

Table 7: Estimation of the required number of replications

STATISTIC	*INTERVAL ESTIMATION*
January Flannels Yarn-Dyed	**(1807,45 ; 1886,41)**
January Scarves Piece-Dyed	**(73,98 ; 88,14)**
January Scarves Yarn-Dyed	**(0,00 ; 2,62)**
January Woolen Yarn-Dyed	**(221,18 ; 235,34)**
January Woolen Yarn-Dyed Double	**(487,47 ; 509,85)**
January Woolen Piece-Dyed	**(714,63 ; 749,89)**
January Linen	**(340,15 ; 363,84)**
January Nylon	**(41,29 ; 50,44)**
January Worsted Yarn-Dyed	**(1562,77 ; 1626,55)**
January Worsted Yarn-Dyed Tasmanian	**(2679,56 ; 2741,23)**
January Worsted Piece-Dyed	**(69,16 ; 84,43)**
January Pile	**(249,04 ; 269,35)**
February Flannels Yarn-Dyed	**(2490,92 ; 2567,2)**
February Scarves Piece-Dyed	**(95,86 ; 106,8)**
February Scarves Yarn-Dyed	**(70,34 ; 78,99)**
February Woolen Yarn-Dyed	**(178,55 ; 193,7)**
February Woolen Yarn-Dyed Double	**(342,47 ; 357,25)**
February Woolen Piece-Dyed	**(1078,99 ; 1135,4)**
February Linen	**(504,51 ; 526,94)**
February Nylon	**(144,21 ; 152,32)**
February Worsted Yarn-Dyed	**(1345,47 ; 1402,25)**
February Worsted Yarn-Dyed Tasmanian	**(2794,14 ; 2908,25)**
February Worsted Piece-Dyed	**(246,71 ; 284,48)**
February Pile	**(84,32 ; 103,4)**
March Flannels Yarn-Dyed	**(3507,57 ; 3570,82)**
March Scarves Piece-Dyed	**(117,49 ; 129,96)**
March Scarves Yarn-Dyed	**(63 ; 73,52)**
March Woolen Yarn-Dyed	**(297,06 ; 321,6)**
March Woolen Yarn-Dyed Double	**(414,97 ; 446,89)**
March Woolen Piece-Dyed	**(1284,02 ; 1350,64)**
March Linen	**(928,83 ; 957,02)**
March Nylon	**(214,76 ; 235,37)**
March Worsted Yarn-Dyed	**(1589,4 ; 1661,79)**
March Worsted Yarn-Dyed Tasmanian	**(1907,03 ; 2082,29)**
March Worsted Piece-Dyed	**(202,39 ; 239,2)**
March Pile	**(66,04 ; 76,88)**
April Flannels Yarn-Dyed	**(2920,6 ; 2985,53)**
April Scarves Piece-Dyed	**(207,06 ; 221,73)**
April Scarves Yarn-Dyed	**(27,91 ; 32,88)**
April Woolen Yarn-Dyed	**(282,93 ; 297,32)**
April Woolen Yarn-Dyed Double	**(528,63 ; 558,29)**

April Woolen Piece-Dyed	**(1019,19 ; 1070,4)**
April Linen	**(624,95 ; 650,77)**
April Nylon	**(287,71 ; 316,02)**
April Worsted Yarn-Dyed	**(1628,79 ; 1722,67)**
April Worsted Yarn-Dyed Tasmanian	**(2386,25 ; 2528,94)**
April Worsted Piece-Dyed	**(155,65 ; 189,94)**
April Pile	**(88,95 ; 104,1)**
May Flannels Yarn-Dyed	**(3722,39 ; 3815,73)**
May Scarves Piece-Dyed	**(245,16 ; 260,43)**
May Scarves Yarn-Dyed	**(141,9 ; 156,75)**
May Woolen Yarn-Dyed	**(510,38 ; 546,68)**
May Woolen Yarn-Dyed Double	**(508,59 ; 536,74)**
May Woolen Piece-Dyed	**(1043,62 ; 1084,37)**
May Linen	**(631,12 ; 667,01)**
May Nylon	**(300,33 ; 314,06)**
May Worsted Yarn-Dyed	**(1534,1 ; 1614,69)**
May Worsted Yarn-Dyed Tasmanian	**(2462,95 ; 2612,24)**
May Worsted Piece-Dyed	**(207,19 ; 242,93)**
May Pile	**(124,85 ; 138,61)**
June Flannels Yarn-Dyed	**(2255,66 ; 2334,19)**
June Scarves Piece-Dyed	**(232,16 ; 252,1)**
June Scarves Yarn-Dyed	**(83,81 ; 101,78)**
June Woolen Yarn-Dyed	**(472,97 ; 508,36)**
June Woolen Yarn-Dyed Double	**(400,72 ; 425,93)**
June Woolen Piece-Dyed	**(883,56 ; 924,43)**
June Linen	**(796,52 ; 820,54)**
June Nylon	**(232,95 ; 257,71)**
June Worsted Yarn-Dyed	**(2012,11 ; 2090,28)**
June Worsted Yarn-Dyed Tasmanian	**(2590,22 ; 2696,17)**
June Worsted Piece-Dyed	**(185,89 ; 227,97)**
June Pile	**(91,26 ; 100,73)**
July Flannels Yarn-Dyed	**(1109,25 ; 1163,81)**
July Scarves Piece-Dyed	**(268,66 ; 293,46)**
July Scarves Yarn-Dyed	**(109,95 ; 120,44)**
July Woolen Yarn-Dyed	**(250,28 ; 269,18)**
July Woolen Yarn-Dyed Double	**(306,75 ; 331,1)**
July Woolen Piece-Dyed	**(1096,29 ; 1156,5)**
July Linen	**(434,97 ; 463,16)**
July Nylon	**(118,76 ; 139,37)**
July Worsted Yarn-Dyed	**(2825,18 ; 2911,34)**
July Worsted Yarn-Dyed Tasmanian	**(2802,15 ; 2932,24)**
July Worsted Piece-Dyed	**(362,73 ; 407,39)**

July Pile	**(146,04 ; 156,88)**
August Flannels Yarn-Dyed	**(1224,45 ; 1267,27)**
August Scarves Piece-Dyed	**(246,16 ; 262,63)**
August Scarves Yarn-Dyed	**(56,21 ; 64,32)**
August Woolen Yarn-Dyed	**(194,13 ; 213,33)**
August Woolen Yarn-Dyed Double	**(245,66 ; 263,13)**
August Woolen Piece-Dyed	**(889,99 ; 1027,86)**
August Linen	**(646,82 ; 665,17)**
August Nylon	**(132,09 ; 153,76)**
August Worsted Yarn-Dyed	**(2190,19 ; 2242,87)**
August Worsted Yarn-Dyed Tasmanian	**(3764,58 ; 3866,35)**
August Worsted Piece-Dyed	**(386,08 ; 422,44)**
August Pile	**(86,92 ; 99,74)**
September Flannels Yarn-Dyed	**(1079,61 ; 1128,38)**
September Scarves Piece-Dyed	**(139,56 ; 154,83)**
September Scarves Yarn-Dyed	**(42,23 ; 50,56)**
September Woolen Yarn-Dyed	**(118,8 ; 130,79)**
September Woolen Yarn-Dyed Double	**(242,05 ; 260,34)**
September Woolen Piece-Dyed	**(396,71 ; 425,68)**
September Linen	**(520,11 ; 547,62)**
September Nylon	**(85,75 ; 101,97)**
September Worsted Yarn-Dyed	**(2300,64 ; 2401,22)**
September Worsted Yarn-Dyed Tasmanian	**(3432,21 ; 3565,11)**
September Worsted Piece-Dyed	**(355,3 ; 402,02)**
September Pile	**(73,53 ; 87,53)**
October Flannels Yarn-Dyed	**(1096,35 ; 1135,1)**
October Scarves Piece-Dyed	**(161,94 ; 175,11)**
October Scarves Yarn-Dyed	**(36,99 ; 44,07)**
October Woolen Yarn-Dyed	**(90,23 ; 99,62)**
October Woolen Yarn-Dyed Double	**(232,88 ; 249,24)**
October Woolen Piece-Dyed	**(648,79 ; 693,07)**
October Linen	**(348,89 ; 373,24)**
October Nylon	**(86,41 ; 103,44)**
October Worsted Yarn-Dyed	**(3285,22 ; 3402,77)**
October Worsted Yarn-Dyed Tasmanian	**(3743,04 ; 3868,68)**
October Worsted Piece-Dyed	**(476,73 ; 542,99)**
October Pile	**(86,23 ; 96,16)**
November Flannels Yarn-Dyed	**(834,29 ; 875,56)**
November Scarves Piece-Dyed	**(96,88 ; 110,05)**
November Scarves Yarn-Dyed	**(16,57 ; 23,96)**
November Woolen Yarn-Dyed	**(110,92 ; 123,74)**
November Woolen Yarn-Dyed Double	**(225,96 ; 238,03)**

November Woolen Piece-Dyed	**(736,28 ; 775,17)**
November Linen	**(858,64 ; 891,75)**
November Nylon	**(91,56 ; 106,83)**
November Worsted Yarn-Dyed	**(3511,75 ; 3632,77)**
November Worsted Yarn-Dyed Tasmanian	**(3095,55 ; 3206,31)**
November Worsted Piece-Dyed	**(384,58 ; 436,75)**
November Pile	**(56,76 ; 64,83)**
December Flannels Yarn-Dyed	**(1271,61 ; 1320,38)**
December Scarves Piece-Dyed	**(61,43 ; 69,76)**
December Scarves Yarn-Dyed	**(6,32 ; 9,67)**
December Woolen Yarn-Dyed	**(110,41 ; 127,44)**
December Woolen Yarn-Dyed Double	**(497,41 ; 521,25)**
December Woolen Piece-Dyed	**(918,69 ; 965,03)**
December Linen	**(1375,5 ; 1418,09)**
December Nylon	**(100,47 ; 119,25)**
December Worsted Yarn-Dyed	**(3099,82 ; 3238,3)**
December Worsted Yarn-Dyed Tasmanian	**(2511,19 ; 2581,07)**
December Worsted Piece-Dyed	**(362,03 ; 405,96)**
December Pile	**(93,01 ; 101,12)**
Piece with a Delay	**(10635,39 ; 10814,6)**
Piece produced	**(122302,52 ; 122416,41)**
TH FlannelsYarn-Dyed	**(35267 ; 35542,72)**
TH ScarvesYarn-Dyed	**(780,44 ; 809,55)**
TH ScarvesPiece-Dyed	**(3150,28 ; 3231,05)**
TH WoolenYarn-Dyed	**(3289,21 ; 3353,98)**
TH WoolenYarn-Dyed Double	**(5102,3 ; 5170,89)**
TH WoolenPiece-Dyed	**(12357,37 ; 12470,62)**
TH Linen	**(9153,62 ; 9247,17)**
TH Nylon	**(2239,35 ; 2300,24)**
TH PettinatoYarn-Dyed	**(35442,15 ; 35635,84)**
TH PettinatoYarn-Dyed Tasmanian	**(45074,38 ; 45232,28)**
TH PettinatoPiece-Dyed	**(5072,22 ; 5164,43)**
TH Pile	**(1470,06 ; 1507,13)**
Flowtime FlannelsYarn-Dyed	**(7197,93 ; 7444,16)**
Flowtime ScarvesYarn-Dyed	**(11297,73 ; 11564,15)**
Flowtime ScarvesPiece-Dyed	**(17258,57 ; 17457,92)**
Flowtime WoolenYarn-Dyed	**(9753,78 ; 10573,2)**
Flowtime WoolenYarn-Dyed Double	**(6152,03 ; 6256,72)**
Flowtime WoolenPiece-Dyed	**(30168,31 ; 32461,44)**
Flowtime Linen	**(8484,73 ; 8523,21)**
Flowtime Nylon	**(22583,59 ; 22805,08)**
Flowtime PettinatoYarn-Dyed	**(12701,22 ; 12990,32)**

Flowtime PettinatoYarn-Dyed Tasmanian	**(14096,64 ; 14522,32)**
Flowtime PettinatoPiece-Dyed	**(33251,82 ; 34027,22)**
Flowtime Pile	**(7242,62 ; 7367,07)**
Record Tardiness	**(18357,47 ; 18630,05)**
January Number Delay	**(579,86 ; 609,33)**
February Number Delay	**(766,4 ; 790,12)**
March Number Delay	**(992,53 ; 1031,59)**
April Number Delay	**(1076,51 ; 1118,28)**
May Number Delay	**(1184,47 ; 1245,25)**
June Number Delay	**(981,24 ; 1034,49)**
July Number Delay	**(822,22 ; 876,04)**
August Number Delay	**(795,17 ; 837,22)**
September Number Delay	**(684,27 ; 711,19)**
October Number Delay	**(824,1 ; 857,23)**
November Number Delay	**(856,46 ; 886,2)**
December Number Delay	**(933,59 ; 956,13)**
January Tardiness	**(17162,29 ; 17837,51)**
February Tardiness	**(17830,04 ; 18612,37)**
March Tardiness	**(18904,68 ; 19775,27)**
April Tardiness	**(19446,55 ; 20223,08)**
May Tardiness	**(19829,51 ; 20499,19)**
June Tardiness	**(18748,11 ; 19410,64)**
July Tardiness	**(17967,47 ; 18911,15)**
August Tardiness	**(17804,23 ; 18580,81)**
September Tardiness	**(16473,95 ; 17415,22)**
October Tardiness	**(16626,06 ; 17125,15)**
November Tardiness	**(16967,78 ; 17631,69)**
December Tardiness	**(17780,32 ; 18354,62)**
Utilization Bruciapelo January	**(0,14 ; 0,15)**
Utilization Bruciapelo October	**(0,16 ; 0,16)**
Utilization Bruciapelo November	**(0,16 ; 0,16)**
Utilization Bruciapelo December	**(0,16 ; 0,17)**
Utilization Bruciapelo February	**(0,14 ; 0,14)**
Utilization Bruciapelo March	**(0,14 ; 0,14)**
Utilization Bruciapelo April	**(0,14 ; 0,14)**
Utilization Bruciapelo May	**(0,14 ; 0,14)**
Utilization Bruciapelo June	**(0,14 ; 0,14)**
Utilization Bruciapelo July	**(0,14 ; 0,14)**
Utilization Bruciapelo August	**(0,15 ; 0,15)**
Utilization Bruciapelo September	**(0,15 ; 0,15)**
Utilization Carbonizzo January	**(0,86 ; 0,88)**
Utilization Carbonizzo October	**(0,59 ; 0,59)**

Utilization Carbonizzo November	**(0,57 ; 0,58)**
Utilization Carbonizzo December	**(0,59 ; 0,59)**
Utilization Carbonizzo February	**(0,86 ; 0,88)**
Utilization Carbonizzo March	**(0,87 ; 0,88)**
Utilization Carbonizzo April	**(0,78 ; 0,79)**
Utilization Carbonizzo May	**(0,73 ; 0,74)**
Utilization Carbonizzo June	**(0,71 ; 0,72)**
Utilization Carbonizzo July	**(0,7 ; 0,71)**
Utilization Carbonizzo August	**(0,66 ; 0,66)**
Utilization Carbonizzo September	**(0,61 ; 0,62)**
Utilization ChemiseYarn-Dyedissatex January	**(0,78 ; 0,83)**
Utilization ChemiseYarn-Dyedissatex October	**(0,72 ; 0,73)**
Utilization ChemiseYarn-Dyedissatex November	**(0,7 ; 0,71)**
Utilization ChemiseYarn-Dyedissatex December	**(0,71 ; 0,72)**
Utilization ChemiseYarn-Dyedissatex February	**(0,87 ; 0,9)**
Utilization ChemiseYarn-Dyedissatex March	**(0,88 ; 0,91)**
Utilization ChemiseYarn-Dyedissatex April	**(0,87 ; 0,9)**
Utilization ChemiseYarn-Dyedissatex May	**(0,84 ; 0,86)**
Utilization ChemiseYarn-Dyedissatex June	**(0,82 ; 0,84)**
Utilization ChemiseYarn-Dyedissatex July	**(0,84 ; 0,86)**
Utilization ChemiseYarn-Dyedissatex August	**(0,8 ; 0,81)**
Utilization ChemiseYarn-Dyedissatex September	**(0,74 ; 0,75)**
Utilization CimatriceWorsted January	**(0,2 ; 0,22)**
Utilization CimatriceWorsted October	**(0,24 ; 0,24)**
Utilization CimatriceWorsted November	**(0,23 ; 0,23)**
Utilization CimatriceWorsted December	**(0,22 ; 0,22)**
Utilization CimatriceWorsted February	**(0,26 ; 0,27)**
Utilization CimatriceWorsted March	**(0,3 ; 0,31)**
Utilization CimatriceWorsted April	**(0,31 ; 0,32)**
Utilization CimatriceWorsted May	**(0,33 ; 0,33)**
Utilization CimatriceWorsted June	**(0,32 ; 0,32)**
Utilization CimatriceWorsted July	**(0,29 ; 0,29)**
Utilization CimatriceWorsted August	**(0,27 ; 0,27)**
Utilization CimatriceWorsted September	**(0,25 ; 0,25)**
Utilization CimatriceScuri January	**(0,13 ; 0,14)**
Utilization CimatriceScuri October	**(0,15 ; 0,15)**
Utilization CimatriceScuri November	**(0,14 ; 0,14)**
Utilization CimatriceScuri December	**(0,14 ; 0,14)**
Utilization CimatriceScuri February	**(0,16 ; 0,16)**
Utilization CimatriceScuri March	**(0,16 ; 0,17)**
Utilization CimatriceScuri April	**(0,17 ; 0,17)**
Utilization CimatriceScuri May	**(0,17 ; 0,17)**

Utilization CimatriceScuri June	**(0,17 ; 0,17)**
Utilization CimatriceScuri July	**(0,17 ; 0,17)**
Utilization CimatriceScuri August	**(0,16 ; 0,17)**
Utilization CimatriceScuri September	**(0,15 ; 0,15)**
Utilization Cimi January	**(0,31 ; 0,36)**
Utilization Cimi October	**(0,64 ; 0,65)**
Utilization Cimi November	**(0,62 ; 0,63)**
Utilization Cimi December	**(0,59 ; 0,6)**
Utilization Cimi February	**(0,41 ; 0,45)**
Utilization Cimi March	**(0,44 ; 0,45)**
Utilization Cimi April	**(0,49 ; 0,51)**
Utilization Cimi May	**(0,54 ; 0,56)**
Utilization Cimi June	**(0,59 ; 0,61)**
Utilization Cimi July	**(0,63 ; 0,64)**
Utilization Cimi August	**(0,65 ; 0,67)**
Utilization Cimi September	**(0,64 ; 0,66)**
Utilization Decatizzo January	**(0,54 ; 0,55)**
Utilization Decatizzo October	**(0,73 ; 0,73)**
Utilization Decatizzo November	**(0,73 ; 0,73)**
Utilization Decatizzo December	**(0,73 ; 0,74)**
Utilization Decatizzo February	**(0,65 ; 0,66)**
Utilization Decatizzo March	**(0,68 ; 0,69)**
Utilization Decatizzo April	**(0,7 ; 0,71)**
Utilization Decatizzo May	**(0,72 ; 0,73)**
Utilization Decatizzo June	**(0,73 ; 0,74)**
Utilization Decatizzo July	**(0,73 ; 0,73)**
Utilization Decatizzo August	**(0,73 ; 0,73)**
Utilization Decatizzo September	**(0,73 ; 0,73)**
Utilization Ecosystem January	**(0,48 ; 0,49)**
Utilization Ecosystem October	**(0,52 ; 0,52)**
Utilization Ecosystem November	**(0,52 ; 0,53)**
Utilization Ecosystem December	**(0,52 ; 0,52)**
Utilization Ecosystem February	**(0,51 ; 0,51)**
Utilization Ecosystem March	**(0,52 ; 0,52)**
Utilization Ecosystem April	**(0,52 ; 0,53)**
Utilization Ecosystem May	**(0,53 ; 0,53)**
Utilization Ecosystem June	**(0,52 ; 0,53)**
Utilization Ecosystem July	**(0,51 ; 0,52)**
Utilization Ecosystem August	**(0,52 ; 0,52)**
Utilization Ecosystem September	**(0,52 ; 0,52)**
Utilization Formula1 January	**(0,00 ; 0,00)**
Utilization Formula1 October	**(0,02 ; 0,02)**

Utilization Formula1 November	**(0,02 ; 0,02)**
Utilization Formula1 December	**(0,02 ; 0,02)**
Utilization Formula1 February	**(0,01 ; 0,01)**
Utilization Formula1 March	**(0,02 ; 0,02)**
Utilization Formula1 April	**(0,02 ; 0,02)**
Utilization Formula1 May	**(0,03 ; 0,03)**
Utilization Formula1 June	**(0,03 ; 0,03)**
Utilization Formula1 July	**(0,03 ; 0,03)**
Utilization Formula1 August	**(0,02 ; 0,03)**
Utilization Formula1 September	**(0,02 ; 0,02)**
Utilization GarzaPiccola January	**(0,24 ; 0,29)**
Utilization GarzaPiccola October	**(0,24 ; 0,25)**
Utilization GarzaPiccola November	**(0,23 ; 0,24)**
Utilization GarzaPiccola December	**(0,22 ; 0,23)**
Utilization GarzaPiccola February	**(0,21 ; 0,23)**
Utilization GarzaPiccola March	**(0,22 ; 0,24)**
Utilization GarzaPiccola April	**(0,23 ; 0,25)**
Utilization GarzaPiccola May	**(0,26 ; 0,27)**
Utilization GarzaPiccola June	**(0,28 ; 0,30)**
Utilization GarzaPiccola July	**(0,28 ; 0,29)**
Utilization GarzaPiccola August	**(0,27 ; 0,29)**
Utilization GarzaPiccola September	**(0,25 ; 0,27)**
Utilization Garza January	**(1,00 ; 1,03)**
Utilization Garza October	**(0,91 ; 0,92)**
Utilization Garza November	**(0,88 ; 0,89)**
Utilization Garza December	**(0,89 ; 0,9)**
Utilization Garza February	**(1,05 ; 1,07)**
Utilization Garza March	**(1,07 ; 1,08)**
Utilization Garza April	**(1,08 ; 1,08)**
Utilization Garza May	**(1,08 ; 1,09)**
Utilization Garza June	**(1,08 ; 1,09)**
Utilization Garza July	**(1,09 ; 1,09)**
Utilization Garza August	**(1,02 ; 1,04)**
Utilization Garza September	**(0,95 ; 0,96)**
Utilization GX January	**(0,30 ; 0,36)**
Utilization GX October	**(0,48 ; 0,51)**
Utilization GX November	**(0,49 ; 0,51)**
Utilization GX December	**(0,49 ; 0,51)**
Utilization GX February	**(0,42 ; 0,46)**
Utilization GX March	**(0,45 ; 0,48)**
Utilization GX April	**(0,47 ; 0,50)**
Utilization GX May	**(0,48 ; 0,51)**

Utilization GX June	**(0,49 ; 0,52)**
Utilization GX July	**(0,49 ; 0,52)**
Utilization GX August	**(0,49 ; 0,51)**
Utilization GX September	**(0,48 ; 0,51)**
Utilization KD January	**(0,4 ; 0,42)**
Utilization KD October	**(0,49 ; 0,50)**
Utilization KD November	**(0,5 ; 0,5)**
Utilization KD December	**(0,49 ; 0,50)**
Utilization KD February	**(0,47 ; 0,49)**
Utilization KD March	**(0,49 ; 0,50)**
Utilization KD April	**(0,49 ; 0,50)**
Utilization KD May	**(0,51 ; 0,52)**
Utilization KD June	**(0,50 ; 0,51)**
Utilization KD July	**(0,5 ; 0,5)**
Utilization KD August	**(0,5 ; 0,5)**
Utilization KD September	**(0,49 ; 0,50)**
Utilization Lavanova January	**(0,53 ; 0,55)**
Utilization Lavanova October	**(0,43 ; 0,44)**
Utilization Lavanova November	**(0,42 ; 0,42)**
Utilization Lavanova December	**(0,42 ; 0,43)**
Utilization Lavanova February	**(0,5 ; 0,51)**
Utilization Lavanova March	**(0,51 ; 0,52)**
Utilization Lavanova April	**(0,5 ; 0,51)**
Utilization Lavanova May	**(0,51 ; 0,52)**
Utilization Lavanova June	**(0,52 ; 0,52)**
Utilization Lavanova July	**(0,5 ; 0,51)**
Utilization Lavanova August	**(0,48 ; 0,48)**
Utilization Lavanova September	**(0,45 ; 0,46)**
Utilization Multicrab January	**(0,38 ; 0,39)**
Utilization Multicrab October	**(0,35 ; 0,35)**
Utilization Multicrab November	**(0,33 ; 0,34)**
Utilization Multicrab December	**(0,34 ; 0,34)**
Utilization Multicrab February	**(0,38 ; 0,39)**
Utilization Multicrab March	**(0,39 ; 0,4)**
Utilization Multicrab April	**(0,39 ; 0,39)**
Utilization Multicrab May	**(0,39 ; 0,4)**
Utilization Multicrab June	**(0,4 ; 0,4)**
Utilization Multicrab July	**(0,39 ; 0,4)**
Utilization Multicrab August	**(0,38 ; 0,38)**
Utilization Multicrab September	**(0,36 ; 0,36)**
Utilization Multipla January	**(0,42 ; 0,42)**
Utilization Multipla October	**(0,43 ; 0,44)**

Utilization Multipla November	**(0,44 ; 0,44)**
Utilization Multipla December	**(0,43 ; 0,44)**
Utilization Multipla February	**(0,42 ; 0,43)**
Utilization Multipla March	**(0,43 ; 0,43)**
Utilization Multipla April	**(0,43 ; 0,44)**
Utilization Multipla May	**(0,44 ; 0,44)**
Utilization Multipla June	**(0,44 ; 0,44)**
Utilization Multipla July	**(0,43 ; 0,44)**
Utilization Multipla August	**(0,43 ; 0,43)**
Utilization Multipla September	**(0,43 ; 0,44)**
Utilization Pentek January	**(0,22 ; 0,24)**
Utilization Pentek October	**(0,34 ; 0,35)**
Utilization Pentek November	**(0,36 ; 0,36)**
Utilization Pentek December	**(0,4 ; 0,4)**
Utilization Pentek February	**(0,28 ; 0,29)**
Utilization Pentek March	**(0,37 ; 0,37)**
Utilization Pentek April	**(0,36 ; 0,37)**
Utilization Pentek May	**(0,36 ; 0,37)**
Utilization Pentek June	**(0,38 ; 0,39)**
Utilization Pentek July	**(0,36 ; 0,37)**
Utilization Pentek August	**(0,36 ; 0,37)**
Utilization Pentek September	**(0,36 ; 0,36)**
Utilization Preparazione January	**(0,29 ; 0,29)**
Utilization Preparazione October	**(0,32 ; 0,32)**
Utilization Preparazione November	**(0,32 ; 0,32)**
Utilization Preparazione December	**(0,32 ; 0,32)**
Utilization Preparazione February	**(0,3 ; 0,31)**
Utilization Preparazione March	**(0,31 ; 0,31)**
Utilization Preparazione April	**(0,31 ; 0,31)**
Utilization Preparazione May	**(0,31 ; 0,32)**
Utilization Preparazione June	**(0,32 ; 0,32)**
Utilization Preparazione July	**(0,31 ; 0,32)**
Utilization Preparazione August	**(0,31 ; 0,32)**
Utilization Preparazione September	**(0,32 ; 0,32)**
Utilization RamaAlea January	**(0,47 ; 0,49)**
Utilization RamaAlea October	**(0,46 ; 0,47)**
Utilization RamaAlea November	**(0,45 ; 0,46)**
Utilization RamaAlea December	**(0,46 ; 0,46)**
Utilization RamaAlea February	**(0,52 ; 0,53)**
Utilization RamaAlea March	**(0,52 ; 0,54)**
Utilization RamaAlea April	**(0,53 ; 0,54)**
Utilization RamaAlea May	**(0,53 ; 0,54)**

Utilization RamaAlea June	**(0,53 ; 0,54)**
Utilization RamaAlea July	**(0,53 ; 0,54)**
Utilization RamaAlea August	**(0,51 ; 0,51)**
Utilization RamaAlea September	**(0,48 ; 0,49)**
Utilization RamaF2 January	**(0,42 ; 0,45)**
Utilization RamaF2 October	**(0,53 ; 0,55)**
Utilization RamaF2 November	**(0,51 ; 0,53)**
Utilization RamaF2 December	**(0,5 ; 0,52)**
Utilization RamaF2 February	**(0,5 ; 0,52)**
Utilization RamaF2 March	**(0,55 ; 0,57)**
Utilization RamaF2 April	**(0,58 ; 0,6)**
Utilization RamaF2 May	**(0,61 ; 0,63)**
Utilization RamaF2 June	**(0,62 ; 0,64)**
Utilization RamaF2 July	**(0,61 ; 0,62)**
Utilization RamaF2 August	**(0,58 ; 0,6)**
Utilization RamaF2 September	**(0,55 ; 0,57)**
Utilization RamaUnitech January	**(0,84 ; 0,85)**
Utilization RamaUnitech October	**(0,95 ; 0,96)**
Utilization RamaUnitech November	**(0,96 ; 0,96)**
Utilization RamaUnitech December	**(0,95 ; 0,96)**
Utilization RamaUnitech February	**(0,9 ; 0,91)**
Utilization RamaUnitech March	**(0,92 ; 0,93)**
Utilization RamaUnitech April	**(0,94 ; 0,95)**
Utilization RamaUnitech May	**(0,95 ; 0,96)**
Utilization RamaUnitech June	**(0,96 ; 0,96)**
Utilization RamaUnitech July	**(0,94 ; 0,95)**
Utilization RamaUnitech August	**(0,94 ; 0,95)**
Utilization RamaUnitech September	**(0,95 ; 0,95)**
Utilization Rotormat January	**(0,63 ; 0,66)**
Utilization Rotormat October	**(0,68 ; 0,69)**
Utilization Rotormat November	**(0,65 ; 0,66)**
Utilization Rotormat December	**(0,63 ; 0,64)**
Utilization Rotormat February	**(0,72 ; 0,76)**
Utilization Rotormat March	**(0,79 ; 0,82)**
Utilization Rotormat April	**(0,82 ; 0,83)**
Utilization Rotormat May	**(0,85 ; 0,86)**
Utilization Rotormat June	**(0,82 ; 0,83)**
Utilization Rotormat July	**(0,76 ; 0,77)**
Utilization Rotormat August	**(0,73 ; 0,74)**
Utilization Rotormat September	**(0,7 ; 0,71)**
Utilization Soliatrice January	**(0,07 ; 0,08)**
Utilization Soliatrice October	**(0,18 ; 0,19)**

Utilization Soliatrice November	**(0,18 ; 0,18)**
Utilization Soliatrice December	**(0,17 ; 0,17)**
Utilization Soliatrice February	**(0,1 ; 0,11)**
Utilization Soliatrice March	**(0,11 ; 0,12)**
Utilization Soliatrice April	**(0,14 ; 0,14)**
Utilization Soliatrice May	**(0,16 ; 0,16)**
Utilization Soliatrice June	**(0,18 ; 0,18)**
Utilization Soliatrice July	**(0,19 ; 0,19)**
Utilization Soliatrice August	**(0,2 ; 0,2)**
Utilization Soliatrice September	**(0,19 ; 0,19)**
Utilization StriccaGreggio January	**(0,44 ; 0,46)**
Utilization StriccaGreggio October	**(0,4 ; 0,41)**
Utilization StriccaGreggio November	**(0,39 ; 0,39)**
Utilization StriccaGreggio December	**(0,39 ; 0,4)**
Utilization StriccaGreggio February	**(0,46 ; 0,47)**
Utilization StriccaGreggio March	**(0,46 ; 0,47)**
Utilization StriccaGreggio April	**(0,47 ; 0,48)**
Utilization StriccaGreggio May	**(0,47 ; 0,48)**
Utilization StriccaGreggio June	**(0,47 ; 0,48)**
Utilization StriccaGreggio July	**(0,47 ; 0,48)**
Utilization StriccaGreggio August	**(0,45 ; 0,45)**
Utilization StriccaGreggio September	**(0,42 ; 0,42)**
Utilization StriccaTinto January	**(0,13 ; 0,14)**
Utilization StriccaTinto October	**(0,17 ; 0,17)**
Utilization StriccaTinto November	**(0,17 ; 0,17)**
Utilization StriccaTinto December	**(0,17 ; 0,17)**
Utilization StriccaTinto February	**(0,19 ; 0,2)**
Utilization StriccaTinto March	**(0,2 ; 0,2)**
Utilization StriccaTinto April	**(0,2 ; 0,2)**
Utilization StriccaTinto May	**(0,2 ; 0,2)**
Utilization StriccaTinto June	**(0,19 ; 0,19)**
Utilization StriccaTinto July	**(0,19 ; 0,19)**
Utilization StriccaTinto August	**(0,19 ; 0,19)**
Utilization StriccaTinto September	**(0,17 ; 0,18)**
Utilization VaporizzoPiano January	**(0,49 ; 0,5)**
Utilization VaporizzoPiano October	**(0,64 ; 0,64)**
Utilization VaporizzoPiano November	**(0,64 ; 0,65)**
Utilization VaporizzoPiano December	**(0,65 ; 0,65)**
Utilization VaporizzoPiano February	**(0,59 ; 0,6)**
Utilization VaporizzoPiano March	**(0,62 ; 0,63)**
Utilization VaporizzoPiano April	**(0,64 ; 0,64)**
Utilization VaporizzoPiano May	**(0,65 ; 0,65)**

Utilization VaporizzoPiano June	(0,65 ; 0,66)
Utilization VaporizzoPiano July	(0,65 ; 0,65)
Utilization VaporizzoPiano August	(0,65 ; 0,65)
Utilization VaporizzoPiano September	(0,64 ; 0,64)
Utilization VaporizzoSpazzolaScarves January	(0,02 ; 0,02)
Utilization VaporizzoSpazzolaScarves October	(0,06 ; 0,06)
Utilization VaporizzoSpazzolaScarves November	(0,05 ; 0,06)
Utilization VaporizzoSpazzolaScarves December	(0,05 ; 0,05)
Utilization VaporizzoSpazzolaScarves February	(0,03 ; 0,03)
Utilization VaporizzoSpazzolaScarves March	(0,03 ; 0,03)
Utilization VaporizzoSpazzolaScarves April	(0,04 ; 0,04)
Utilization VaporizzoSpazzolaScarves May	(0,05 ; 0,05)
Utilization VaporizzoSpazzolaScarves June	(0,05 ; 0,06)
Utilization VaporizzoSpazzolaScarves July	(0,06 ; 0,06)
Utilization VaporizzoSpazzolaScarves August	(0,06 ; 0,06)
Utilization VaporizzoSpazzolaScarves September	(0,06 ; 0,06)
Utilization VaporizzoSpazzola January	(0,25 ; 0,26)
Utilization VaporizzoSpazzola October	(0,29 ; 0,29)
Utilization VaporizzoSpazzola November	(0,28 ; 0,28)
Utilization VaporizzoSpazzola December	(0,28 ; 0,28)
Utilization VaporizzoSpazzola February	(0,29 ; 0,3)
Utilization VaporizzoSpazzola March	(0,31 ; 0,32)
Utilization VaporizzoSpazzola April	(0,33 ; 0,33)
Utilization VaporizzoSpazzola May	(0,33 ; 0,34)
Utilization VaporizzoSpazzola June	(0,33 ; 0,34)
Utilization VaporizzoSpazzola July	(0,33 ; 0,34)
Utilization VaporizzoSpazzola August	(0,32 ; 0,32)
Utilization VaporizzoSpazzola September	(0,3 ; 0,3)
Utilization WoolPower January	(0,03 ; 0,04)
Utilization WoolPower October	(0,05 ; 0,05)
Utilization WoolPower November	(0,05 ; 0,06)
Utilization WoolPower December	(0,06 ; 0,06)
Utilization WoolPower February	(0,04 ; 0,05)
Utilization WoolPower March	(0,04 ; 0,05)
Utilization WoolPower April	(0,04 ; 0,04)
Utilization WoolPower May	(0,04 ; 0,04)
Utilization WoolPower June	(0,04 ; 0,04)
Utilization WoolPower July	(0,04 ; 0,05)
Utilization WoolPower August	(0,05 ; 0,05)
Utilization WoolPower September	(0,05 ; 0,05)
Utilization Zonco January	(0,95 ; 0,96)
Utilization Zonco October	(0,66 ; 0,66)

Utilization Zonco November	**(0,64 ; 0,64)**
Utilization Zonco December	**(0,65 ; 0,66)**
Utilization Zonco February	**(0,92 ; 0,94)**
Utilization Zonco March	**(0,91 ; 0,93)**
Utilization Zonco April	**(0,85 ; 0,87)**
Utilization Zonco May	**(0,81 ; 0,82)**
Utilization Zonco June	**(0,78 ; 0,8)**
Utilization Zonco July	**(0,77 ; 0,79)**
Utilization Zonco August	**(0,72 ; 0,74)**
Utilization Zonco September	**(0,68 ; 0,69)**

Table 8: Interval Estimation of the required statistics

FROM / TO MACHINE	*TRANSPORTED PIECES*
Bruciapelo	**57054**
Ecosystem	48168
Lavanova	8886
Carbonizzo	**11159**
Lavanova	11159
Cimi	**4856**
Rama F2	2035
Rama Unitech	2821
Controllo Finito	**7192**
Rama Alea	3596
Rama F2	3596
Controllo intermedio	**2035**
Multicrab	2035
Controllo Lunato	**13199**
Bruciapelo	4298
Cimatrice Scuri	8901
Controllo Tintoria	**14690**
Tintoria	14690
Decatizzo	**87902**
Controllo Finito	82355
Garza Piccola	2035
Multicrab	2035
Formula1	1477
Ecosystem	**72029**
Rama Unitech	28237
Rotormat	43792
Garza Piccola	**5283**
Controllo intermedio	2035
Rama Alea	990
Stricca Greggio	2258
Lavanova	**42260**
Carbonizzo	2258
Multicrab	14568
Pentek	6065
Rama Alea	990
Rama Unitech	2821
Zonco	15558
Multicrab	**24849**
Cimi	544
Rama Alea	9076

Rama F2	2035
Soliatura	2035
Garza	11159
Multipla	**65767**
Rama Alea	990
Rama Unitech	64777
Pentek	**12130**
Pentek	6065
Rammendo Esterno	6065
Preparazione	**74653**
Bruciapelo	6065
Multipla	47681
Wool Power	2821
Cimatrice Pettinati	18086
Rama Alea	**44603**
Controllo Lunato	8901
Controllo Tintoria	8901
Garza Piccola	990
Preparazione	990
Rammendo Fino	990
Garza	14568
Cimatrice Scuri	5667
GX	3596
Rama F2	**29278**
Controllo Tintoria	1491
Decatizzo	2035
Rammendo Fino	2035
Vaporizzo Spazzola Frangiati	2035
Vaporizzo Piano	18086
GX	3596
Rama Unitech	**151044**
Controllo Lunato	4298
Controllo Tintoria	4298
Ecosystem	4298
Preparazione	67598
Rama Unitech	1477
Rammendo Fino	18086
Rammendo Esterno	50989
Rammendo Fino	**35679**
Vaporizzo Spazzola	14568
Vaporizzo Spazzola Frangiati	2035

Wool Power	990
KD	18086
Rotormat	**44336**
Multicrab	544
Rama Unitech	43792
Soliatura	**3526**
Rama F2	3526
Stricca Greggio	**14568**
Multicrab	5667
ChemisetFissatex	8901
Stricca Tinto	**8901**
Rama Alea	8901
Tintoria	**14690**
Rama Unitech	4298
Soliatura	1491
Stricca Tinto	8901
Vaporizzo Spazzola	**14568**
Vaporizzo Piano	14568
Vaporizzo Spazzola Frangiati	**4070**
Decatizzo	4070
Wool Power	**3811**
KD	3811
Zonco	**15558**
Lavanova	15558
Garza	**25727**
Rama Alea	11159
Stricca Greggio	8901
Policlean	5667
KD	**68588**
Rama F2	18086
Vaporizzo Piano	50502
Policlean	**5667**
Garza Piccola	2258
Stricca Greggio	3409
ChemisetFissatex	**8901**
Rama Alea	8901
Cimatrice Pettinati	**18086**
Multipla	18086
Cimatrice Scuri	**14568**
Rammendo Fino	14568
Formula1	**1477**

Controllo Finito	1477
Rammendo Esterno	**57054**
Rama Unitech	2821
KD	46691
Vaporizzo Piano	7542
Vaporizzo Piano	**90698**
Controllo Finito	8901
Decatizzo	81797
GX	**7401**
Controllo Finito	7401
TOTAL	***1177857***

Table 9: Number of piece of fabrics transported every year

DAILY TARDINESS PENALTY (€/(u*dd))	*NUMBER OF TRANSPORTERS*	*COST OF TRANSPORTERS (€)*	*TOTAL TARDINESS PENALTIES (€)*	TOTAL COST (€)
1	1	150.336	137.779	288.115
10	1	150.336	1.377.522	1.527.858
20	1	150.336	2.755.015	2.905.351
30	1	150.336	4.132.507	4.282.843
40	1	150.336	5.510.000	5.660.336
50	1	150.336	6.887.492	7.037.828
60	1	150.336	8.264.984	8.415.320
70	1	150.336	9.642.477	9.792.813
80	1	150.336	11.019.969	11.170.305
90	1	150.336	12.397.461	12.547.797
100	1	150.336	13.774.954	13.925.290
110	1	150.336	15.152.446	15.302.782
120	1	150.336	16.529.939	16.680.275
125	2	300.672	17.067.457	17.368.129
130	2	300.672	17.750.153	18.050.825
140	2	300.672	19.115.545	19.416.217
150	2	300.672	20.480.937	20.781.609
200	2	300.672	27.307.896	27.608.568
300	2	300.672	40.961.814	41.262.486
400	2	300.672	54.615.732	54.916.404
500	2	300.672	68.269.650	68.570.322
600	2	300.672	81.923.568	82.224.240
700	2	300.672	95.577.485	95.878.157
800	2	300.672	109.231.403	109.532.075
900	2	300.672	122.885.321	123.185.993
1000	2	300.672	136.539.239	136.839.911

Table 10: Evaluation of costs with different levels of tardiness penalty

MONTH	*DISTRIBUTION*
January	3.14 + GAMM(0.275, 2.59)
February	3.23 + LOGN(0.91, 0.557)
March	TRIA(3.18, 3.85, 4.23)
April	3.28 + LOGN(0.83, 0.453)
May	3.68 + GAMM(0.148, 3.23)
June	3.13 + ERLA(0.231, 5)
July	3.81 + 1.52 * BETA(2.13, 2.67)
August	3.69 + LOGN(0.801, 0.524)
September	3.49 + LOGN(0.805, 0.48)
October	TRIA(3.75, 4.46, 5.2)
November	3.75 + 1.25 * BETA(1.34, 1.67)
December	3.12 + 1.87 * BETA(1.5, 1.94)

Table 11: Monthly interarrival times distribution

TYPES	*DISTRIBUTION*
Nylon	TRIA(4, 55.9, 60)
GarzatiTFD	TRIA(15, 51.6, 63)
Frangiati TF	15 + WEIB(9.37, 3.59)
Lino	48 + ERLA(1.41, 2)
Flanelle TF	40 + 29 * BETA(14.2, 21)
PeloNonPelo	23 + 36 * BETA(0.754, 0.8)
Garzati TF	46 + 12 * BETA(3.71, 3.97)
Pettinati TF	45 + 15 * BETA(10.4, 12.5)
Pettinati TFT	46 + 12 * BETA(7.2, 7.78)
Pettinati TP	47 + 9 * BETA(8.75, 7.49)
Frangiati TP	24.4 + LOGN(1.41, 0.566)
Garzati TP	44 + 17 * BETA(16.9, 20.3)

Table 12: Distributions of the length of the fabrics

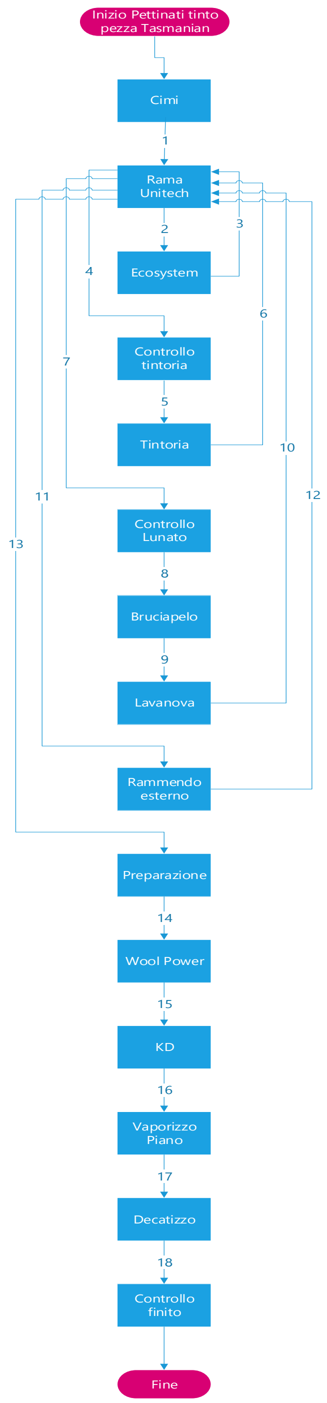

Figure 21: Production cycle Tasmanian piece-dyed

Bibliography

1. Derya Deliktasa, Orhan Torkula and Ozden Ustunb, 2017. A flexible job shop cell scheduling with sequence-dependent family setup times and intercellular transportation times using conic scalarization method. International Transactions in Operational Research (2017).
2. www.myliuc.it, 2017, http://my.liuc.it/MatSup/2017/N91328/Design%20of%20Manufacturing%20Systems%20%E2%80%93%20Job%20Shop.pdf.
3. El Khoukhi, Lamoudan, Boukachour, Alaoui, 2011. Ant colony algorithm for just-in-time job shop scheduling with transportation times and multirobots. ISRN Appl. Math. 2011, 1-19 (2011).
4. www.lvmh.it, 2013, https://www.lvmh.it/le-maison/moda-e-pelletteria/loro-piana/
5. www.ilsole24ore.com, 2013, https://www.ilsole24ore.com/art/finanza-e-mercati/2013-07-08/loro-piana-entra-gruppo-182802.shtml?uuid=AbhDESCI
6. Garey, E.L., Johnson, D.S and Sethi, R. (1976) The complexity of flow shop and job shop scheduling. Mathematics of Operations Research, p117–129.
7. Sun.L, Cheng.X and Liang.Y (2010) Solving job shop scheduling problem using genetic algorithm with penalty function. International Journal of Intelligent Information Processing, volume1, No.2.
8. Zhang, C., Rao, Y., Li, P., 2008. An effective hybrid genetic algorithm for the job shop scheduling problem. Int. J. Adv. Manuf. Technol. 39, 965–974.
9. Wang, Y.M., Xiao, N.F., Yin, H.L., Hu, E.L., Zhao, C.G., Jiang, Y.R., 2008. A two-stage genetic algorithm for large size job shop scheduling problems. Int. J. Adv. Manuf. Technol. 39, 813–820.

10. Eswaramurthy, V.P., Tamilarasi, A., 2009. Hybridizing tabu search with ant colony optimization for solving job shop scheduling problems. Int. J. Adv. Manuf. Technol. 40, 1004–1015.
11. Li, J.-Q., Pan, Y.-X., 2013. A hybrid discrete particle swarm optimization algorithm for solving fuzzy job shop scheduling problem. Int. J. Adv. Manuf. Technol. 66 (1), 583– 596.
12. Tamilarasi, A., Anantha kumar, T., 2010. An enhanced genetic algorithm with simulated annealing for job-shop scheduling. Int. J. Eng. Sci. Technol. 2 (1), 144–151.
13. Kuo, R.J., Cheng, W.C., 2013. Hybrid meta-heuristic algorithm for job shop scheduling with due date time window and release time. Int. J. Adv. Manuf. Technol. 67 (1), 59–71.
14. A. Jamili, 2018. Job shop scheduling with consideration of floating breaking times under uncertainty. Engineering Applications of Artificial Intelligence 78, 28–36.
15. Rui Zhang, Raymond Chiong, 2015. Solving the energy-efficient job shop scheduling problem: a multi- objective genetic algorithm with enhanced local search for minimizing the total weighted tardiness and total energy consumption. Journal of Cleaner Production 112 (2016), 3361-3375.
16. Tang Dunbing, Dai Min, 2015. Energy-efficient Approach to Minimizing the Energy Consumption in An Extended Job-shop Scheduling Problem. Chinese journal of mechanical engineering, Vol. 28, 2015.
17. Liji Shena, Stéphane Dauzère-Pérèsb, Janis S. Neufeldd, 2018. Solving the flexible job shop scheduling problem with sequence-dependent setup times. European Journal of Operational Research 265 (2018), 503–516.
18. Liang-Liang Fu.,Mohamed Ali Aloulou, Chefi Triki, 2017. Integrated production scheduling and vehicle routing problem with job splitting and delivery time windows. International journal of production research (2017), Volume 55.

19. Bilge, Ulusoy, 1995. A time window approach to simultaneous scheduling of machines and material handling system in an FMS. Oper. Res. 43(6), 1058-1070 (1995).
20. Zhang, Manier, Manier, 2012. A genetic algorithm with tabu search procedure for flexible job shop scheduling with transportation constraints and bounded processing times. Comput. Oper. Res. 39(7), 1713-1723 (2012).
21. Caumond, Lacomme, Moukrim, Techernev, 2009. An milp for scheduling problems in an FMS with one vehicle. Eur. J. Oper. Res. 199(3), 706-722 (2009).
22. http://www.dii.unisi.it/~agnetis/locals.pdf
23. Jian Yang, Patrick Jaillet, Hani Mahmassani, (2004) Real-Time Multivehicle Truckload Pickup and Delivery Problems. Transportation Science 38(2):135-148.
24. OptQuest for Arena user's guide, 2009. Rockwell Automation Technologies
25. João Ferreira Netto Rui Carlos Botter, 2013. Simulation model for container fleet sizing on dedicated route. Proceedings of the 2013 Winter Simulation Conference.
26. Pawel Pawlewski Patrycja Hoffa, 2014. Optimization of cross-docking terminal using flexsim/optquest – Case study. Proceedings of the 2014 Winter Simulation Conference
27. Omar Bataineh, Raid Al-Aomar, Ammar Abu-Shakra, 2010. Simulation-Based Optimization for Performance Enhancement of Public Departments. Jordan Journal of Mechanical and Industrial Engineering, 2010, Volume 4, Number 3, 346 – 351.
28. Neeraj, Pranav Nithin, Niranjhan, Sumeshb, Thenarasu, 2019. Modelling and simulation of discrete manufacturing industry. ScienceDirect, Materials Today: Proceedings 5 (2018) 24971–24983

29. Pierreval, Daures, Both, Szimczak, Gonzalez, Framinan, 2013. A simulation optimization approach for reactive ConWIP Systems. 8th EUROSIM Congress on modeling and simulation, 2013.
30. Won Young Yun, Yu Mi Lee, Yong Seok Choi, 2011. Optimal inventory control of empty containers in inland transportation system. Int. J. Production Economics 133 (2011) 451–457.
31. Feng, Qing-hua, San-tao, Wei, 2010. Simulation and Optimization of Vehicle Scheduling in Flight Logistic Support Process Based on Arena. 2010 International Conference on Computer Application and System Modeling (ICCASM 2010).
32. Mehmet A. Ilgin, Surendra m. Gupta, 2008. Joint optimization of transportation and spare parts inventory policies in a reverse logistics network using OptQuest. 2008 ASME International Mechanical Engineering Congress and Exposition.
33. Małopolski Waldemar, 2014. Cost Optimization in Manufacturing System with Unidirectional AGVs. Applied Mechanics and Materials Vol. 555 (2014) pp 822-828.
34. Averill M. Law, 2015. Simulation Modeling and Analysis, Fifth edition. McGraw-Hill Education.