Shift scheduling in multi-item production lines: A case study of a mineral water bottling company

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ABSTRACT
It is well-known that the use of quantitative methods and modern analytics by companies in competitive markets is of vital importance both for their efficiency and financial profit. This study presents a novel, mathematical production-planning model for a real-world production optimization problem of a company located in Northern Greece. The company produces non-alcoholic soft drinks and needs to continuously allocate its human resources in order to have the optimum profit. Therefore, the objective of the model is the minimization of the company's idle human-hours subject to the fulfillment of the demand of customers. As algebraic modeling languages are well-suited for prototyping and developing optimization models, this production planning, mathematical model is implemented in Python v3.7.3 and solved using Gurobi solver v9.0. Furthermore, we also describe the competitive advantages offered by our quantitative approach and the initial allocation plan by the company.

KEYWORDS
Production optimization; shift scheduling; mathematical modeling

1. Introduction

In today's complex business environment, where the market is affected by globalization and is constantly becoming more competitive, companies are urged to make proper use of their resources and particularly their staff in order to make the most of them and meet their customers' needs. Therefore, the impact of modern analytics and operational research techniques Sifaleras and Petridis (2019); Mladenović, Sifaleras, and Kuzmanović (2020) have vitally helped production companies to make better strategic decisions, as well as improve their productivity, their human resources scheduling and, thus, their sustainability.

Typically, a company operating with multi-item production lines has the ability to produce multiple products in a single line. This procedure significantly accelerates both the production, as well as the company's effectiveness and performance. Despite the fact that multi-item production lines have significantly increased the productivity of companies (Gharaei, Karimi, and Hoseini Shekarabi (2019); Gharaei, Hoseini Shekarabi, and Karimi (2020); Rahmouni, Hennet, and Fnaiech (2015); Hedjar, Garg, and Tadj (2015)), an employee scheduling plan as well as a scheduling plan of

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the company shifts are still necessary.

In this paper we try to overcome the uncertainties regarding the production personnel planning and shift scheduling problems, which concern numerous companies. For that reason we propose a solution methodology to the scheduling and production problems dealt by such companies. A deterministic mixed integer programming model (MIP) for multi-lines and multi-product demands is developed to tackle these problems and is applied to a mineral water, bottling company based in Northern Greece.

The manuscript is organized as follows. In Section 2, a literature review of various production planning, workers and shift scheduling problems is presented. Section 3 includes an introduction and some brief information about the company of our case study, presents the problem, and also our methodology and the mathematical formulation of the optimization model. In Section 4 a numerical example with the results' interpretation is presented and also a scenario analysis is performed. Finally, Section 5 summarize our work and propose some interesting future research ideas.

2. Literature Review

Production planning is a vast research topic with several applications in several scientific fields worldwide. Some novel work was introduced by Johnson and Montgomery (1974) about the effects of operations research in production planning and scheduling, followed by Peterson and Silver (1979) discussion on production planning and inventory control decision systems.

However, production planning is a rapidly growing field and a lot of research has been done since its introductory works. Similarly to our model, Pochet and Laurence (2006) describe the mixed integer programming (MIP) effect on production planning and propose solutions to these problems, while numerous optimization models for production planning are presented in Voß and Woodruff (2006). Mula et al. (2006) present a literature review on production planning models, while taking uncertainty into consideration. Salomon (2013) develops various deterministic lot-sizing mathematical models.

In supply chains, and, more specifically, in reverse logistics the effect of production planning is quite popular. Nenes and Nikolaidis (2012) develop a multi-period stochastic model for managing used product returns, while Cunha et al. (2017) propose a MIP solution in a multi-item and uncapacitated production environment by independently solving each item. To add more in the field of reverse logistics and multi-item environment, Sifaleras and Konstantaras (2015) develop a variable neighborhood descent heuristic for solving multi-item dynamic lot-sizing problems.

A comprehensive literature review on production planning problems can be found in the following sections. More specifically, subsection 2.1 presents an introduction and a review on similar employee and shift scheduling problems, while subsection 2.2 introduces some crucial factors affecting the aforementioned problems.

2.1. Employee and shift scheduling problems

Employee scheduling, roughly speaking, is a problem related with the allocation of employees to specific time-slots (shifts) in order to meet specific types of demands based on employees' skills and qualifications. A review on similar shift and personnel scheduling problems follows.

Several applications and studies on employee scheduling problems have been made in various research fields besides production. Barnhart et al. (2003) and Kohl and Karisch (2004) apply the employee scheduling problem in the airlines field, Malhotra and Ritzman (1994), and Bard, Binici, and deSilva (2003) in postal services, while Ertogral and Bamuqabel (2008) in telecommunication call centers.

Brucker, Qu, and Burke (2011) develop not only a general but also a specific mathematical model for personnel scheduling problems, alongside with the description of four problems that can be solved with their models. Ásgeirsson (2014) develops an algorithm that creates feasible employee schedules, which is tested with real world data from different companies. This algorithm manages to decrease under-staffing and ensures that employees' working hours are within the feasible range. Artigues et al. (2009) propose exact hybrid branch and bound methods based on integer linear and constrained programming, as a means to solve the employee timetabling and job-shop scheduling problem.

Castillo, Joro, and Li (2009) introduce a novel three-phase paradigm to workforce scheduling seeking the optimal employee shift arrangement alongside with a real world data example of a North American call center. Sagnak and Kazancoglu (2015) recommend an integer programming model with fuzzy logic in order to assign employees to shifts, making sure they take various breaks (lunch break, rest break, etc) with the minimum cost. Jones and Nolde (2013) introduce a mixed integer linear programming model (MILP) tackling the employee scheduling problem by minimizing the over/under-staffing. This is a demand driven model and is applied by more than 38 small to mid-sized retail stores in Swiss Market.

Sabar, Montreuil, and Frayret (2008) developed a mathematical model for the personnel scheduling in a multi-line and multi-product center in order to minimize personnel dissatisfaction and operational costs. Due to limited historical data and uncertain values about machine availabilities and production rates, Morton and Popova (2004) use a Bayesian stochastic programming approach to a production-planning, employee-scheduling problem in order to optimally allocate the staff in the planning horizon of month.

A research concerned with a similar to ours employee assignment problem is discussed by Al-Yakoob and Sherali (2008) who proposed a mixed integer program applied to Kuwait National Petroleum Corporation (KNPC), in order to optimally assign employees to every gas station of the Corporation in Kuwait for each of the three daily workable shifts. Furthermore two exact methods for solving an integrated employee timetabling and production scheduling problem are proposed by Guyon et al. (2010).

Also, Begen, Puterman, and Wu (2019) presented a logistics optimisation case study for a Canadian beverage manufacturer and distributor. Although, their work was not intended for employee assignment the proposed tool assisted the company to determine production, distribution, and inventory plans for a given product line. This planning tool was implemented in Excel with VBA and provided solutions to 'what if' scenarios.

2.2. Factors influencing optimal employee allocation

In order to optimally allocate their employees, decision makers have to consider several factors. Besides the employees' skills and qualifications, such factors are the total number of the available employees, the number of production lines and number of products/services the company produces/offers, the capacity of each production line, and the number of workable days, the demand for each product etc.

In our analysis we consider that demands and capacities are deterministic. However, other research has studied the cases where demand and/or capacities are unknown and stochastic. Li et al. (2009) consider the demand of products unknown, taking random variables depending on its consumption while, Zhang, Prajapati, and Peden (2011) further consider that demand is seasonal. Additionally, Leung and Chan (2009) study the case where demand prices vary between a lower bound which is known and an upper bound which is forecasted. Moreover, Aliev et al. (2007) experiment with the case where both demand and capacity are unknown and have stochasticity.

In a multi-line production environment, multiple products can be produced in each line, accelerating this way the overall production. Each line is composed by machines with specific capacities; we assume that these capacities are fixed and represent the machines' maximum production ability. In Paquet, Martel, and Montreuil (2008) an optimization methodology is proposed for the design of a manufacturing network where the capacities are fixed and deterministic. However, in practice the capacities of machines may change (e.g. due to partial failure, total failure or maintenance) and thus, their values present stochasticity, which means that capacities are not fixed and deterministic anymore (see Lin and Chang (2012)).

By combining multiple working lines in production the benefits received by companies are numerous. Lan (2007) address the fact that multiple production lines can help companies manufacture products in a more flexible and efficient way. A heuristic solution method to the scheduling problem for parallel production lines is introduced by Meyr and Mann (2013). Also, Bollapragada, Della Croce, and Ghirardi (2011) apply a discrete time dynamic demand model in a multi-machine environment, aiming to allocate item production in different production lines by minimizing various costs (e.g. set up, inventory, lost sales). Furthermore, a three-phase procedure is developed by Lin, Chang, and Chen (2013) in order to evaluate the performance of a footwear manufacturing system using multiple production lines and stochastic capacity. A comprehensive literature review on mix-model assembly lines is presented in Boysen, Fliedner, and Scholl (2009).

In order to meet specific product demands, companies occasionally have to use more than one shift. A solution methodology and an extensive model for the flexible, shift-scheduling problem of physicians in hospitals is developed by Brunner, Bard, and Kolisch (2010). Often, however, the addition of extra shifts is indeed beneficial; other times instead, the results are not favorable. Hanna et al. (2008) investigate the negative effects of extra shifts during a workable day in construction, which amounts to productivity loss between 11% to 17%. Jun and El-Rayes (2010) develop a multi-objective model to schedule multiple shifts in construction projects, where the acceleration of schedules is essential, aiming at the minimization of the negative effects that an evening or night shift may have in construction cost and productivity. Rekik et al. (2010) propose two implicit models dealing with a continuous shift scheduling problem.

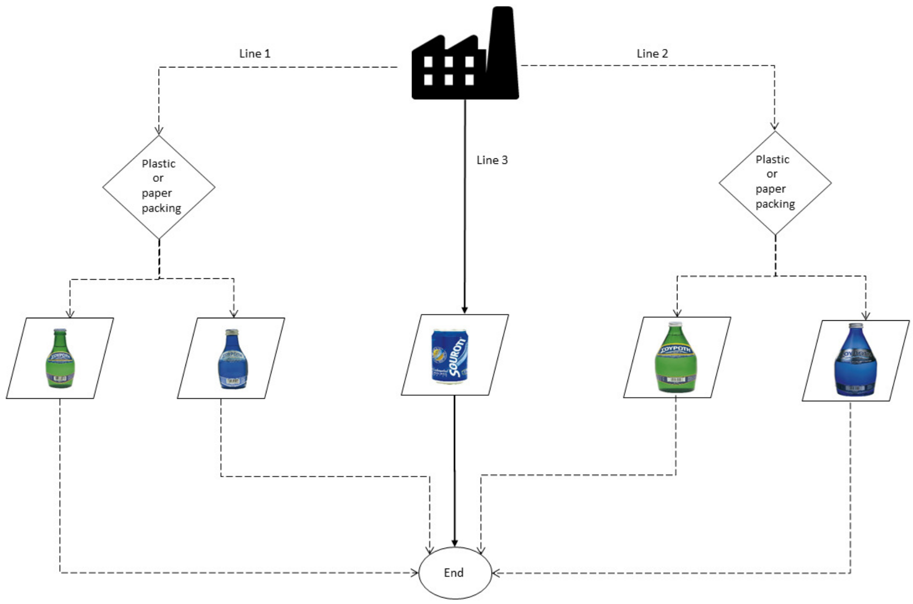
3. Problem description

Souroti S.A. is a mineral-water, bottling company founded in 1916. It is located in a region called Souroti, almost 30 kilometers far out of the city of Thessalonki, in Northern Greece (`http://souroti.gr`). It is housed in modern buildings of 7,500 m^2 and it mainly produces natural-sparkling, mineral water. Additionally, Souroti S.A. also produces mineral water, various soft drinks, and ice tea. A milestone of its history is 1992, when the company earned in Madrid the International Gold Award "Golden

Star", which is given to the finest products of the world. Currently, the company is growing dynamically in new markets worldwide, such as the Middle East, Australia, Canada, Germany, Belgium, the Netherlands, Sweden and Cyprus.

In Figure 1 the whole production process of Souroti S.A. is depicted (Figure 1 include icons retrieved from `http://icons8.com`). The company under study produces multiple items in a multi-line production environment. Lines 1 and 2 (denoted with dotted lines) cannot work simultaneously. The only possible scenario for Souroti S.A. to have two lines working at the same time is by having one of these two lines working together with Line 3 (depicted with a continuous line in Figure 1).

Figure 1.: Production process of Souroti S.A.



As it can also be seen in Figure 1, two of the working lines produce multiple products, i.e. plastic or paper. However, only one product can be produced per time, since the machines belonging in each line can be settled to produce only one type of product per time. More specifically Souroti S.A. produces five types of products, namely 0.25 ml plastic packing, 0.25 ml paper packing, 0.75 ml plastic packing, 0.75 ml paper packing, and 0.33 ml aluminum box. Table 1 and Figure 1 describe the type of products that can be produced in each Line.

Table 1.: Matching between production lines and their corresponding products

Line 1		**Line 2**		**Line 3**
0,25ml plastic	0.25 ml paper	0.75 ml plastic	0.75 ml paper	0.33 ml aluminum

As mentioned above, apart from the multi-item and multi-line capability of the production of Souroti S.A. there is also the potential of simultaneous production. However, there are restrictions, as the products manufactured in Lines 1 and 2 cannot be simultaneously produced. In Table 2 the alternatives of simultaneous product manufacturing are presented. As we can figure out the 0.33 ml aluminum box can be produced simultaneously with any of the other products of Souroti S.A. On the contrary, no other pair of the remaining products can be simultaneously produced in two Lines.

Table 2.: Cases of potential simultaneous production

	0.25 ml plastic	**0.25 ml paper**	**0.75 ml plastic**	**0.75 ml paper**	**0.33 ml aluminum**
0.25 ml plastic	-	x	x	x	✓
0.25 ml paper	-	-	x	x	✓
0.75 ml plastic	-	-	-	x	✓
0.75 ml paper	-	-	-	-	✓
0.33 ml aluminum	-	-	-	-	-

Usually, workers employed in production companies such as Souroti S.A. work in single, eight-hour shifts. In order to meet increased, seasonal demand, however, the company may sometimes require double shifts. We assume that if a second shift is to be requested then this is going to happen after the use of the first shift. Moreover, we assume that no worker works more than one shift per day. A detailed description of a Mixed Integer Programming (MIP) mathematical model for the solution of this problem is presented in the following Section.

Nowadays, numerous production companies face the problem of optimal allocation of their production personnel, while trying to reduce and hopefully eliminate large idle human-hours, which do not contribute in the production process. Roughly speaking, each worker dealing with anything else except for the production process is considered idle so the respective human-hours are considered idle. By considering a worker idle, it does not mean that they do nothing at all but rather that the worker is just occupied with tasks irrelevant to the production process and not with tasks which are their main competence, the main essence of their work, for which the worker is paid for.

Large idle human-hours have a significant impact in production efficiency. Provided that a company cannot meet the expectations of the production required, it is obvious that the available resources are not used in an optimal way. That indicates that there is room for significant improvements in the the work allocation.

Furthermore, large stock in warehouses concerns numerous companies over time. The major objective of all production companies is to meet their demands. However, in case of overproduction large holding costs appear in order to upkeep the large stock, while numerous materials are wasted in order to produce this extra quantity of products. Recapping overproduction leads not only to large inventories and production costs, but also to potential machine failure and larger, unnecessary, environmental pollution.

In this work, we tackle the concerns regarding production planning and scheduling problems and apply our solution to real data arising from Souriti S.A.. Furthermore, in this analysis, all the parameters are assumed to be deterministic.

The company under consideration has to decide how and where to allocate its human resources, for each workable day. More precisely, the company has to decide in which product and in which shift, it should allocate the available human-power for each workable day. The choices should result in the minimal possible idle human-hours and the potential production should be as close as possible to the demands; thus having better utilization of the available human resources and minimizing the holding cost that a potential over-production would cause. The available human-resources of the company and the products' demands are assumed to be known in advance.

The proposed MIP model is developed on a monthly basis, but each examined month features a different number of workable days. In order to produce the required amount of products, a certain number of workers should be allocated in each product line and in each shift. Thus, we consider a minimum number of workers, w_p, who are required for the production of the P products. It should be taken into consideration that in the production of each product a minimum number of men needs to be allocated, because the nature of work required in some production stages requires physical strength. Thus, the whole personnel is divided in groups of women and men.

The machines that are part of the production of each product in Souroti S.A. have fixed capacities c_p for each product per shift, depending on the speed they work. Therefore this specific setting has to be adjusted before the beginning of the production. In this study we assume that machines work at the same processing speed (i.e. identical machines) using 100% of their capacity.

Finally, the produced amount for each product should not be less than the respective demand dem_p, but it should also not exceed it by too much due to holding costs of the excess product. The mathematical programming formulation relies on the following notation:

Indices:

$d = 1, \ldots, D - Days.$
$g = 1, 2 - Gender$ (1 for men, 2 for women).
$s = 1, \ldots, S - Shifts.$
$p = 1, \ldots, 5 - Products.$

Parameters:

D: Number of workable days per month.
S: Number of shifts.
P: Number of products.
dem_p: Demand per product.
c_p: Capacity of machines per product.
w_p: Workers required per product.
M: Number of male workers.
lnM_p: Required minimum number of male workers per product.
F: Number of female workers.
q: When the production of 0.33 ml aluminum is simultaneous with any of the other products then, the required workers of this product line are q fewer than without simultaneous production.

Decision variables:

x_{dgsp}: Number of allocated (non-idle) workers per day, gender, shift, and product.
z_{dsp}: Binary variables for the potential allocation of workers per day, shift, and product. For example, $z_{111} = 1$ denote allocation of (non-idle) workers for the first day, first shift, and first product and zero otherwise).
y: Binary variable denoting the simultaneous production of products $1, \ldots 4$, with

product 5, (i.e., $y = 1$ denotes simultaneous production of one of the products $1, \ldots 4$ with product 5 and zero otherwise).

The proposed MIP model has two objectives, i.e., it aims to minimize both the excess production capacity and the idle human-hours. This multi-objective model can be transformed into a single-objective model where the objective function to be optimized is a combination of two objective functions with equal priorities. The first part of the objective function (1) aims to minimize the excess production capacity (positive sign) while the second part aims to maximize the total number of allocated (non-idle) workers (negative sign). The latter part is equivalent to minimizing the idle human-hours, since the idle human-hours can be computed by the formula: $D \times (M + F) - \sum_{d=1}^{D} \sum_{g=1}^{2} \sum_{s=1}^{S} \sum_{p=1}^{P} x_{dgsp}$.

$$\min \sum_{p=1}^{P} \left(c_p \times (\sum_{d=1}^{D} \sum_{s=1}^{S} z_{dsp}) - dem_p \right) - \sum_{d=1}^{D} \sum_{g=1}^{2} \sum_{s=1}^{S} \sum_{p=1}^{P} x_{dgsp} \tag{1}$$

subject to:

$$\sum_{s=1}^{S} \sum_{p=1}^{P} x_{d1sp} \leq M, \ \forall d \tag{2}$$

$$\sum_{s=1}^{S} \sum_{p=1}^{P} x_{d2sp} \leq F, \ \forall d \tag{3}$$

$$x_{d1sp} \geq lnM_p \times z_{dsp}, \forall d, \ \forall s, \ \forall p \tag{4}$$

$$y \leq \sum_{p=1}^{4} z_{dsp} \leq 1, \ \forall d, \ \forall s \tag{5}$$

$$\sum_{p=1}^{4} z_{dsp} + z_{ds5} - 1 \leq y, \ \forall d, \ \forall s \tag{6}$$

$$z_{d1p} \geq z_{d2p}, \ \forall d, \ \forall p \tag{7}$$

$$\sum_{g=1}^{2} x_{dgsp} = w_p \times z_{dsp}, \ \forall d, \ \forall s, \ p = 1, \ldots, 4 \tag{8}$$

$$\sum_{g=1}^{2} x_{dgs5} = w_5 \times z_{ds5} - q \times y, \ \forall d, \ \forall s \tag{9}$$

$$\sum_{d=1}^{D} \sum_{s=1}^{S} z_{dsp} \times c_p \geq dem_p, \ \forall p \tag{10}$$

Constraints (2) and (3) ensure that, the total number of available male and female workers is not exceeded, respectively. The minimum required number of male workers per product, day, and shift is satisfied by enforcing constraint (4). The left inequality of constraint (5) imposes that in case of simultaneous production, at least one of the first four products will be produced. On the other hand, the right inequality of constraint (5) restricts the simultaneous production of the first four products.

Constraint (6) imposes that in order to have simultaneous production, the 5^{th} product should be produced simultaneously with any of the other 4 products. Constraint (7) ensures that the first shift should be always used before the potential use of the second shift.

Constraint (8) ensures that the required workers for the four first products is present, in the case where there is no simultaneous production with the fifth product. However, in case of simultaneous production, constraint (9) ensures that the workers required in the production of the fifth product (0.33 aluminum) are fewer by two than those required when there is not simultaneous production (i.e., 3 workers instead of 5 according to our numerical example). Finally, constraint (10) guarantees the satisfaction of each product's demand.

4. Numerical example and scenario analysis

An illustrated example of the previously described MIP model, using real data for one indicative month provided by Souroti S.A., is presented subsequently. The purpose of this numerical example is to:

(1) illustrate the optimal worker-scheduling monthly plan
(2) illustrate the optimal shift-scheduling monthly plan
(3) illustrate a comparison between the potential production and the various products' demand
(4) assist the company for scenario analysis.

As mentioned before, we are seeking a monthly shift scheduling plan of the company human resources. The general data for the numerical example are presented in Table 3. The month under study features twenty two workable days, i.e. $d = 22$, and the available human resources of Souroti S.A. are divided to: ten male workers i.e. $M = 10$

and fifteen female workers i.e. $F = 15$. Souroti S.A produces five products (presented in previous section) i.e. $p = 5$.

The parameter values per product for the month under study are presented in Table 4. The capacities per product (or equivalently per shift) are 5,000, 5,600, 3,000, 3,000, and 3,500 items, while the monthly demand per product is 72,000, 21,000, 2,100, 3,500, and 40,000 items, respectively. We assume that the necessary number of workers per product is 16, 11, 11, 10 and 5 or 3 respectively and, finally, the minimum required men are 3, 3, 3, 3 and 1 per product.

In Tables 5, 6 and 7 the optimal solution of our real data application is presented. More specifically Tables 5 and 6 contain the male and female workers' allocation in the two shifts per day for the examined month achieving thus the purposes (2) and (3). Table 7 contains the number of optimal idle human-hours of our solution, a comparison between the potential production of the proposed scheduling plan and the demands achieving the purpose (3).

Let us focus on Tables 5, 6: for the first day the company should allocate 3 men and 13 women in the production of the 0.25 ml plastic packing, in the first shift. As per the second day and the first shift, our optimal allocation plan advises Souroti S.A. to have simultaneous production of the 0.25 plastic packing and 0.33 aluminum box, by allocating 8 men and 8 women in the production of the first product, and 1 man and 2 women in the production of the second one. According to our optimal plan for this day, the company has to work double shifts, by allocating 1 man and 4 women to the production of the 0.33 aluminum box in the second shift. Similarly, our optimal scheduling plan allocates workers to each single workable day (out of the 22 of the month under study) and suggests the use of 9 double shifts in order to satisfy the demands and, simultaneously, minimize the number of idle human-hours.

As already mentioned, besides the minimization of the idle human-hours the other objective of our model is to minimize the excess production; that is the the excessive stock. In Table 7 the reader can find out the differences between the proposed production quantities and the actual product demands. As we can observe, apart from the 0.75 plastic and the 0.75 paper packings, the potential surplus per product does not exceed 10% of the demand; this results in small stock quantities in company's warehouses. We notice that although the excess produced quantity of these two products is relatively high (reaching 42.9% and 71.4% of their demand, respectively), the absolute of excess (namely 900 and 2,500 items, respectively) constitutes a rather small amount of stock and, thus, it is considered manageable by the company.

The aforementioned excess of products cannot be avoided, since their demand could not be satisfied otherwise; apparently the primary goal of our model is to fulfill the demand of products and secondly the minimization of excess production.

Table 3.: General data of the numerical example

1. Planning horizon = one month
2. Number of workable days, d = 22
3. Number of male workers, M = 10
4. Number of female workers, F = 15
5. Number of products, p = 5

[1]When the production of 0.33 ml aluminum is simultaneous with any of the other products then the workers needed are 3 instead of 5

Table 4.: Data per product of the numerical example

	0.25 ml plastic	**0.25 ml paper**	**0.75 ml plastic**	**0.75 ml paper**	**0.33 ml aluminum**
capacity	5,000	5,600	3,000	3,000	3,500
demand	72,000	21,000	2,100	3,500	40,000
workers	16	11	11	10	5 or 3[1]
required men	3	3	3	3	1

Table 5.: Men allocation in shifts

	1st Shift					**2nd Shift**				
	0,25 plastic	*0,25 paper*	*0,75 plastic*	*0,75 paper*	*0,33 aluminum*	*0,25 plastic*	*0,25 paper*	*0,75 plastic*	*0,75 paper*	*0,33 aluminum*
1	3	-	-	-	-	-	-	-	-	-
2	8	-	-	-	1	-	-	-	-	1
3	5	-	-	-	3	-	-	-	-	1
4	10	-	-	-	-	-	-	-	-	-
5	-	3	-	-	-	-	7	-	-	-
6	3	-	-	-	-	-	-	-	-	-
7	-	-	-	3	-	-	-	-	3	-
8	-	-	-	-	1	-	-	-	-	1
9	10	-	-	-	-	-	-	-	-	-
10	10	-	-	-	-	-	-	-	-	-
11	10	-	-	-	-	-	-	-	-	-
12	-	-	-	-	5	-	-	-	-	5
13	-	3	-	-	-	-	7	-	-	-
14	10	-	-	-	-	-	-	-	-	-
15	3	-	-	-	-	-	-	-	-	-
16	5	-	-	-	3	-	-	-	-	1
17	-	-	-	-	1	-	-	-	-	5
18	10	-	-	-	-	-	-	-	-	-
19	10	-	-	-	-	-	-	-	-	-
20	10	-	-	-	-	-	-	-	-	-
21	10	-	-	-	-	-	-	-	-	-
22	-	-	10	-	-	-	-	-	-	-

Table 6.: Women allocation in shifts

	1st Shift					2nd Shift				
	0,25 plastic	*0,25 paper*	*0,75 plastic*	*0,75 paper*	*0,33 aluminum*	*0,25 plastic*	*0,25 paper*	*0,75 plastic*	*0,75 paper*	*0,33 aluminum*
1	13	-	-	-	-	-	-	-	-	-
2	8	-	-	-	2	-	-	-	-	4
3	11	-	-	-	0	-	-	-	-	4
4	6	-	-	-	-	-	-	-	-	-
5	-	8	-	-	-	-	4	-	-	-
6	13	-	-	-	-	-	-	-	-	-
7	-	-	-	7	-	-	-	-	7	-
8	-	-	-	-	4	-	-	-	-	4
9	6	-	-	-	-	-	-	-	-	-
10	6	-	-	-	-	-	-	-	-	-
11	6	-	-	-	-	-	-	-	-	-
12	-	-	-	-	0	-	-	-	-	0
13	-	8	-	-	-	-	4	-	-	-
14	6	-	-	-	-	-	-	-	-	-
15	13	-	-	-	-	-	-	-	-	-
16	11	-	-	-	0	-	-	-	-	4
17	-	-	-	-	4	-	-	-	-	0
18	6	-	-	-	-	-	-	-	-	-
19	6	-	-	-	-	-	-	-	-	-
20	6	-	-	-	-	-	-	-	-	-
21	6	-	-	-	-	-	-	-	-	-
22	-	-	1	-	-	-	-	-	-	-

Table 7.: Comparison between proposed production and demands

	0.25 ml plastic	**0.25 ml paper**	**0.75 ml plastic**	**0.75 ml paper**	**0.33 ml aluminum**
potential production	75,000	22,400	3,000	6,000	42,000
product demand	72,000	21,000	2,100	3,500	40,000
excess production capacity	3,000	1,400	900	2,500	2,000
excess production capacity (%)	4.2%	6.7%	42.9%	71.4%	5.0%
idle human-hours			181		

Furthermore, according to the statistics derived from the log file of Gurobi solver v.9.0, the proposed model using this real data contains 731 constraints, 704 integer (264 binary) variables, and 2684 nonzeros. These statistics highlight the computational difficulty of such production optimization models and justify the necessity of quantitative approaches.

Scenario analysis constitutes a useful tool, in case the values of some of the model parameters change. More specifically, in what follows we study potential changes of

- i the workable days per month,
- ii the number of male workers,

iii the number of female workers,
iv the demand of products and
v the machine capacities.

These “What-if-questions” have a large practical significance for any company since changes like those frequently occur in a daily routine. Thus, our scenario analysis aims i) to observe how robust the computed optimal solution is and ii) to identify the required actions by Souroti S.A. in case of parameter differentiations, in advance. Note that the analysis that follows assumes that only single parameter changes occur and not changes of multiple parameters at the same time.

First, as per the number of available workable days, Table 8 presents the scenario analysis that arises by examining of either the increase or the decrease of the particular parameter. As it can be seen, a decrease of the workable days decreases the idle human-hours, therefore improving the optimal solution. A critical point of the analysis is when the number of workable days becomes 18 (i.e. D = 18): in that case our problem becomes infeasible. For this reason, the company should be aware of the minimum number of days which are required to meet its products' demand.

Table 8.: The effect of workable days per month

	Workable days per month		**Idle human-hours**	
	Value	**Change(%)**	**Value**	**Change(%)**
#1	25	13.6	250	38.12
#2	24	9.1	227	25.41
#3	23	4.5	204	12.71
#4	22	0.0	181	0.00
#5	21	-4.5	158	-12.71
#6	20	-9.1	135	-25.41
#7	19	-13.6	112	-38.12
#8	**18**	**-18,2**	**Infeasible**	**-**

The results of the scenario analysis regarding the number of male workers are depicted in Table 9, where both the increase and the decrease of this parameter are studied. It turns out that a decrease of male workers has less impact than the decrease of workable days on the optimal solution of the idle human-hours. In addition, a critical value of the number of male workers is when they become three, where the problem becomes infeasible. Therefore the minimum number of male workers in order for Souroti S.A. to meet its products demand is four.

Table 10 presents the results of a similar analysis for the number of female workers. The impact of the decrease of female workers is almost identical to that of male workers. More specifically, the decrease in the number of female workers has less impact than the decrease of workable days on the optimal number of the idle human-hours. The minimum number of female workers that the company should have in order to meet its demands is nine. Scenario analysis, such as the one presented, is significant

Table 9.: The effect of the number of male workers

	Number of male workers		Idle human-hours	
	Value	**Change(%)**	**Value**	**Change(%)**
#1	9	-10	159	-12.15
#2	8	-20	141	-22.10
#3	7	-30	119	-34.25
#4	6	-40	97	-46.41
#5	5	-50	77	-57.46
#6	4	-60	67	-62.98
#7	**3**	**-70%**	**Infeasible**	**-**

for companies since it enables them to schedule the absences of each month without endangering their production plan. For example, by using the above information, Souroti S.A. knows that the maximum number of women in vacation (or pregnancy leaves etc.) is equal to six for this specific month.

Table 10.: The effect of the number of female workers

	Number of female workers		Idle human-hours	
	Value	**Change(%)**	**Value**	**Change(%)**
#1	14	-7	159	-12.15
#2	13	-13	141	-22.10
#3	12	-20	119	-34.25
#4	11	-27	97	-46.41
#5	10	-33	75	-58.56
#6	9	-40	55	-69.61
#7	**8**	**-47%**	**Infeasible**	**-**

Table 11 shows the results of the scenario analysis we carried out to study potential changes of product demand. It comes that each change in the value of demand is inversely proportional to the optimal idle human-hours. As the demand decreases it is obvious that the optimal idle man-hours increase and vice versa. In this case the problem becomes infeasible when the demand's increase is 21%. Therefore, the company should know that the possible solutions in order to satisfy its demands are to hire (at least temporarily) additional workers or to add a third shift per day.

Finally, Table 12 presents the results of the scenario analysis concerning the capacities of each product line, depending on the type of product manufactured. As the capacities presented in Table 4 denote the maximum production levels of each product per shift and we assume that the machines of Souroti S.A. perform at their full potential (100%), there is no point to study the effect of further increase in capacities.

Having said that, we find out that the decrease in capacities is proportional to the optimal value of idle human-hours. Moreover, a critical point arises when the decrease reaches 18%, where the problem becomes infeasible.

Table 11.: Percentage differentiation of demand

	Demand	**Idle human-hours**	
	Change(%)	**Value**	**Change(%)**
#1	**0.21**	**Infeasible**	**-**
#2	0.18	136	-24.86
#3	0.15	136	-24.86
#4	0.12	141	-22.10
#5	0.09	155	-14.36
#6	0.06	164	-9.39
#7	0.03	181	0.00
#8	-0.03	195	7.73
#9	-0.06	200	10.50
#10	-0.09	200	10.50
#11	-0.12	214	18.23
#12	-0.15	227	25.41
#13	-0.18	243	34.25
#14	-0.21	254	40.33

Table 12.: Percentage differentiation of machines' capacities

	Machines' capacities	**Idle human-hours**	
	Change(%)	**Value**	**Change(%)**
#1	-0,03	181	0,00
#2	-0,06	164	-9,39
#3	-0,09	155	-14,36
#4	-0,12	141	-22,10
#5	-0,15	136	-24,86
#6	**-0,18**	**Infeasible**	**-**

5. Discussion, managerial insight, and future work

The knowledge of the scenario analysis results presented in the previous section constitutes a valuable tool for managers of companies such as Souroti S.A. By studying the effect of changes in the available workable days, the company knows that the minimum workable days per month required to meet its demands is 19; thus, there is a margin of three workable days (from 22 now, to 19 at most). The importance of this information becomes clear if all the cases where the company remains closed (e.g. during frost in winter) are considered. If surpassing the minimum workable days required to satisfy demands is unavoidable, then the alternative solutions to face the arising problem is usually to work in three shifts or to hire (at least temporarily) extra personnel.

As far as the number of available workers is concerned, a scenario analysis (such as the one shown in Tables 9 and 10) is also quite meaningful, as it provides decision makers with information about the scenarios where the idle human-hours are reduced. It also offers insight on the minimum number of male and female workers needed for the company to meet its customer demands.

Product demands can be easily differentiated in practice. Consequently, it is of vital importance for any company to have alternative optimal production plans in order to satisfy them. More specifically, as far as the scenario of decreased demand is concerned, less human-hours will be needed. Thus it is reasonable for a company to consider the respective periods as the most appropriate to schedule workers' leaves. On the other hand, in case of increased demands the scenario analysis allows the company to know over which point demand is impossible to be met and, thus, either use three shifts or hire additional personnel.

Changes in product line capacities also concern any manufacturing company. For example, potential power failures, machine failures or maintenance constitute indicative reasons which may decrease product line capacities and, consequently, the overall production. Consequently, the companies' managers have to consider all those cases of decreased capacity, otherwise their company runs the risk of failing to satisfy customers.

Overall, the proposed MIP model offers significant insights to a company like the one under study on how to properly handle cases of vacation planning, machine maintenance planning, as well as emergency situations such as cases of sickness, pregnancy, power outage and extreme weather conditions. In order for the company to use the proposed model, the Production Manager firstly needs to carefully select the data requirements. These data requirements are the problem parameters as presented in Section 3 (e.g., products demand, capacities, available number of male/female workers). Afterwards, the Operational Analyst of the company may follow the proposed model based on the provided data. The company may use the proposed model on a monthly basis and find the optimal shift scheduling accordingly. Ideally, the results should also be communicated with other staff executives (or members) in the company, such as the Human Resource Manager.

This paper presents a deterministic MIP model aiming to optimize the production of Souroti S.A., which is a leading mineral water bottling company in Northern Greece. Our model provides the optimal shift scheduling plan for the company's human resources which can be used for the allocation of available employees, while also minimizing the possible idle human-hours and potential stock quantities of products.

Some of the benefits that arise from the use of the proposed model (or any similar one) is that any interested company has an automated, reliable, and fast way of planning the allocation of its human resources. This is absolutely useful in the competitive business environment of nowadays, where companies are forced to utilize their assets and especially their staff in a way that allows not only to take advantage of them, but also to address their customers needs. Furthermore, the exploitation of the proposed model allows the company to be flexible in cases of emergency or other unpredictable situations, which may affect the availability of human resources or the machines capacities or the demand of.

Since the optimal plan given by our model minimizes not only the total idle human-hours, but also the excess production, it offers an additional advantage in any interested company: it leads to the minimum usage of its production machines. This, in turn, leads to less frequent machine maintenance, longer life of machines and even less environmental pollution. The latter consequences are actually benefits, which contribute undoubtedly to the sustainability of the involved company; this is a byproduct, but certainly an important one, of the use of our MIP model, as sustainability is also one of the contemporary requirements for modern businesses.

Finally, as per the future research is concerned, an interesting direction would be to add stochasticity in the examined model. For example, the study of a different way of change in machine capacity. Our model considers that product line capacities are deterministic and known in advance. Adding stochasticity in capacity would allow the study of the production machines' behavior in a more realistic way. Another area of future research with high potential would be the multiple-factor scenario analysis which will allow any company like Souroti S.A. to study more likely scenarios of parameter changes, with significant practical applicability. Though, an alternative way to study stochasticity would be to simulate various parameters' changes according to particular probability distributions.

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