Short-term Production Scheduling in the Soft Drink Industry

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Abstract: In this study, the formulation of a mixed-integer linear programming model applied to production scheduling in the soft drink industry is addressed. The model considers the production of beverages with different flavors and formats in two synchronized production stages: preparation of syrup in storage tanks and bottling syrup in packaging lines. This model defines the order of the products at each stage of production with makespan minimization, taking into account aspects such as sequence-dependent set-up times, synchronisation between production stages, several tanks and packaging lines, capacity constraints, time constraints (deadlines). Also considered is the property of job splitting in first stage, which reduces waiting times in the packaging lines. We include the method of application in a real-world problem of a beverage bottling company. The results show that on average the application managed to improve 15.67% the company's current solution.

1 INTRODUCTION

The soft drink industry is present in every consumer market with a variety of products, such as carbonated beverages, waters, juices and functional beverages, each in different flavors and formats. Production plants must submit finished products through a vast territory to distinct points of sale, so its production levels are quite high. This situation forces plants to produce products more effectively. A recurring problem is how to convert the production plan from macro planning (medium term) to manufacturing orders that determine a detailed program (short-term), in which the order that products are processed in each stage is specified. Having tools to manage this order can be a big advantage over competitors.

In the soft drink industry, this aspect is of great importance mainly due to the existence of sequence-dependent set-up times, i.e. the set-up time depends on the product processed before, so the order in which products are produced has great impact on the overall production time. Broadly speaking, the production process of this industry consists of two main stages: preparation of syrup and packaging. In preparing the syrup, storage tanks are used to prepared the liquid. In the packaging step, the liquid is transported from the storage tanks to packaging lines where the packings are filled with the corresponding liquid.

This article describes the development of a mixed-integer programming model representing the above mentioned manufacturing process, which determines the order in which the products are produced, in order to minimize the makespan in a short period of time. The main features of the model are the incorporation of sequence-dependent set-up times, synchronisation between production stages, several tanks and packaging lines, capacity constraints, time constraints (deadlines) and job splitting. Controlling these variables maximizes the use of packaging lines when a job exceeds the capacity of the tank.

The rest of the paper is organized as follows: A literature review focused on related work, is addressed in section 2. In section 3, the production process of the soft drink industry, its problems, the mathematical model proposed and methodology for solution are detailed. In the 4 section, the methodology and its computational results applied to a real-world problem of a bottling company are presented. Finally, in section 5 the main conclusions are shown, along with a look at future research.

2 LITERATURE REVIEW

This section briefly describes the work related to this article. For an introduction to models and methods for planning and scheduling in manufacturing and service industries, see (Pinedo, 2005). On the other hand, (Salomon, 1991) describes sizing models and tech-

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niques for planning and production scheduling. In both texts, computational difficulties raised by these problems are shown, because of its combinatorial characteristics and, in general are classified as NP-Hard.

With regard to production scheduling, including sequence-dependent set-up is a thoroughly researched topic, see (Allahverdi et al., 2008), where a review of the literature that addresses this problem is presented. In (Ríos-Mercado and Bard, 1998), two models of integer linear programming (MIP) with makespan minimization are presented for a flow shop environment with sequence-dependent set-up times, which are then solved by Branch-and-Cut algorithms. These models are used in (Kurz and Askin, 2004) and (Karmakar and Mahanty, 2010), which are extended to Flexible Flow Shop, with identical parallel machines at each stage. (Rocha et al., 2008) propose two MIP models for programming non-parallel machines, considering sequence-dependent set-up times. In (Yilmaz Eroglu and Ozmutlu, 2014) MIP programming models for unrelated parallel machines with job splitting are presented, where a job can be divided between machines available for processing separately. The solution of these models is through hybrid heuristic methods between genetic algorithms and local search. (Hnaien et al., 2015) tackle the two-machine flowshop with an availability constraint on the first machine. Two MIP models and a branch and bound (B&B) algorithm based on a set of new lower bounds and heuristics are presented. In (Jia et al., 2015), a makespan minimization in parallel batch machines with non-identical capacities is solved, through two different heuristics. The first is based on the First-Fit-Decreasing (FFD) rule and the second based on Max-Min Ant System (MMAS).

All these papers have a continuous time MIP models and the same function objective which is makespan minimization. With regard to this study, the method of solution is the same, but when applied to the soft drink industry additional problems arise, such as synchronization between production stages, which will be explained in section 3.

The lot sizing and scheduling problem also provides solutions to the problem in matter, where a lot sizing simultaneously exist with the production scheduling. For more information, see (Drexl and Kimms, 1997), which presents a survey on this issue and a literature review. One of the most important works in this area corresponds to (Fleischmann and Meyr, 1997), where a model of planning and scheduling with sequence dependent set-up and cost minimization, called The General Lot-Sizing and Scheduling Problem (GLSP), is presented. In that article, the technique to simultaneously determine lot sizing and scheduling corresponds to the use of a special structure of time, which is divided into macro periods, where each macro period is subdivided into micro periods. In each macro period, elements that provide external information to the problem are caught, such as demand and inventory costs. Micro periods determine the order in which the products are produced since each micro period allows the production of only one product. (Meyr, 2000) extends the GLSP to include sequence-dependent set-up time, called GLSPST, where the solution method of the model corresponds to a dual re-optimization algorithm combined with local search heuristics. In (Seeanner and Meyr, 2013) a new extension is made, this time to a multi stage environment and, in addition, properties that allow better use of production lines are incorporated: quantity and splitting set-up, allowing split quantities and set-up times in consecutive micro periods. Small instances are solved by standard solver and relax-and-fix heuristics, before being compared.

(Ferreira et al., 2009) use a model based on the GLSP, but applied to the soft drink industry, in which a two-stage model with parallel machines, sequence-dependent times and synchronization between the two stages is presented, what fits quite well to the problem to be solved in this study, except for the difference that the objective of GLSP is a long-term plan to minimize inventory costs and set-up. A relaxation approach and several strategies of the relax-and-fix heuristic are proposed to solve the model. This same model is solved in (Toledo et al., 2011), but using tabu search algorithms. In (Ferreira et al., 2012), 4 formulations are presented of only one stage to model the problem of two stages of the soft drink industry addressed in previous articles, two of them based on GLSP and the other two on the asymmetric traveling salesman problem (ATSP). In (Toledo et al., 2014), the model presented in (Ferreira et al., 2009) is also solved, but in this case the combination of a genetic algorithm with mathematical programming techniques is used.

These articles related to the soft drink industry, have lot sizing models in conjunction with production scheduling, in order to minimize costs, which differs from the model shown here. The main objective of this paper is to provide a production scheduling for a short term period with makespan minimization. Another difference with the previous articles is that this paper allows the division of a lot to be processed in different tanks, which reduces waiting time in the packaging lines. Besides this, this paper incorporates a solution strategy using the plan currently employed by the firm as the upper limit for the model solution.

3 PROBLEM DEVELOPMENT FOR THE SOFT DRINK INDUSTRY

3.1 The Productive Process

The production of soft drinks is mainly carried out in two clearly identifiable interdependent stages. The first stage of production is in the preparation of syrup, which serves to produce different types of beverages, whether juices, waters, carbonated and functional beverages. Syrup preparation takes place in the storage tanks where the ingredients are mixed and the corresponding quality controls are carried out. After the syrup is ready, it proceeds to the second stage of production for bottling in packaging lines. At this stage, the syrup is transferred from the storage tanks to the packaging lines, specifically to the filler, where the syrup is bottled, inspected, coded, labeled, boxed and palletized. All these processes are automatically performed in series in a continuous process by conveyor belts, from the accumulation of empty bottles to creation of pallets of finished products. This series of machines correspond to the packaging line. Because of these characteristics, without loss of generality, packaging lines will be considered in this article as a single machine.

The first stage of production it has several storage tanks of different capacities and each tank may store a subset of the flavors produced by the plant. In the second stage of production, there are several packaging lines, with different speeds, and each production line can package a subset of the formats produced by the plant. To supply the syrup to packaging lines, tanks can be connected to any line. For lines, they may receive syrup from any tank, but only from one tank at a time that is, there can not be more than one tank connected to a line simultaneously.

As mentioned above, during the production process, set-up times are sequence-dependent, corresponding to cleaning and machine adjustments, but it is in the first stage where set-up times are substantially higher, which may vary between 2 and 12 hours. Besides this, there are types of drinks in batches of a product that exceed the available capacity of the tank, so the line is required to wait more syrup after the tank is empty. This is because in general, bottling plants have a number of tanks greater than the number of packaging lines. This feature is taken into account in the formulation of the model in section 3.2, since the division of the batch of a product to be accumulated in more than one tank is allowed, allowing supply part of the batch from a tank while preparing the rest of the batch in other tanks. Thus, the packaging lines remain longer in operation and reduce waiting times.

Despite the existence of two different production stages, production is carried out simultaneously on both stages, so synchronization should be considered between them. The packaging line can not operate without the tank is ready to provide the appropriate liquid, and, in the same way, a tank can not supply syrup without line is ready for packaging, so the process must match. An example where you can appreciate the importance of synchronization between the stages is shown in Figure 1. This feature is particularly in the soft drink industry, unlike flow shop environment, where the products are processed sequentially at each stage. In Figure 1 also can be appreciated the division of the batch in more than one tank, which must be synchronized with the line processing the batch, taking care that the batches not overlap between tanks, given that as mentioned above, there can not be more than one tank supplying syrup to a line simultaneously. To achieve this, the proposed model assign a position to each tank where the batch was divided, indexed by the subscript "o". Therefore, the order in which the tanks will provide syrup to the packaging line for that product is given by the assigned positions.

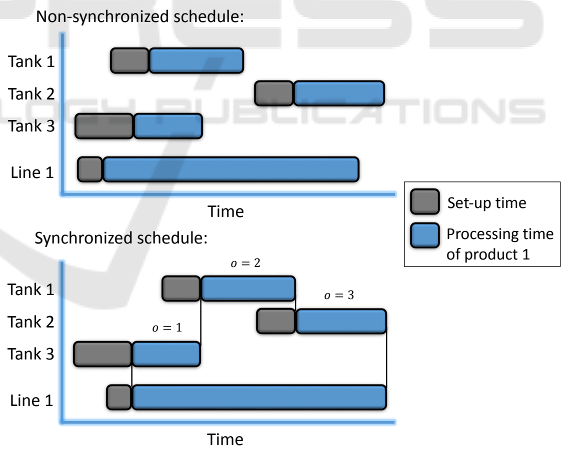

Figure 1: Synchronization between stages.

Products are identified by two main features, the syrup flavor and bottling format. The identification of each product is given by the SKU (Stock Keeping Unit). To determine the quantity to produce of each product, the plant generates a production plan in a certain period of time. Applied to the case in this article, the plan is carried out for a week. The objective of the proposed model is to minimize production time, so if the current plan takes less time, the plant can plan more products in the same time period, increasing its efficiency.

3.2 The Model

The proposed model and its features are detailed next. It is important to mention the considerations taken for the creation of this model. It is assumed that there is always availability of raw material for the preparation of syrup. A product can be assigned to more than one tank, but must be assigned to only one line. The demand for a product corresponds to the plan generated by the company, and determines the size of the batch of the product. The parameters are similar to those in (Ferreira et al., 2009), and exhibits the characteristics of the industry here studied.

Model variables are related to the production stage acting, the index above "T" refers to the first stage: Tanks, the index above "L" refers to the second stage: Lines. The constraints are divided into three parts, based on the stage acting and synchronization.

Sets:

- J Set of products.
- J_0 Set of products including a dummy job 0 ($J_0 = J \cup \{0\}$).
- α_m Set of products that can be produced in tank/line m.
- β_j Set of tanks that can produce product j.
- γ_j Set of lines that can produce product j.

Parameters:

- D_j Demand of product j.
- d_j Deadline of product j.
- s^T_{ij} Set-up time from product i to j in Tanks.
- s^L_{ij} Set-up time from product i to j in Lines.
- a_{jm} Processing time for one unit of product j in Line m.
- r_j Quantity of liquid necessary to produce one unit of product j.
- K_m Capacity of Tank m.
- G Upper bound for the completion time of a product.

Variables:

- x^T_{ijm} 1 if product j is processed immediately after product i in Tank m; 0 otherwise.
- x^L_{ijm} 1 if product j is processed immediately after product i in Line m; 0 otherwise.
- y^T_{jmo} 1 if product j is processed in Tank m at the oth position; 0 otherwise.
- y^L_{jm} 1 if product j is processed in Line m; 0 otherwise.
- p^T_{jmo} Quantity of liquid of product j in Tank m at the oth position.
- C^T_{jmo} Completion time of product j in Tank m at the oth position.
- C^L_j Completion time of product j in Lines.
- $C_{\max}$ Makespan ($C_{\max} = \max\{C^L_j\}$).
- v_j Waiting time of the line while processing product j.
- q^T_{jmo} Number of set-up needed from product j to j in Tank m at the oth position.
- R_j Delay in completion time of product j.

Objective Function:

$$Min \quad C_{\max} + \sum_j R_j \tag{1}$$

Constraints:

Tanks:

$$\sum_{m \in \beta_j} \sum_{o=1}^{|\beta_j|} y^T_{jmo} \geq 1 \qquad j \in J \tag{2}$$

$$\sum_{o=1}^{|\beta_0|} y^T_{0mo} = 1 \qquad m \in \beta_0 \tag{3}$$

$$\sum_{j \in \alpha_m} x^T_{ijm} = \sum_{o=1}^{|\beta_i|} y^T_{imo} \qquad i \in J_0,\ m \in \beta_i \tag{4}$$

$$\sum_{i \in \alpha_m} x^T_{ijm} = \sum_{o=1}^{|\beta_j|} y^T_{jmo}, \qquad j \in J_0,\ m \in \beta_j \tag{5}$$

$$\sum_{o=1}^{|\beta_j|} C^T_{jmo} + G\left(2 - x^T_{ijm} - y^L_{jw}\right) \geq \sum_{o=1}^{|\beta_i|} C^T_{imo} + \sum_{o=1}^{|\beta_j|} s^T_{ij} y^T_{jmo} + \sum_{o=1}^{|\beta_j|} \frac{a_{jw} p^T_{jmo}}{r_j} + \sum_{o=1}^{|\beta_j|} q^T_{jmo} s^T_{jj} \qquad i \in J_0,\ j \in J,\ w \in \gamma_j,\ m \in \beta_i \cap \beta_j \tag{6}$$

$$\sum_{m \in \beta_j} \sum_{o=1}^{|\beta_j|} p^T_{jmo} \geq r_j D_j \qquad j \in J \tag{7}$$

$$p^T_{jmo} \leq r_j D_j \cdot y^T_{jmo} \qquad j \in J,\ m \in \beta_j,\ o = 1...|\beta_j| \tag{8}$$

$$C^T_{jmo} \leq G \cdot y^T_{jmo} \qquad j \in J,\ m \in \beta_j,\ o = 1...|\beta_j| \tag{9}$$

$$\sum_{o=1}^{|\beta_j|} y^T_{jmo} \leq 1 \qquad j \in J,\ m \in \beta_j \tag{10}$$

$$\sum_{m \in \beta_j} y^T_{jmo} \leq 1 \qquad j \in J,\ o = 1...|\beta_j| \tag{11}$$

$$\sum_{m \in \beta_j} y^T_{jm(o-1)} \geq \sum_{m \in \beta_j} y^T_{jmo} \qquad j \in J,\ o = 2...|\beta_j| \tag{12}$$

$$q^T_{jmo} \leq \frac{p^T_{jmo}}{K_m} \qquad j \in J,\ m \in \beta_j,\ o = 1...|\beta_j| \tag{13}$$

$$q^T_{jmo} \geq \frac{p^T_{jmo}}{K_m} - 1 \qquad j \in J,\ m \in \beta_j,\ o = 1...|\beta_j| \quad (14)$$

$$x^T_{iim} = 0 \qquad i \in J,\ m \in \beta_i \quad (15)$$

Lines:

$$\sum_{m \in \gamma_j} y^L_{jm} = 1 \qquad j \in J \quad (16)$$

$$y^L_{0m} = 1 \qquad m \in \gamma_0 \quad (17)$$

$$\sum_{j \in \alpha_m} x^L_{ijm} = y^L_{im} \qquad i \in J_0,\ m \in \gamma_i \quad (18)$$

$$\sum_{i \in \alpha_m} x^L_{ijm} = y^L_{jm} \qquad j \in J_0,\ m \in \gamma_j \quad (19)$$

$$C^L_j + G(1 - x^L_{ijm}) \geq C^L_i + s^L_{ij} + a_{jm} D_j + v_j \qquad i \in J_0,\ j \in J,\ m \in \gamma_i \cap \gamma_j \quad (20)$$

$$C_{\max} \geq C^L_j \qquad j \in J_0 \quad (21)$$

$$d_j + R_j \geq C^L_j \qquad j \in J_0 \quad (22)$$

$$x^L_{iim} = 0 \qquad i \in J,\ m \in \gamma_i \quad (23)$$

Synchronization:

$$C^L_j - a_{jw} D_j - v_j \leq G(1 - y^L_{jw}) + \sum_{m \in \beta_j} C^T_{jm1} - \sum_{m \in \beta_j} \frac{a_{jw} p^T_{jm1}}{r_j} - \sum_{m \in \beta_j} q^T_{jm1} s^T_{jj} \qquad j \in J,\ w \in \gamma_j \quad (24)$$

$$\sum_{m \in \beta_j} C^T_{jmo} + G\left(2 - \sum_{m \in \beta_j} y^T_{jmo} - y^L_{jw}\right) \geq \sum_{m \in \beta_j} C^T_{jm(o-1)} + \sum_{m \in \beta_j} \frac{a_{jw} p^T_{jmo}}{r_j} + \sum_{m \in \beta_j} q^T_{jmo} s^T_{jj} \qquad j \in J,\ o = 2...|\beta_j|,\ w \in \gamma_j \quad (25)$$

$$C^L_j \geq \sum_{o=1}^{|\beta_j|} C^T_{jmo} \qquad j \in J,\ m \in \beta_j \quad (26)$$

$$x^T_{ijm},\ y^T_{jmo} \in \{0,1\} \qquad i,j \in J_0,\ m \in \beta_i \cap \beta_j,\ o = 1...|\beta_j| \quad (27)$$

$$x^L_{ijm},\ y^L_{jm} \in \{0,1\} \qquad i,j \in J_0,\ m \in \gamma_i \cap \gamma_j \quad (28)$$

$$q^T_{jmo} \in Z^+_0 \qquad j \in J,\ m \in \beta_j,\ o = 1...|\beta_j| \quad (29)$$

$$C^L_j,\ C^T_{jmo},\ C_{\max},\ R_j,\ p^T_{jmo},\ v_j \geq 0 \qquad j \in J_0,\ m \in \beta_j,\ o = 1...|\beta_j| \quad (30)$$

The objective function (1) corresponds to minimizing the makespan with the sum of the tardiness for each product. The value of the objective function are meaningless, but the makespan and delays do have separately and both are measured in time. By minimizing the makespan the total time that the products remain in the system is decreased, determining the time at which the last product is finished. Incorporation of the delay allows relax deadline imposed on some products. Constraints (2) allows the assignment of a product in at least one tank. Subscript "o" indicates the position where the tank will be used by the product j. As there is a one to one relationship between tanks and their position, i.e. each tank can have only one position and each position is used by only one tank (constraints (10) and (11)), the sum in "o" does not affect the result of the constraints that were not designed for proper allocation of positions between the tanks. Constraints (3), (4) and (5) correspond to the correct assignment and sequencing of products in tanks, using the structure of the Traveling Salesman Problem (TSP). The first (3) assigns the dummy job 0 to all tanks, the second (4) defines that each product has only one successor for each tank, only if it has been assigned to that tank, and the third (5) defines that each product has only one predecessor in each tank, only if it has been assigned to that tank. The dummy job is used to create a sequence that the first and last product will always be the dummy job, so constraints (4) and (5) are not violated.

Constraints (6) defines the correct relationship between the completion time of each product in each tank. The time difference between the completion of two consecutive products is given by the last three terms of this constraint: the set-up time from the product i to j, the processing time of product j, and possible refilled set-up time of the same tank for very large batches if necessary. The latter makes it possible to use a tank more than once for each product, without assigning a new position o, as refills are performed successively, assigning only one position for all possible refills of the tank. Therefore, q^T_{jmo} indicates the number of set-up time added to fill a tank with liquid of the same product. This constraint is only active when the product j is processed immediately after product i in the tank m ($x^T_{ijm} = 1$) and the product j is assigned to the line w ($y^L_{jw} = 1$), since the processing time depends on the speed of the line processing that product. The G parameter can be calculated as:

$$G = \sum_{j \in J_0} \left(\left(\max_{w \in \gamma_j} a_{jw} \right) D_j + \max_{i \in J_0} s^T_{ij} + \left\lfloor \frac{r_j D_j}{\min_{m \in \beta_j} K_m} \right\rfloor s^T_{jj} \right)$$

Constraints (7) allows it to meet the demand of each product. Constraints (8) and (9) define the upper bound for the amount of liquid and the completion time of each product in each tank. As mentioned above, constraints (10) and (11) define the one to one relationship between tanks and positions. Constraints (12) defines the correct order of the positions of the tanks for each product, that is, if a position was not assigned, all subsequent positions are not assigned. Constraints (13) and (14) defines the minimum and maximum amount of refills can have a product in a tank and constraints (15) prevents the scheduling of same products successively.

With regard to restrictions on lines, constraints (16) assign products to only one line. Constraints (17), (18), (19) and (20) are similar to constraints (3), (4), (5) and (6). Constraints (21) defines makespan as the maximum completion time in lines. Constraints (22) enables fulfillment of deadlines for possible delays, and constraints (23) is similar to constraints (15).

With regard to the restrictions of synchronization, constraints (24) defines the processing of a product in tanks not start before processing on the line, that is, the left limits of each product in the tanks and lines in the Figure 1 match. Constraints (25) defines the correct sequencing of the positions of the tanks for each product, that is, avoid overlap between tanks. Constraints (26) allows the processing of a product in tanks not exceeding processing on the line, that is, that the rights limits of each product in the tanks and lines in Figure 1 match. Finally, constraints (27), (28), (29) and (30) define the domain of decision variables.

3.3 Model Application Methodology

Due to the complexity of the model and its solution for very large instances, a special implementation methodology is used. This methodology includes two main phases. First, the problem is divided into clusters with certain characteristics in common, enabling the implementation of the model to smaller instances. For the cluster division, it is necessary to identify packaging lines that produce only certain products, which may be due to the type of syrup or its format. The products can only be produced in one of the clusters and each line and tank can be in only one cluster. Thus, the production plant is divided and the model is applied to each cluster. However, each cluster could still be difficult to solve for large plants that produce a variety of products, so the second phase of this methodology is applied.

In this second phase, before applying the model, a priori programming of a subset of products to schedule in each cluster is made. This a priori programming is done by fixing the variables that determine the sequence in each of the lines belonging to a cluster, that is, setting to 1 some of the variables x^L_{ijm} to determine the sequence in each line of the subset of selected products. The a priori programming criteria used were: first, a programming in ascending order of delivery time of products; and second, programming in descending order of processing times of the products. Both criteria are implemented in order to minimize the makespan, i.e. programming products in lines vacate first, as long as that line can process the product. This is shown in Figure 2 using the criteria in order of delivery. The number of a priori programmed products is experimentally determined so as to achieve at least one feasible solution within the time limit and an acceptable GAP by the programmer.

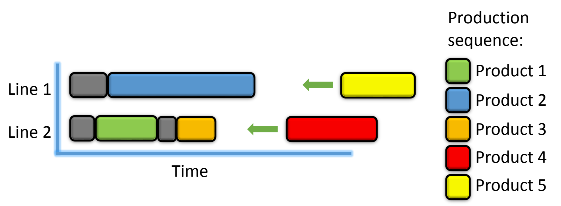

Figure 2: A priori programming by delivery order.

With this method of application it is possible address the total production and exploit the model in the scheduling of products in tanks, since it is at this stage where higher set-up times occur.

4 APPLICATION TO THE STUDY CASE AND COMPUTATIONAL RESULTS

This section describes the application of the model and its methodology to a real-world problem of a bottling company of soft drinks in Chile.

Applying the above methodology, the first phase corresponds to the division of the plant in clusters. To do this, the lines that produce products with certain characteristics in common were pooled. The products that the company produces can be classified into two groups: Still beverages and Sparkling beverages. The set-up time between these two types of products are quite high, as it should comprehend a rigorous cleaning, so the company has packaging lines dedicated to each of these two groups. Besides this, there are products that can be produced only in a specific line, in this case, products using tin cans. Given the characteristics listed above, the cluster considered and their sizes are summarized in Table 1.

The model is solved for each cluster implementing the second phase of the methodology, then these results are compared with what is currently done by the company. This methodology was applied to instances spanning three weeks, with data provided by

Table 1: Cluster division for the study case.

	Description	Tanks	Lines
Cluster 1	Still beverages	3	2
Cluster 2	Sparkling beverages	3	2
Cluster 3	Specific line	3	1

the company. In several weeks, there are lines that do not work because they are in maintenance, so they are not necessarily the same lines forming a cluster in different weeks. Table 2 shows sizes of each instance solved, along with the amount of products to schedule.

Table 2: Size of the cluster instances for each week.

Week-Cluster	Products	Variables	Constraints
1-1	21	2907	3910
1-2	15	1933	2926
1-3	11	1049	1245
2-1	9	881	1280
2-2	18	2584	3940
2-3	14	1496	1749
3-1	18	2260	2932
3-2	15	1733	2342
3-3	16	1834	2125

The model was programmed in AMPL language and solved by CPLEX solver 12.4.0.0 on a computer with Intel Core i5 and 2.6GHz processor. The stopping criterion is set for solutions with an error (GAP) less than or equal to 10 %, within the time limit of 18000 seconds (5 hours). In practice, the company can run the model any longer, because the programming is done every week with several days in advance. To reduce solution time, the company solution was used as the upper bound for the solution of the model in each cluster, i.e. the solver did not divide the nodes of the Branch-and-Bound containing a solution greater than company, so every feasible solution produced by the model is better than the company solution. This was made by changing the upper cut off parameter in the Cplex options. The results are summarized in Table 3.

Still beverages require a high use of storage tanks, unlike sparkling beverages, where most of contents of one bottle corresponds to water, which is added directly from the lines. This makes the products of Cluster 1 using largely the division of lots in the tanks, compared to Cluster 2 and 3, so it was expected that the Cluster 1 would have higher solution time and would need to schedule more products a priori. Despite this, the results show that the solution is able to improve the company's current solution in all instances, which shows the feasibility of using complex models together with an appropriate implementation strategy, as presented in this article.

When comparing the two criteria used for a priori programming of products, the results show that the processing times criteria exceed in 5 of 9 opportunities, obtaining an average improvement over the company of 16.72%, while the delivery times criteria obtained an average of 14.61%, which have similar behaviors. Although they are two different criteria, both are applied to minimize the makespan, as mentioned in section 3.3, which explains their similar results.

While the methodology improved the company's solution, the complexity of the model makes it difficult to choose the number of products to program a priori in every instance, where an average of 55.14% of the products were established a priori, wich proves the difficulty in solving the model for large instances.

5 CONCLUSIONS

In this paper the programming of short-term production for a soft drink plant is addressed. A mixed integer linear programming model and method of application to real instances of a Chilean company is presented. The model involves minimizing production time of soft drinks in two synchronized stages.

The proposed methodology allows the use of sophisticated optimization models for solving real problems of a company. The results show that on average managed to improve 15.67% the company's previous solution, which proves the benefits of using optimization tools like these. The two criteria used for the a priori programming of products obtained similar results, so the application will depend on the priorities of each company. Despite the fact that on average it must establish a priori half of the products (55.14%), we obtained better solutions than what was done in those weeks, saving almost 30%.

In future research, other ways to solve the model may be explored, like special heuristics or metaheuristics combined with mathematical programming, which could reduce or even eliminate the a priori programming stage.

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Table 3: Computational results for the instances of the study case.

		Criteria for a priori scheduling	Products to schedule	A priori scheduled products	Delayed products	Makespan	GAP [%]	Time [min]	Company's current solution	Improvement over company [%]
Week 1	Cluster 1	Delivery time Processing time	21	13 15	0 0	10550 9551	8.97 9.81	277 33.0	10640	0.85 10.24
	Cluster 2	Delivery time Processing time	15	7 7	0 0	2695 2684	9.97 9.99	11.4 26.4	3044	11.47 11.83
	Cluster 3	Delivery time Processing time	11	2 2	0 0	1086 1086	9.99 9.94	8.4 5.4	1535	29.25 29.25
Week 2	Cluster 1	Delivery time Processing time	9	4 4	0 1	7389 7175	9.62 11.83	216 300	9117	18.95 21.30
	Cluster 2	Delivery time Processing time	18	14 15	0 0	4131 4534	9.84 9.50	9.0 3.0	5411	23.66 16.21
	Cluster 3	Delivery time Processing time	14	7 6	0 0	2102 1988	9.98 9.94	4.8 7.2	2492	15.65 20.23
Week 3	Cluster 1	Delivery time Processing time	18	15 15	2 2	10678 8806	6.15 9.70	14.4 25.2	10798	1.11 18.45
	Cluster 2	Delivery time Processing time	15	9 9	0 0	3691 3775	9.47 8.69	3.0 4.2	4361	15.36 13.44
	Cluster 3	Delivery time Processing time	16	8 8	0 0	2167 2312	10.00 9.99	36.0 9.6	2555	15.19 9.51

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