Lot Sizing in Production Scheduling at a Personal Protection Equipment Company

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Abstract

This work presents an optimization model to support decisions during production planning and control in the personal protective equipment (PPE) industry (in particular, gloves). A case study was carried out at a Brazilian company with the aim of increasing productivity and improving customer service with respect to meeting deadlines. In this case study, the mixed integer linear programming model of Luche (2009) was revisited. A new model for single-stage lot sizing was applied to the production scheduling of gloves. Optimizing this scheduling was not a simple task because of the scale of the equipment setup time, the diversity of the products and the deadlines for the orders. The model was implemented in GAMS IDE and solved by CPLEX 12. The model and the associated heuristic produce better solutions than those currently used by the company.

1. Introduction

This work presents an optimization model to support decisions for production planning and control (PPC) of personal protection equipment (PPE). A case study was carried out at a Brazilian company to increase productivity and improve customer service with respect to meeting deadlines. The company primarily manufactures gloves and clothing used in metallurgy, foundries and electrical industries. The company has 20 onsite employees and 12 outsourced employees to perform sewing. The production volume is 25,000 pairs of gloves/month and 5000 clothing garments/month.

Planning and production scheduling are significant problems in this industry. Many of these problems can be modeled by linear optimization. Linear programming (LP)

can be used to determine optimal production schedules, while using limited resources to meet varying goals, for example, cost, profit, time and production volume. LP is frequently applied in industry settings where a number of features, such as number of workers, materials and machinery are limited and must be effectively combined to produce one or more products. Among numerous feasible solutions, it is desirable to determine which solutions maximize and minimize the numerical quantities defined in the objective function. Some of the issues resolved by LP are listed below.

- Mixed production problems, where it is necessary to decide which products will be produced and in what quantity;
- Process selection problems that arise when the company manufactures various products that require different processes;
- Lot sizing problem that occurs when different types of products are requested by different clients, most often in large quantities with different scheduled delivery dates.

Lot sizing problems require a plan for the amount of items produced over a finite time horizon in order to meet demands and optimize production, for example, to minimize costs and maximize profit. Solving lot sizing problem has become increasingly difficult because general manufacturing techniques are becoming increasingly complex [1]. We suggest the following five dimensions of complexity for the problem of lot sizing.

1) Limited availability of multiple resources;
2) Multiple products sharing the same resources;
3) Variable demand from period to period, with several periods in the planning horizon;
4) Setup time;
5) Setup costs to produce a batch of the product.

When considering setup times and cost times, the lot sizing problems become NP-hard and may be formulated with mixed integer linear programming with decision variables indicating the production of each product over each period [2].

The lot sizing problem has been reviewed previously [3]-[8]. Lot sizing has also been recently investigated in several additional research studies [9]-[12]. A recent study provided a survey of the lot sizing problem [13]. Several industrial studies in small foundries [14], animal feed companies [15] and soft drinks companies [16] [17] have sought to optimize the production schedule. In addition, the problem of production scheduling in the chemical processing industry has been investigated with the objectives of minimizing the penalty for delay and anticipating production [18].

Another study examined the lot sizing and selection processes [19] to determine a production schedule that minimized shortages of items based on the choice of a production process over a certain period, where each process defined by the company is able to produce a mixture of products at different quantities.

In the present study, we model a real-world problem using actual data to determine a specific production schedule. A mixed integer model is solved using general-purpose optimization software written in the GAMS modeling language, with a branch and cut

method in the CPLEX solver. It is common for a production schedule to be modified several times in response to urgent orders and unexpected equipment failures, thus highlighting the importance of a modeling approach capable of generating efficient production programs in a feasible amount of time was adapted a mixed integer linear programming model to determine the production schedules for PPE [19]. The results from the model were compared to two existing practices used by the company, revealing that the model was effective and greatly improving the ability of the company to provide items on time.

This paper is organized as follows. In Section 2, the production process is briefly presented. The discussion is based on the production plant of the company studied in this research, but also applies to other companies in this industry. Section 3 describes the algebraic model of the problem. In Section 4, the computational results are presented. Finally, Section 5 provides conclusions and future research directions.

2. Problem Definition

The production system of the company is intermittent and repetitive. Changes in the type of gloves always take place, resulting in a great variety of products. The layout is set as a function of the product. Cutting machines and workbenches are arranged according to the operation sequence of the product. Since all products have basically the same sequence of operations, the production system flow pattern is a flow-shop.

2.1. Product Characterization

Gloves can be manufactured in various designs using various materials. Their physical characteristics must comply with NR6, the regulatory norm from Ministry and Employment (Brazil) for personal protective equipment. The manufacturing process involves cutting, sorting, gluing, seam stitching, modeling and packaging.
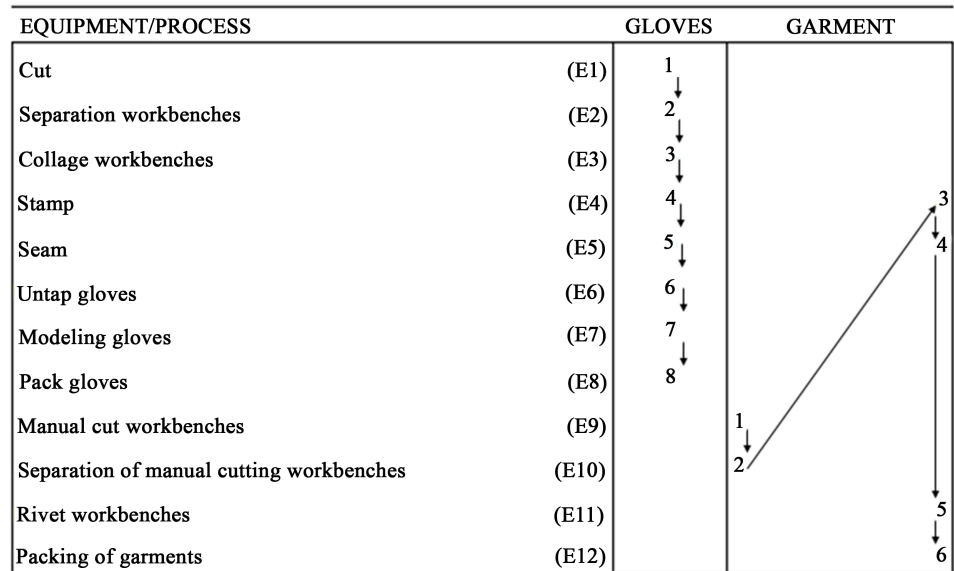
Garments, such as aprons, jackets, pants and leggings, can be manufactured in various designs using various materials. Their physical characteristics must comply with NR6.The manufacturing process is done with manual cutting, separation, seam (when necessary), mounting (placement of straps and buckles, whenever necessary) and packaging.

2.2. The Production System

Figure 1 shows the flowchart of the production process for the gloves and garments. As seen in the flowchart, only two operations are needed.

The company in this study does not have a PPC department. The production schedule is determined from the orders.   In general the deadlines for submission of applications are always urgent, ranging from twenty to thirty working days from the date of manufacturing. The manufacturing process for gloves shown in Figure 1 requires ten days.

Some orders are met partially so that customers are not left without the product. Rush orders can also affect the schedule, changing the delivery date and/or the amount

EQUIPMENT/PROCESS		GLOVES	GARMENT
Cut	(E1)	1	
Separation workbenches	(E2)	2	
Collage workbenches	(E3)	3	
Stamp	(E4)	4	3
Seam	(E5)	5	4
Untap gloves	(E6)	6	
Modeling gloves	(E7)	7	
Pack gloves	(E8)	8	
Manual cut workbenches	(E9)		1
Separation of manual cutting workbenches	(E10)		2
Rivet workbenches	(E11)		5
Packing of garments	(E12)		6

Figure 1. Flowchart of the production process.

to be delivered to another client. In periods of high demand, the company considers using overtime to meet demands.

The monthly production is approximately 25,000 pairs of gloves. During normal working hours, the operators cut on average 1000 pairs of gloves per day. Approximately 5000 pairs are produced during overtime work. According to labor convention, overtime pay should be increased by 100%. Thus, the company absorbs this extra cost to meet the deadline.

The products are identified according to the following nomenclature.

P1—leather glove with stitching on the dorsum;

P2—leather glove with canvas dorsum and cuff knit;

P3—leather glove seamless the dorsum;

P4—leather glove reversible model;

P5—leather glove seamless on the dorsum and short handle;

P6—leather glove with canvas back and cuff;

P7—leather glove with lining;

P8—soft leather glove seamless the dorsum;

P9—soft leather glove and dorsum with leather;

P10—soft leather glove and handle with leather.

The daily production capacity when concentrating on manufacturing a single item for each shift is shown in Table 1, where the first column refers to the product and the second column refers to the amount that the company is able to produce on a normal working day.

Some items take longer to manufacture because they are produced in smaller quantities. This is due to the amount of material used for production and the complexity of the manufacturing process.

Table 1. Production capacity for a single product

Product	Pair/day
P1	900
P2	1100
P3	1000
P4	1000
P5	1100
P6	900
P7	450
P8	1200
P9	1000
P10	950

3. Problem Modeling

The initial goal of the company is to meet the delivery dates of the customers. Due to the difficulty in estimating the shortage costs, a model that minimizes the slackness of production is adapted [19]. The proposed model is designed to optimize production, meet the requests within the agreed upon time, schedule production and distribute the manufactured products according to their production capacity over the planning horizon.

Algebraic model: Minimize the production shortage (in pairs)

Index:

i: Item $\{1,\cdots,m\}$;

t: production period $\{1,\cdots,T\}$;

Variables:

x_{it}: quantity (whole) of item i produced in period t ($i=1,\cdots,m$; $t=1,\cdots,T$);

I_{it}^{-}: slackness of product i at end of period t ($i=1,\cdots,m$; $t=1,\cdots,T$);

I_{it}^{+}: surplus (stock) of item i at end of period t ($i=1,\cdots,m$; $t=1,\cdots,T$);

Parameters:

m: amount of product;

T: programming horizon (over the production periods);

a_i: maximum quantity of product i produced over a period ($i=1,\cdots,m$);

d_{it}: demand of product i in period t ($i=1,\cdots,m$; $t=1,\cdots,T$);

c_t: portion of the day that the line will be available in period t ($c_t \geq 0$; $t=1,\cdots,T$).

$$\text{Min } z = \sum_{t=1}^{T}\sum_{i=1}^{m} I_{it}^{-} \tag{1}$$

$$I_{it-1}^{+} - I_{it-1}^{-} + x_{it} - I_{it}^{+} + I_{it}^{-} = d_{it} \qquad \forall i,t \tag{2}$$

$$\sum_{i=1}^{m}\frac{x_{it}}{a_i} \leq c_t \qquad \forall t \tag{3}$$

$$x_{it}, I_{it}^-, I_{it}^+ \geq 0 \quad \forall i, j, t \tag{4}$$

$$I_{i0}^- = I_{i0}^+ = 0$$

Objective function (1) minimizes the production shortage of the products. The demand constraint (2) includes the slackness and surplus variables of each product i in each period t. The total amount of a product produced before a certain period plus the slackness (minus a surplus) should be equal to the accumulated demand before this period. Constraint (3) ensures that the total time used for each period does not exceed the capacity of the period. Constraint (4) establishes the non-negativity variables.

For $c_t > 1$, the company will use overtime. For example, for a period of eight hours, if $c_t = 1$, the $c_t = 1.25$ and the period will be ten hours. This notation allows the manager to allocate the capacity for certain periods, such as Saturdays, when the company operates only part of the time.

The model aims to minimize the slackness of production such that there is no build-up of missing items from one period to another. This results in an increasing penalty. For example, for a missing 10 units of a given product in period 5, the shortage is met in period 6. Thus, the objective function is 10. However, if the shortage is not met until period 7, the objective function is 20 and so on. The model does not consider the sequencing of multiple production batches at a time. Rather, each period should produce a single batch. The presence of discrete and integer variables along with continuous variables adds to the complexity of the optimization problem [20].

In cases where the company penalizes both shortages and excesses, the following model can be considered.

Algebraic model: Minimizes production shortages and excesses

New Parameter:

h_i: inventory cost of item i (fraction to be considered I_{it}^+ in objective function)

$$\text{Min } z = \sum_{t=1}^{T} \sum_{i=1}^{m} \left(I_{it}^- + I_{it}^+ h_i \right) \tag{5}$$

$$I_{it-1}^+ - I_{it-1}^- + x_{it} - I_{it}^+ + I_{it}^- = d_{it} \quad \forall i, t \tag{2}$$

$$\sum_{i=1}^{m} \frac{x_{it}}{a_i} \leq c_t \quad \forall t \tag{3}$$

$$x_{it}, I_{it}^-, I_{it}^+ \geq 0 \quad \forall i, j, t \tag{4}$$

$$I_{i0}^- = I_{i0}^+ = 0$$

Objective function (5) minimizes the production shortages and surpluses, where h_i represents the fraction of I_{it}^+ that is considered and h_i represents the monetary cost. The other restrictions remain. Thus, the numbering from the previous model is carried forward.

4. Results

The experiments were performed using an Intel I5 processor with 4.0 Gb of RAM. The GAMS modeling language with the CPLEX 12 solver was used to solve the mixed in-

teger models. [21] [22] present reviews on modeling languages. We used the default parameters of CPLEX with a null tolerance for the gap in optimality.

The data included two months of production at the company, where each month was treated as an instance, *i.e.*, "Month 1" and "Month 2".

Even without the records of time on the solutions, the employees generally require several hours (even days) to find a suitable production program.

Table 2 shows the results for "Month 1" and "Month 2" versus the results for the model that minimizes shortages. These data are related to the actual product shortage in the last phase of production and the penalty generated by the objective function of the model.

The program conducted for the 27 period planning horizon of "Month 1"indicates the slackness of the 2230 pairs, where the same program production calculated for the objective function of the model generates a value of 34,830. In the model there is a slackness of 337 pairs of gloves over the last period. With the objective function of the model, the best solution is 7,663 for only twelve minutes of performance, thus proving the optimality of the solution.

For the "Month 2" program there is a shortage of 2020 pairs of gloves indicating that at the end of the planning horizon of 31 periods, the value of the objective penalty function is 27,500. The model gives a slackness of 146 pairs of gloves for model 7 in the last period. The penalty function for the model is 1.403 for only seventeen minutes of performance, thus proving its optimality.

In Table 3, the model glove P7 is no longer produced, because the product demands excessive time for manufacturing, leading to lost costs/profits associated with the objective function of the model. The company has thus endeavored to produce items that require shorter manufacturing times.

Table 2. Results obtained for the two instances.

	Month 1		Month 2	
	Company	Model	Company	Model
Product shortage in the last phase of production	2.230	337	2.020	146
Objective function	34.830	7.663	27.500	1.403
Time required to obtain the solution	Several hours	12 min	Several hours	17 min

Table 3. Production shortage.

Product	Amount not produced	
	Month 1	Month 2
P2	1	-
P3	1	-
P5	1	-
P6	1	-
P7	332	146
P8	1	-

5. Conclusions and Future Works

We examined a problem with practical relevance to planning and production control in the PPE industry. We presented the main raw materials used in this industry. We then described the production process in the PPE industry, in particular the problems associated with product lot sizing.

The proposed solution to the problem of production scheduling of gloves analyzed in this work was the use of a mixed integer linear programming model with a penalty for lack of product delivery at the agreed upon time. The model was able to optimize production to meet deadlines and reduce delays in the delivery of products in a very short time compared to the model currently used by the company.

The model used to support the decision making tool can be adapted to generate various production scenarios, allowing the decision maker to choose the best strategy for the objective analysis tool.

The integration of the production scheduling model with enterprise resource planning (ERP) can also help in the control the inventories and provide greater reliability in the input data.

In addition, the times and setup costs should be incorporated into the model.

Conflict of Interests

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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