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CITIES
CIUDADES INTELIGENTES TOTALMENTE INTEGRALES, EFICIENTES Y SOSTENIBLES

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Sustainable Production Planning Optimization Using Integer Programming

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Abstract. This paper presents how integer linear programming can be used to optimize and develop a sustainable production plan for a medium-sized cold stamping company. The objective is to develop a model to minimize the total production cost, which includes the manufacturing process cost, inventory holding cost, and unproductive machine cost. The model takes into account weekly demands, inventory levels, and idle machine time during a planning horizon of one month. The output is a plan containing all products that have to be manufactured, their weekly optimal quantities, and a prediction of the final inventory level. By minimizing the total production cost, the model ensures that the company is consuming only the necessary amount of resources. The mathematical model is related to the real-world constraints that are part of the company's production scenario, reflecting both direct and indirect impacts of resource usage. This model enables to simulate three scenarios, and their results indicate that the total production cost is minimum when a company produces in volumes slightly greater than the demand. By better allocating resources, the company can contribute to sustainability in the context of responsible production.

Keywords: Integer Programming · Production planning · Sustainability

1 Introduction

The United Nations (UN) has set 17 Sustainable Development Goals (SDGs), which are a group of guidelines that intend to build a better world by 2030. The topic of these goals involves all aspects of society, such as social (hunger, poverty, equality), economic (industry, innovation, partnership), and environmental (natural resources, fauna, flora) [1]. This paper intends to contribute to the 12th SDG, entitled "Responsible Consumption and Production", which states that the global economy's dependence on the natural environment and its resources increased over 65% from 2000 to 2019 [2]. All targets set by the 12th SDG are related to sustainable management and efficient use of resources while reducing all kinds of waste through prevention, reduction, recycling, and reuse. In this context, the optimization technique, Linear Programming (LP), can be used as an efficient approach to promote sustainable production, since it allows companies to save resources and operate in an optimal way, independent of their economic sector [3]. The most common application of LP involves determining the optimal scenario for a set of activities toward an objective. Most of the time, these activities compete for resources between each other, such as energy and raw material.

Production planning is an essential and complex activity inside a company that requires simultaneous cooperation between everyone responsible for the decision-making process. A good plan will always lead to a good workflow, promoting efficient resource usage and responsible production. Usually, production planning can be separated into three different time horizons: (i) long-range plans, (ii) medium-range plans, and (iii) short-range plans [4]. Long-range plans are related to new infrastructure, research and development, new products, and facility location and/or capacity. Medium-range plans are elaborated to always match supply and demand in terms of rough volume and product mix, which mean maintaining enough raw material, work in process, and inventory level to meet the demand while also absorbing possible demand fluctuations. The ultimate output of a medium-range plan is the master production schedule (MPS), which outlines all products that need to be manufactured, when, and in what quantities, usually referring to finished goods. Finally, short-range plans are concerned with determining job assignments, ordering, job scheduling, and dispatching [5].

Omara et al. [6] developed a model to optimize the MPS using Fuzzy Mixed Integer Linear Programming (FMILP). Herrmann [7] proposed a linear model to optimize the MPS using a commercially available software ILOG. Sawik [8] addressed production scheduling optimization based on Mixed Integer Linear Programming (MILP), seeking to minimize tardiness. Al-Ashhab and Fadag [9] developed a model to optimize the MPS based on maximizing profit using MILP and Genetic Algorithms (GA). Within this context, no studies that integrate directly the sustainability in the MPS planning were found. To fill this gap, this study intends to propose an Integer Linear Programming model - or simply Integer Programming (IP) - that allows a real medium-sized cold stamping company to create a sustainable MPS. Hence, this model seeks to minimize costs, proposing an efficient and responsible production plan.

This paper is organized as follows: the next section describes the MPS planning, and how IP can be used to optimize it. Section 3 proposes an IP model for a medium-sized cold stamping company and describes all data that are required; section 4 discusses three different scenarios of the proposed model; Finally, section 5 presents the conclusions and further work.

2 Literature Review

This section aims to present some important topics regarding manufacturing planning and control optimization. First, it is intended to state a brief introduction to MPS and its basic concepts and definitions; next, it is discussed some general methods that are used by many industries to plan their production activities; afterwards, IP is introduced under a production planning context.

2.1 Master Production Planning

Creating the MPS is the task of disaggregating the company's sales and operations plan (S&OP) into a tangible manufacturing schedule, determining all products that must be manufactured with their quantities and production timing. For the MPS to be developed, two other plans must have already been done: long-term capacity planning and Aggregate Production Planning (APP) [4, 5].

Every MPS aims to develop a production schedule over a medium-term period, usually in terms of weeks. For each product manufactured within the planning period, the MPS indicates production quantities, machine capacity, required levels of raw materials and unfinished goods, and any other pertinent detail. Lastly, it is possible to estimate both intermediate and final inventory levels, based on what is planned to be consumed [10]. In most scenarios, some of the leading MPS guidelines and constraints are the time available for production, whether or not including overtime, the demand, the availability of resources, and the maximum inventory capacity for each product.

Since every MPS belongs to the medium-range plans, when unexpected adversities occur, such as machine breakdowns or quality problems, planned tasks may not be executed accordingly to the schedule, leading to delays. In other words, planning does not guarantee due dates compliance, precisely because of these unpredictable factors that are intrinsic to the production process. Still, having a well-defined plan helps to react to these adversities in the best possible way [4, 5].

Concerning loading capacity, which is the process of assigning jobs to specific machines, workstations, or processes, it is important to consider that, in reality, all machines and equipment have limited capacity, usually defined in terms of available time to operate. When production schedules consider this assumption, the planning is said to have finite loading. Production planning techniques that ignore the maximum capacity of machines and equipment are called infinite loading models. In this case, there is a greater probability of not meeting delivery deadlines, and in cases of overload, it is required overtime or outsourcing [4].

Omara et al. [6] proposed a model to minimize the costs of the MPS using FMILP, taking into account production cost, setup cost, inventory, and backorder costs. However, none direct analysis was done regarding sustainability.

Herrmann [7] developed a model to minimize tardiness for companies that produce in small batches while having to meet high demand. This approach involves detailed scheduling based on production completion times, leading to reduced capacity problems, out-of-stock situations, and most importantly, tardiness. The commercially available tool ILOG was used to run the linear model.

Sawik [8] also addressed production planning optimization based on tardiness, elaborating a model based on IP that divides and allocates customer orders into planning periods to meet due dates while minimizing the total number of delays. Despite referring to reducing operational costs, the model is not directly attached to sustainability.

Al-Ashhab and Fadag [9] proposed a model to maximize the profit of a company considering transportation logistics and production costs, selling prices, inventory, batch size and capacity. MILP and GA were used to solve the model, and both methods gave the same optimal values for most variables, seeming to be equally efficient.

As can be noticed, sustainability is not a prominent topic when it comes to optimizing the MPS of a company. Hence, the model proposed in this paper intends to contribute to sustainable production by minimizing costs.

2.2 Integer Programming (IP)

Integer programming is a method that uses a set of mathematical linear functions to describe a certain problem and then solve it to obtain a set of optimal decision variables expressed in integer numbers [11, 3]. When defining an IP mathematical model, four groups of elements should be defined: the decision variables, the objective function, the functional constraints, and the nonnegativity constraints [3].

The decision variables represent the model's solution. When an IP problem is modeled, the goal is to find a set of optimal integer values - the decision variables - that satisfy all constraints while maximizing or minimizing the objective function[3]. Most of the time, within the context of the MPS, the decision variables represent the quantities to be produced for each different product.

The objective function is a mathematical expression that relates directly every decision variable to the objective of the model, which can be a maximization or minimization function, depending on the approach to solve the problem. In the literature review carried out concerning MPS optimization problems, three objectives were identified: (i) to minimize costs [6], (ii) to minimize tardiness [7], and (iii) to maximize profit [9].

The functional constraints are a set of inequalities that give realism to the model by restricting the solution span based on certain criteria, imposing upper and bottom limits to the decision variables. In the MPS model, these constraints often represent the machine capacity, the minimum demand, the maximum quantities able to be stocked, and so forth [11, 3].

3 Methodology

This section aims to describe the methodology used to develop the proposed IP model, by introducing the context of the problem and its elements, correlating them with sustainable production planning.

3.1 Context setting

The company under study is a medium-sized firm that produces cold stamping parts of exhaust systems for the automobile industry. These parts are sold to customers who assemble the full exhaust system. Specifically, the company is in the middle of the automobile industry supply chain, and therefore, there is huge pressure on accomplishing due dates.

In the company's stamping sector, there are four hydraulic presses: (i) Zani 600 tons, (ii) Rovetta I 600 tons, (iii) Rovetta II 600 tons, and (iv) Cattaneo 1000 tons. Each machine is capable of producing a limited range of products, although some products can be manufactured on more than one machine. Despite this, the proposed model involves the MPS of one machine at a time, because based on production costs and productivity rates, the company already knows in which machine (first option) a particular product is more viable to be manufactured. The alternative machine is only used when the first option machine is unavailable due to unscheduled maintenance or breakdown.

The company's production process is briefly explained through Figure 1.

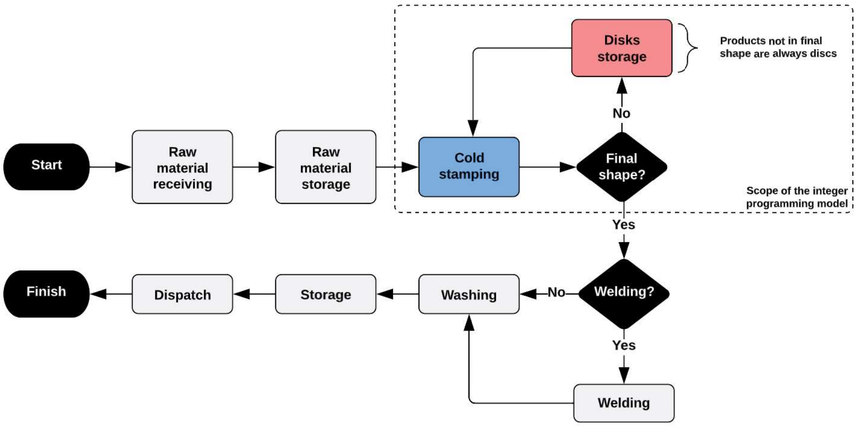

Fig. 1. Company's production chain

The production process begins with raw material receiving, most of the time in the form of metal coils. When the raw materials arrive from the suppliers, they are stocked in the warehouse and stay there until demand occurs, when then one of the hydraulic presses is fed with these metal coils. From this point, there are two possibilities: (i) the metal sheet is stamped by the press and the output is a part in its final shape; (ii) the metal sheet is cut into disks by the hydraulic press, and these disks are stocked to later be stamped again and finally be shaped to their final form. After going through the stamping sector, a part may be welded by a semi-automatic machine. Later, the part is washed and dried by another machine, obtaining the product in its finished state. Finally, the product has to be stocked in the warehouse until its dispatched.

Throughout this entire production process, only the cold stamping sector presents bottlenecks, and therefore this is the main scope of the proposed model.

3.2 Integer Programming Model

The following notation concerning indices, sets, parameters, and variables are used in the model formulation.

i	Product code to be manufactured (i=1, 2, 3, . . . , 10)
j	Week designation (j= 1, 2, 3, 4)
TPC	Total production cost [€]
MPC_i	Manufacturing process cost for the product i [€/unit]
IHC_i	Inventory holding cost per week for the product i [€/unit]
II_{ij}	Initial inventory for the product i at the beginning of week j [unit]
SS_i	Safety stock level for the product i [unit]
FS_i	Final inventory for the product i at the end of the four weeks [unit]
D_{ij}	Demand for the product i and week j [unit]
UMC	Unproductive machine cost [€/hour]
S_j	Number of shifts available to work during week j [unit]
P_i	Time required to produce one unit of product i [hour/unit]
PT	Total productive time [hour]
UT	Total unproductive time [hour]

The formulation of the proposed integer programming model is presented in 3.2(1).

$$\text{Minimize} \quad \begin{aligned} &\sum_{i=1}^{10}\sum_{j=1}^{4} MPC_i \cdot X_{ij} + \\ &\sum_{i=1}^{10}\sum_{j=1}^{4} IHC_i \cdot (X_{ij} + II_{ij} - D_{ij}) + \\ &\sum_{i=1}^{10}\sum_{j=1}^{4} UMC.(7.25 \cdot S_j - P_{ij} \cdot X_{ij}) \end{aligned} \tag{1}$$

$$\text{s.t.} \quad SS_i + D_{ij} - II_{ij} \leq X_{ij} \tag{C1}$$

$$\sum_{j=1}^{4} X_{ij} \leq M_i \tag{C2}$$

$$\sum_{i=1}^{10} X_{ij} \cdot P_{ij} \leq 7.25 \cdot S_j \tag{C3}$$

$$X_{ij} \geq 0 \tag{C4}$$

$$X_{ij} \in \mathbb{Z}$$

$$i = \{1, 2, 3, \ldots, 10\}$$
$$j = \{1, 2, 3, 4\}$$

The integer programming model (1) allows determining the optimum quantity to be produced of each product i in week j (X_{ij}). These are the decision variables required to develop the MPS of the company. The sub-index i can vary from 1 to 10, because historically this is the maximum amount of product types that a single machine produces per month, while the sub-index j ranges from 1 to 4 weeks, corresponding to a planning horizon of one month. Since X_{ij} represents a set of quantities, all values must be positive integer numbers.

To ensure sustainability within a productive and competitive context, a company always aims to increase its profit margin by using fewer resources. These imply minimizing the production costs which means that only the necessary amount of all associated resources are being used. In practice, the model should determine the optimal quantities to produce for each product at the right moment, leading to reduced costs and waste. This is captured by the definition of the objective function which minimizes the total production cost that includes three main production cost factors within the company: (i) manufacturing process costs (MPC_i), (ii) inventory holding cost (IHC_i), and (iii) unproductive machine cost (UMC).

The MPC_i represents the cost for a certain machine to operate and produce one unit of product i. For a product i that can be manufactured on more than one machine, its MPC_i will probably be different for each one of them. The MPC_i tends to increase proportionally to the power of the hydraulic press in which the product i is produced. The second term of the objective function is the inventory holding cost (IHC_i) which includes all the fees and expenses required to maintain the product i in the company's warehouse. These costs involve security, fixed costs, product depreciation, and salaries which are proportional to the stored quantity of the product i. The third and last term UMC is linked to the unproductive machine cost (UMC), which is different for each of the four machines and is mainly determined by the hourly cost of depreciation, fees, and insurance.

To reflect the reality of the production process, three functional constraints were considered: (i) the minimum quantity to be produced to satisfy the demand (C1), (ii) the maximum quantity allowed to be produced (C2), and (iii) the machine availability (C3).

Concerning the minimum quantity to be produced (C1), it is determined based on the week's initial inventory (II_{ij}), safety stock level (SS_i), and demand (D_{ij}). Regarding demand, the company works with production forecasts that support medium-term planning. These forecasts provide aggregated volumes of demand that must be met during the next four months, however, they are subject to change. In other words, the company always has an aggregate production planning (APP) for four months from the present. Production volumes are only disaggregated for the current month, that is, for the next 28 days from the present. This process originates weekly demands for each product for the next four weeks. To absorb possible market fluctuations or unexpected setbacks, the company works with a predetermined safety stock level (SS_i), which is equivalent to the two-week average demand for the planning period.

The maximum quantity allowed to be produced (C2) for each product i in week j takes into account the manager's expertise, as it may depend on the combined effect of numerous factors, such as raw material shortage, forecasted demand, warehouse capacity, and so forth. In other words, the manager's knowledge is essential to set an upper limit (M_i) to all products that must be manufactured over the planning horizon.

The planning model adopted by the company is based on limited loading, and therefore, the total available time to produce (C3) must be sufficient to cover all product units that are going to be manufactured. In practice, knowing the number of available working shifts (S_j) in each week j and the productive hours per shift (7.25), it is possible to calculate how many working hours each machine will be able to operate over the planning horizon. Based on the average time to produce one unit of each product (P_i), these available working hours end up as an upper limit on the total number of parts that can be manufactured.

3.3 Data

The data used to test, validate, and implement the model were collected in the company. It is possible to classify the required data into three large groups: (i) product structure, (ii) machines, and (iii) storage information.

All product structure information was obtained directly through a formal document, containing all levels of each product, from raw material to the finished good. In terms of cold stamping, among the entire company's portfolio, the vast majority of parts is only submitted to a single stamping step, but on the other hand, there is a range of products that must go through two subsequent stamping steps, as described before. Despite being dependent on each other in terms of manufacturing, these two subsequent processes can be considered independent in the proposed model, simply because they occur at two very different moments. In practice, the first stamping process generates disks that are stocked to be used later, meaning a complete planning cycle. When there is demand, the second stamping process is planned and executed, consuming some of those disks and leading to the product in its final shape, meaning another complete planning cycle. The same disk type can be used for more than one product, which is why the company adopts the strategy of stocking disks, seeking to absorb any fluctuations or unforeseen events.

All machine data were easily accessible, as it was only necessary to regroup and rearrange them. The main set of information was obtained from an electronic spreadsheet frequently used by the company. For all hydraulic presses, it was possible to extract what products each of them can produce, their respective average production rates (P_i), the costs of each stamping process (MPC_i), and their unproductive costs (UMC_i).

The information about inventory costs (IHC_i) for both finished and unfinished products required processing before they could be used. With the company's support, for each product, finished or not, storage costs were determined based on the volume that each product container occupies inside the warehouse and the logistic costs involved to manipulate it.

To select the most suitable software for solving the model, the main concern was the dimension of the problem in terms of the number of decision variables and constraints, as well as the ability of the company to use it. Since the company uses Excel extensively, it was necessary to improve and adjust the mathematical formulation for it to be solved by the add-on Solver from Excel.

4 Results and Discussion

In order to relate the total production cost (TPC) with sustainability, model (1) was used to simulate and compare three different situations: no initial inventory and no safety stock (NINS); no initial inventory but with safety stock (NIWS); with initial inventory and safety stock (WIWS). In all scenarios, the same products were considered as well their respective weekly demand (D_{ij}) and maximum production levels (M_i), according to Table 1.

Table 1. Weekly demand and maximum production level per product

Product code i	D_{i1}	D_{i2}	D_{i3}	D_{i4}	M_i
Product 1	9000	9000	0	0	36000
Product 2	0	0	4500	4500	18000
Product 3	0	4500	4500	0	18000
Product 4	0	0	15000	15000	60000
Product 5	3000	3000	3000	0	18000
Product 6	0	9000	9000	0	36000
Product 7	0	0	0	20000	40000
Product 8	0	8000	8000	0	32000
Product 9	15000	15000	0	0	60000
Product 10	4500	4500	4500	4500	36000

The first scenario (NINS) refers to a situation in which initial inventory (IS_i) and safety stock level (SS_i) are null. In practice, this means that the company does not have inventory and will only produce surplus if the model identifies that this approach is more beneficial than leaving the machine unproductive. The optimum solution for the first scenario is shown in Table 2.

Table 2. Quantities to be produced of each product in scenario NINS.

Product code i	SS_i	IS_i	X_{i1}	X_{i2}	X_{i3}	X_{i4}	FS_i	$FS_i - SS_i$
Product 1	0	0	9000	9000	0	18000	18000	18000
Product 2	0	0	0	0	4500	4500	0	0
Product 3	0	0	0	4500	4500	0	0	0
Product 4	0	0	0	0	15000	15000	0	0
Product 5	0	0	3000	3000	3000	0	0	0
Product 6	0	0	0	9000	14840	12160	18000	18000
Product 7	0	0	0	0	0	20000	0	0
Product 8	0	0	0	8000	8000	0	0	0
Product 9	0	0	15000	15000	0	30000	30000	30000
Product 10	0	0	4500	4500	4500	22500	18000	18000

Analyzing Table 2, it is clear that the model (1) identified that most of the time, it is better to leave the machine not operating rather than producing surplus units. The only exceptions identified that would compensate the unproductive costs are products 1, 6, 9, and 10, which are suggested to be produced to stock. In other words, producing surplus units of these products and generating inventory is better than keeping the machine in an unproductive state.

The second scenario (NIWS) represents a situation where initial stocks (IS_i) are null, but now it considers a safety stock (SS_i) equivalent to 50% of the sum of the total demand. This 50% margin is the current value that the company uses to determine its safety stock level. The optimum solution for the second scenario is shown in Table 3.

Table 3. Quantities to be produced of each product in scenario NIWS.

Product code i	SS_i	IS_i	X_{i1}	X_{i2}	X_{i3}	X_{i4}	FS_i	$FS_i - SS_i$
Product 1	9000	0	18000	9000	0	27000	36000	27000
Product 2	4500	0	4500	0	4500	4500	4500	0
Product 3	4500	0	4500	4500	4500	0	4500	0
Product 4	15000	0	15000	0	15000	15000	15000	0
Product 5	4500	0	7500	3000	3000	0	4500	0
Product 6	9000	0	9000	9000	36000	0	36000	27000
Product 7	10000	0	10000	0	0	20000	10000	0
Product 8	8000	0	8000	8000	8000	0	8000	0
Product 9	15000	0	30000	15000	0	45000	60000	45000
Product 10	9000	0	13500	4500	11145	24855	36000	27000

As shown in Table 3, during the first week of the NIWS scenario, all products have to be produced in order to achieve their respective safety stock level, but during the following weeks, most production is only to meet demand. Similarly to the NINS scenario, the products 1, 6, 9, and 10 are suggested to be overproduced, but now differing from the first scenario by their quantities.

The third scenario (WIWS) considers both initial (IS_i) and safety stock (SS_i), with an initial inventory level higher than the safety level. In this simulation, the safety stock corresponds to 50% of the sum of the total demand (such as in the NIWS scenario), while the initial inventory is 60% of that sum. The 60% margin enables to represent how the model would react to a situation when it can consume stocked units to partially satisfy the demand. The optimum solution for the third scenario is shown in Table 4.

Based on Table 4, the scenario WIWS is very different from the others. This time, only products 1, 5, 9, and 10 are to be produced in the first week, whereas by the end of the planning horizon, only products 6, 9, and 10 are recommended to be overproduced.

Table 5 summarizes all results for each scenario at the optimum solution, presenting their values regarding the total production cost (TPC) and its components, the manufacturing production cost (MPC), the inventory holding cost (IHC), and the unproductive machine cost (UMC). Moreover, the total unpro-

Table 4. Quantities to be produced of each product in scenario WIWS.

Product code i	SS_i	IS_i	X_{i1}	X_{i2}	X_{i3}	X_{i4}	FS_i	$FS_i - SS_i$
Product 1	9000	10800	7200	9000	0	0	9000	0
Product 2	4500	5400	0	0	3600	4500	4500	0
Product 3	4500	5400	0	3600	4500	0	4500	0
Product 4	15000	18000	0	0	12000	15000	15000	0
Product 5	4500	5400	2100	3000	3000	0	4500	0
Product 6	9000	10800	0	7200	46800	0	46800	37800
Product 7	10000	12000	0	0	0	18000	10000	0
Product 8	8000	9600	0	6400	8000	0	8000	0
Product 9	15000	18000	12000	15000	0	49532	64532	49532
Product 10	9000	10800	2700	4500	7224	39576	46800	37800

ductive time (UT) and the total productive time (PT) are also shown for each scenario.

Table 5. Production costs and working time results

Scenario	MPC [€]	IHC [€]	UMC [€]	TPC [€]	UT [h]	PT [h]
NINS	4.511,40	718,71	8.052,66	13.282,77	136	154
NIWS	6.767,08	4.109,15	3.483,42	14.359,65	59	231
WIWS	5.241,53	4.302,06	6.079,67	15.623,26	102	188

As stated in Table 5, the total production cost (TPC) for the first scenario (NINS) is €13.282,77, of which €4.511,40 (34%) are from the MPC, €718,71 (5%) from the IHC, and €8.052,66 (61%) from the UMC. Relating to these costs, it is estimated a total of 136 unproductive hours that lead to the UMC, whereas the 154 productive hours lead to both the MPC and the IHC. This means that the model found the balance between the costs to produce surplus units and leaving the machine in an unproductive state.

For the second scenario (NIWS), the total cost (TPC) is €14.359,65, composed by €6.767,08 (47%) from the MPC, €4.109,15 (29%) from the IHC, and €3.483,42 (24%) from the UMC. This plan results in a total of 59 unproductive hours face 231 productive hours. This time, because it is necessary to replenish all units required by the safety stock level, the UMC represents the lowest contribution to the total cost (TPC), whereas the MPC is the highest, exactly because there is a an incentive to produce more (demand plus safety stock).

In the third scenario (WIWS), there is a need to replace the safety stock. Thus, the total cost (TPC) is €15.623,26, in which the MPC is €5.241,53 (34%), the IHC is €4.302,06 (28%), and the UMC is €6.079,67 (39%). The third plan leads to 188 productive hours and 102 unproductive hours.

Comparing all scenarios, it is clear that the most sustainable is the first one (NINS), where the approach is to produce only what is necessary, avoiding to keep inventory. This is aligned with lean manufacturing, which is known to promote efficiency and reduce waste. However, the second scenario (NIWS) is a better planning approach for the company under study, because it works with high demand levels, and if there is a machine breakdown, safety stock can reduce or even avoid delays, leading to less impact on customer expectation. The third scenario (WIWS) shows that excessive production above the safety level generates high costs and higher consumption of resources, just because all surplus units are costing to be maintained over time.

5 Conclusion

Bear in mind what has been presented, one can assure that IP consists of a powerful tool for developing a sustainable MPS model. This approach gives the possibility of predicting and analyzing a vast number of different scenarios which is fundamental for a firm that wants to prosper and grow, using a sustainable and a competitive strategy.

The main contribution of this paper is to develop a sustainable MPS model based on IP, which allows a medium-sized cold stamping company to find the optimal balance between letting unproductive machines or generating inventory by producing units in surplus, which means producing more with less waste in order to obtain a responsible and sustainable production.

Three different scenarios (NINS, NIWS, WIWS) were simulated using the proposed model, and the results indicate that the total production cost is lower when a company produces in volumes close to the demand. However, not every company is capable of doing it, because of possible unscheduled events intrinsic to the production process that can lead to delays and decrease customer satisfaction. The worst scenario is when a company generates an excessive inventory, since it turns into high costs required to maintain them in the warehouse.

The proposed model does not consider uncertainty for two main reasons: (i) it was designed to be continuously applied at the end of each week, meaning that only during the first week the proposed plan is going to be executed, whereas all plans concerning the following weeks (2, 3, and 4) are going to be weekly rescheduled until they take place; (ii) given that the company has a limited number of customers and produces based on orders, the demand fluctuation is predictable and absorbed by the weekly review of all plans.

Since the model is still in development, no comparisons were made with the real plan developed and applied by the company. Some of the further work intends to extend the model to determine the short-range plans based on an effective job sequencing rule, involving setup time. With the final model in hand, the validation encompasses the comparison of the MPS planning of the proposed model with the real planning of the company. Additionally, the proposed model will be tested to support the real production planning of the decision makers.

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