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# TheProductivity Improvement in Operational Performance Focusing on the Behaviourof Performance Indicators

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--------------------------------------------------------***ABSTRACT***--------------------------------------------------------
*This research has two objectives. The first one is to show the importance to the productivity improvement analyzing the behaviour of performance indicators and the second one is to present a mathematical formulationto simulate multi-level capacitated lot-sizing problems as a challenging task. By establishing a framework based on the fundamental elements inherent to decision-making processes pertinent to plastic production, we identify several opportunities for advancing research and practice. The problem is in the process of optimizing the factory production lines, focusing on productivity, minimizing lead time and production cost. The main objective is to control production levels to meet demand adequately. The existing restrictions in each of the levels of production and the problem of the frame as a sizing problem and scheduling are also addressed. The research aims to create an optimization model for an integrated lot sizing problem and production scheduling in an industrial environment with parallel machines that have capacity constraints, costs and preparation times dependents on the production sequencing. The challenge is to determine both sizing and minimal cost of raw materials, equipment and human resources.*
***KEYWORDS****: productivity; production scheduling; lot sizing; optimization.*
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## I. INTRODUCTION

In the literature on production scheduling, most research admit that the resources are always available. However, in the shop floor, resource unavailability including breakdown, failure and inspection often occurs, which interrupts the current production. The most studies focus on single resource during production scheduling, which may not be sufficient to improve production system reliability as a whole because in the shop floor usually involves several substantial resources simultaneously. For example, in plastic production, injection machines and matched injection moulds should work together.

The motivation for this research comes from industrial problems involving the manufacture of plastic packaging in a case study. The raw materials are basically resin and pigment, incorporating the label in customization for each client. Some machines have several moulds and others are fixed moulds. There are cardboard boxes and plastic for the transport of products on pallets.

The changing of the mould of a particular product leads to a loss of time, generating a delay of several hours in the start of production of the next product. This changeover time (time setup) is influenced by the production sequence, ie the order in which the products are produced. There are four production lines within the plant and can usually produce various types of products in a single production unit. Thus, various products can be manufactured in production lines arranged in parallel, but also within the same production line with sequence parallel machines.

The research problem has capacity constraints, the demands must be met within a monthly horizon divided into weekly periods. The lines have different production speeds, resulting in different production capacities. Moreover, the warehouses have a maximum storage capacity limited, while the drive-in (process inventory) absorbs still unfinished products or leftovers from production orders, but with limited capability as well. The combination of these factors limits the capacity of the plant.

The research problem can be classified as a lot-sizing problem and production scheduling in parallel machines with capacity constraints, dependent costs and preparation times of the production sequence. In short,

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it is an integrated lot sizing problem and scheduling, capacity constraint, whose optimization is relatively difficult.

One common approach to solve the continuous optimization problem is based on estimated gradient information which drives the optimization process to a minimal point. Most research on lot size optimization has focused on single stage batch production systems. However, in practice it is of interest to optimize performance over multiple processing stages, where stages are not independent.

Determining the production schedule means to calculate the necessary amounts of raw materials, intermediate items and final products that should be purchased or produced in each period while minimizing total costs respecting the capacity limitations. In the production planning process the right decisions in lot-sizing have an essential impact on the system performance and its productivity.

The plastic production is an extremely complex and theproductionsystem is dynamic. Immersed in a market characterized by a large number of stakeholders with often conflicting goals, the industry has been evolving rather erratically, in amidst of cycles of booming and instability ([17] and[16]). In a comprehensive report, [29] identified the main issues affecting performance of operations:

1. low levels of productivity, with high input and production costs;
2. highly unstable commodity prices, affecting the growth trajectory of many developing markets with high exposure to international trade;
3. an innovation imperative, with a more integrated approach to mine design and planning, and attention to energy supply and demand;
4. higher debt levels, and a trend for market consolidation;
5. questionable capital allocation practices;
6. intensifying demands from communities on the social license to operate;
7. rising hostility in government relations;
8. ever-stricter regulatory environments;
9. a zero harm to zero fatalities imperative;
10. a significant gap in talent acquisition and retention.

The tactical decision level seeks effective resource allocation to satisfy demand requirements and operation constraints on a given time horizon, while operations control is concerned with short-term decisions, usually involving low-level programming and scheduling.

According to [8], [9] and [12], operating performance is best assessed when operational indicators are also associated with financial variables and aligned with corporate strategy.

## II. LITERATURE REVIEW

Productivity has been discussed in the literature in a conceptual way, generating conflicts between productivity and operations. These conflicts are perfectly minimized or solved by production planning and scheduling associated with the management and monitoring of performance indicators.

Some researchers have tried to incorporate productivity into production scheduling with different optimization goals in different factories ([28], [27], [26]). [45], [21], [4], [18],[12],[5])andstudied the problem of simultaneous scheduling of tasks and maintenance tasks to minimize the sum of cycle times. [19] and [20]proposed an integrated fault-time model subject to a Weibull distribution, to minimize the delay in production scheduling. [35] and [34] studied a problem of correlating the performance of machines with flexible maintenance activities. [6], [22] and [47]considered the integrated programming problem with different preventive maintenance policies. [41], [36]and [52]investigated a problem of scheduling activities of the shop floor with cycle times dependent on the sequence and maintenance activities. Both studied production scheduling problems with multiple maintenance on identical parallel machines to minimize total time and cycle time separately. [37],[38], [39]and [42]investigated an entire scheduling problem with periodic preventive maintenance of equipment.

For the single machine, [32] and [30] extended the model to a multiobjective optimization problem to minimize maintenance cost, cycle time, total weighted delay, and machine downtime. [23] and [31]discussed a multi-objective production scheduling problem focused on maintenance shutdowns, with equally treated and weighted goals, proposing metaheuristic algorithms and genetic algorithm as a solution. [33]and [24]studied a parallel production scheduling problem with flexible maintenance activities to minimize the total cost involved, considering completion time and unavailable time. [25]and [43]investigated a problem of production scheduling failure with flexible maintenance activities to minimize the cost of delays and maintenance cost. [48]studied the minimization of production scheduling problem including maintenance activities.

According to[13], [10], [11]and [9], all the mostmethods have provided a solid foundation for further research, however, there is a clear approach to considering integrated problems as single goal optimization problems. On the other side, there is a huge gap in not considering production and maintenance in achieving the common goal of maximizing productivity, as well as incorporating variables such as production time, cycle times, sales volume and capacity utilization.

In production lines with parallel machines, [15],[40]and [44]studied a programming problem to minimize unavailability of the production system. [14]and [49]studied an integrated programming problem with preventive maintenance activities that must be performed within a tolerance range. [51], [7] and [46] considered a multi-objective parallel production scheduling problem with maintenance constraint once per machine, to minimize the total sum of the weighted work cycle times and the preventive maintenance cost.

Considering the survey of cited researches, it was observed that productivity was treated as a result as a programming problem and with the main focus on machines. In view of this, it is well known that there is little research available on integrated production scheduling with multi-resource productivity, although there are relevant research results on multiobjective production scheduling. Incidentally, [53] and [54], [2];[3] and [1]considered production times in conjunction with planning the maintenance shutdowns of injection machines and injection molds to minimize the in the context of plastic production systems. However, only a single objective was related to the aspect of production.

In a broad way, if production is continuous, the availability or reliability of the machines will be lower. It is well known that preventive maintenance requires time in production, but increases the availability and reliability of the machines in the production lines. In the procedure of optimizing the objective function with constraints, the objectives of production and maintenance may even be conflicting, but are mutually dependent and supportive of one another.

In this article, based on a real case, we investigated a problem of productivity improvement in operational performance based on decision variables and as parameters of performance indicators. Two types of features were crucial to the actual case study, machines and molds. The optimization procedure considered the correspondence between machines and molds with partial flexibility, within what was feasible on the factory floor. The correspondence between machines and molds complicates this problem substantially further. As far as we are aware, there is no research with these precedents documented in the literature.

## III. DESCRIPTION OF THE PROBLEM

The problem is in the process of optimizing the factory production lines, focusing on productivity, minimizing lead time and production cost. The main objective is to control production levels to meet demand adequately. The existing restrictions in each of the levels of production and the problem of the frame as a sizing problem and scheduling are also addressed.

The research aims to create an optimization model for an integrated lot sizing problem and production scheduling in an industrial environment with parallel machines that have capacity constraints, costs and preparation times dependents on the production sequencing. The challenge is to determine both sizing and minimal cost of raw materials, equipment and human resources. The optimization procedure was performed within the Matlab environment.

### 1. Problem stages

The manufacture of plastic packaging involves the use of these raw materials (resin and pigment), however, with pigments and different moulds, resulting in various products (basically buckets with lids and plastic handles). Resins and pigments are stored in sheds where seep into the production lines.

As for the packaging labels, there are four options: smooth bucket (without customization), in mould label (resin injection already labeled), offset (serigraphy), heat transfer (heat adhesion).

At first, the problem involves the sizing and programming of the buckets and lids. It must be decided how much and when a product is produced in accordance with the production order, considering the logistics involved, productivity, minimizing the lead time and production cost.

Each product can be produced in different machines. There are between three and ten options for each type of product, but the restriction is the mould, which requires three hours to remove and install another.

The equipment downtime is compensated for increasing the size of the production batches. This is intended to reduce losses arising from long setups. On the other hand, the creation of stocks will result in overflow of storage.

The economic lot size, updated every demand, depicts the amount of product for production orders. Considering the importance of the inventory carried, the cost characteristics and demand for the products can influence so much the economic lot size.

Master Production Schedule (MPS) is a method generated from a production plan within a time horizon. For the simulation of the MPS, information such as late orders, order backlog, available capacity, orders scheduled, products, materials and other information are considered.

The goal of the program is to meet the delivery times within the customer specifications and make the best use of productive resources. Production scheduling defines the priorities of production orders, which must occur to meet its goals. Programming is the positioning of activities in time, following the defined sequencing and restrictions involved. Therefore, control of production consists of the collection and analysis of information in order to monitor discrepancies between actual performance and expected performance.

The production control system is responsible for establishing the priorities of each production order, updating information on inventory levels in the process, supporting the management of productive capacity, monitoring performance through indicators of efficiency, productivity, operating profitability among others.

**2. Restrictions and decisions involved**

There are several constraints and objectives that should be considered while developing a production schedule. Initially, we present the restrictions on equipment, moulds and production lines:

1. All the equipment involved has a maximum production capacity that can not be exceeded. It must consider the setup time of each piece of equipment and stops for preventive and corrective maintenance.
2. Each piece of equipment will only produce one type of product at a time, but the same product can be produced by more than one device, provided that there is more than one available mould.
3. A product goes into production line when the color tone is exactly within the specifications required by the client. There is a loss of raw materials when the product does not meet specifications of standards and this loss can vary from 200 to 400 products. These initial products are considered scrap and the color scale affects costs and time. Lighter tones should be used before darker tones in the same mould, so there is a need to observe the sequence in which the products are produced.
4. For each product, there is an established percentage of pigment and resin proportional to the final weight of the product because the pigment is very expensive. During the production process, there is no loss in final weight of the product in relation to the weights of raw materials.
5. The production of buckets, covers and handles are synchronized and a final product is the assembling of these three elements. Any delay in production affects delivery, consequently, costs.
6. Various sizes of moulds, each one with specific number of cavities, limit the number of products that are generated in each cycle time. However, not always use the maximum amount per mould cavity, affecting the result of the production line.
7. The batch production is continuous on a 24 hours cycle with several machines working in parallel and stops only twenty days a year for collective holidays.
8. The cycle time is associated with the product and the mould. In general, a single production line has different processing time for different types of moulds and equipment.
9. The weekly demand must be met and the storage time should not exceed two days in order to minimize stocks of unfinished goods, storage space and costs.

The restrictions and decisions involved characterize the optimization problem as multi-level, requiring an integrated and synchronized solution to have an effect on production scheduling.

The research problem has constraints that impact the production capacity of the four production lines. The demands must be met within a month divided into weekly periods. The lines have different processing speeds that lead to different production capacities within the periods considered.

In addition, the flow of production depends on transport logistics and loading of trucks. The acquisition of raw materials is not a problem. The combination of these factors limits the capacity of the plant. Furthermore, the problem may be classified as a lot-sizing and scheduling problem on parallel machines with capacity constraints, costs and preparation times depending on the following.

[50]also highlight some benefits arising from the use of a hierarchical planning associated mainly with an optimization method:

a) increasing the profit
b) better use of raw materials
c) better balance of inventories
d) more systematic and analytical decision-making
e) better knowledge and control of production processes
f) systematization of production data
g) organizational learning.

The structure of products produced by the company has three components considered as three levels. The highest level of aggregation, called final product, the set of items covering a spectrum of demands by customers. The second level, the structures of the products are grouped products that have similar characteristics with respect to the structure and production process. At the third level, SKU (Stock Keeping Unit) has the final configuration of each product, packaging, pallets, accessories and other. The company's product portfolio contains about 1,700 products, 2,000 structures and 2,400 SKU.

## 3. Mathematical formulation

The objective function is used to describe minimize production costs, time and stock involved in the production lines. To ensure that a solution is found, there is reprogramming in order to cover demand. The unmet targets have highly penalty.

The indices adopted in the model formulation are as follows:
$t$ – indicates the unit of time (month).
$p$ – indicates the available products.
$c$ – indicates the components used in the assembly products $p$.
$m$ – manufacturing lines.
$i$ – indicates the aggregate customers who buy each product $p$.

Parameters:
$hr_{m,t}$ = regular hours available in assembly line $m$ in period $t$.
$he_{m,t}$ = overtime available on the assembly line $m$ in period $t$.
$hr_{p,t}$ = regular hours available for manufacture of the product $p$ (bucket, cover, pot, handle etc) in period $t$.
$he_{p,t}$ = overtime available for manufacturing of product $p$ in period $t$.
$pp_{m,t}$ = products produced on a hour in the assembly line $m$ in period $t$.

The parameters of overtime cost represent variable costs related to the payment of human resources and the use of manufacturing resources.

Thus:
$che_{m,t}$ = cost of overtime on the assembly line $m$ in period $t$.
$chef_{c,t}$ = cost of overtime for the production of product $p$ in period $t$.

The cost of inventories opportunity is calculated by multiplying the historical standard cost of the product by an interest rate associated with the cost of capital of the company.

$ct_{p,t}$ = a unit cost of product $p$ in period $t$.
$t$ = interest rate adopted by the company to calculate the opportunity cost.

The margin of unitary contribution comes from the difference between the production cost and its variable cost.

$Mc_{p,t}$ = contribution margin of a product $p$ at a time $t$.
$d_{p,t}$ = demand of product $p$ units in period $t$.

The parameters related to the restrictions ensure the viability of the production plan, ie, ensure the existence of production resources available for the production of products $p$ allocated in the production plan.

$pm_{p,m}$ = connects the products $p$ with the assembly lines $m$ able to mount them.

When this association is possible, it is $pm_{p,m} = 1$. Otherwise, $pm_{p,m} = 0$.

$Ei_p$ = initial stock of product $p$ in units.

### 3.1. Decision variables

The decision variables are those whose values may fluctuate in finding an optimal solution for the production system.

$Pr_{p,m,t}$ = regular production of the product $p$, on the assembly line $m$, in period $t$.
$Pe_{p,m,t}$ = overtime production of product $p$ on the assembly line $m$, in period $t$.

$E_{p,t}$ = units of the product *p* in stock at the end of a period *t*.
$V_{p,t}$ = sales volume in units of product *p* in period *t*.
$Cap_{p,m,t}$= production capacity of the product *p*, on the assembly line *m*, in period *t*.
$C_v$ = cavities of the moulds used.
$t_c$ = cycle times.

### 3.2. Objective function

The main objective of optimization is the design of a monthly production plan that maximizes the operational profitability of the company, considering the manufacturing constraints. The objective function maximizes the marginal contribution for the profit of the company by adding unit margins of sales and subtract costs related to the production of components and finished goods.

To maximize:

$$Z = \sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{p=1}^{P}\left[mc_{p,t}V_{p,t} - ct_{p,t}tE_{p,t} - \sum_{m=1}^{M}\left(che_{m,t}Pe_{p,m,t}\right)\right]$$

The stocks conservation equation calculates the stock at the end of a period *t*, in order to stock at the end of period *t-1*, total production and sales in period *t*.

If t > 1:

$$E_{p,t} = E_{p,t-1} + \sum_{m=1}^{M}\left(Pr_{p,m,t}Pe_{p,m,t}\right) * pm_{pm} - \sum_{i=1}^{I}V_{p,t}, \quad \forall p = 1,\dots,P, \quad \forall = 1,\dots,T$$

If t = 1:

$$E_{p,t} = Ei_p + \sum_{m=1}^{M}\left(Pr_{p,m,t}Pe_{p,m,t}\right) * pm_{pm} - \sum_{i=1}^{I}V_{p,t}, \quad \forall p = 1,\dots,P, \quad \forall t = 1,\dots,T$$

### 3.3. Assembly Line Capacity Restrictions

Capacity constraints guarantee that the volumes of each assembly line *m* on each machine, referring to a product *p*, respect the availability of production of each resource in a period *t*. Therefore, the restrictions linked to regular production capacity of the assembly line indicates that the number of products must be produced in each period and not whether to produce or not.

$$\sum_{p=1}^{P}Pr_{p,m,t}pm_{p,m} = hr_{m,t}pp_{m,t}, \quad \forall m = 1,\dots,M, \quad \forall t = 1,\dots,T$$

$$\sum_{p=1}^{P}Pe_{p,m,t}pm_{p,m} \le he_{m,t}pp_{m,t}, \quad \forall m = 1,\dots,M, \quad \forall t = 1,\dots,T$$

Each machine must not exceed its production capacity, taking into account total time of the stops (setup, maintenance, replacement of moulds etc):

$$\sum_{p=1}^{P}Cap_{p,m,t}pm_{p,m} \le Cap_{m,t}pp_{m,t}, \quad \forall m = 1,\dots,M, \quad \forall t = 1,\dots,T$$

The production capacity should be restricted to the mould cavities used and each mould cycle times:

$$\sum_{p=1}^{P} Cap_{p,t} \leq Cap_{molde}\, t_c, \quad \forall t = 1, \ldots, T$$

3.7 Restriction of no negativity

$Pr_{p,m,t}$, $Pe_{p,m,t}$, $E_{p,t}$, $V_{p,t}$ e $Cap_{p,m,t}$ must be higher than or equal to zero.

According to [55], the optimal point must contain a solution that meets the following criteria:
a) alignment of organizational guidelines with the dictates of the market;
b) consideration of the constraints of the infrastructure of the company and resource capabilities;
c) quality properties of products and availability of raw materials and inputs;
d) maximization of financial return, based on selling price, costs, expenses and variable costs, logistics and so on;
e) minimization of inventory, considering its financial impact.

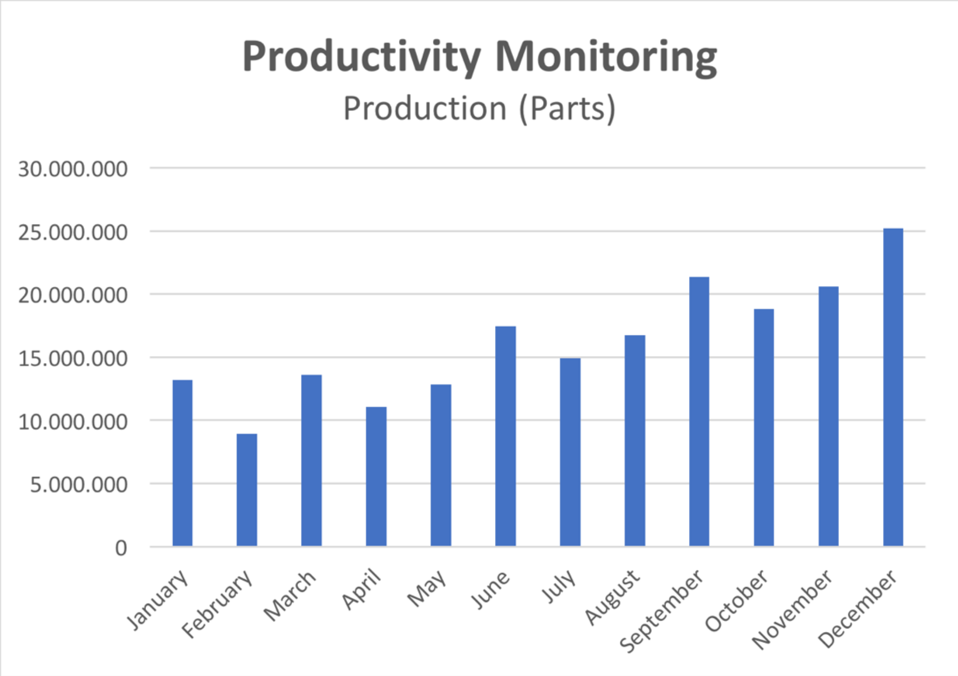
## IV. RESULTS ANALYSIS

After one year of observation, intervention and monitoring[3] of the behavior of performance indicators based on productivity, we observed the residual improvement of productivity in relation to the use of productive capacity. This was due to the improvement of the MTBF (Mean Time Between Failure) with the reduction of unscheduled stops, the adequacy of production scheduling, a better level of predictability, a higher order fulfillment capacity and lead time reduction. As a result, production lines were better utilized, lower inventory levels, lower material losses, less time and equipment shortages.

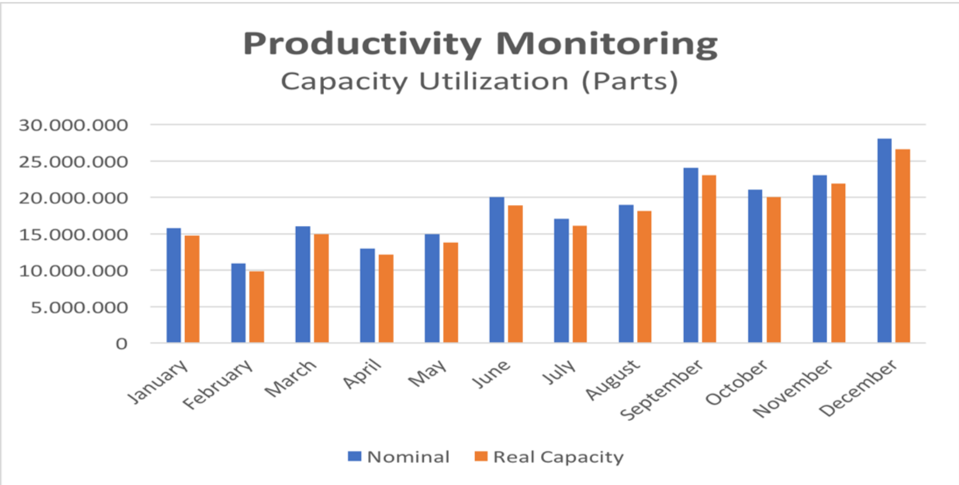
Some actions were required to achieve such performance, such as:
a) better drive-in and pallet occupancy for better logistics performance;
b) the productions and the expeditions of buckets and lids became more paired;
c) greater accuracy in predicting resource use;
d) identification of nonconformities in inventory management;
e) changes in cycle times.

Another result was also important as the reduction of 3.2% in the total cost of production, with potential predicted to 8% in two years.The productivity increased by 5.55% in this period considering that this improvement occurred only due to the optimization process. If the options of alternative process scripts and equipment changes had been studied, this improvement could have been much greater.

[3]MATLAB was used as a computational tool in the optimization procedure.

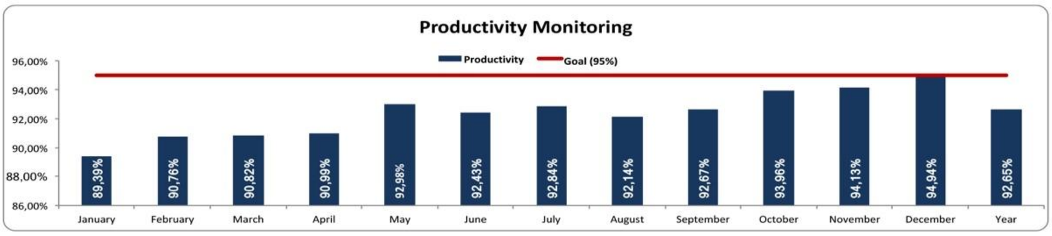



Another interesting aspect is that the actual capacity was always very close to the nominal capacity during the period, highlighting the influence of the requests on the capacity constraints, in relation to logistics, the composition of products versus orders, inventory turnover and delivery.

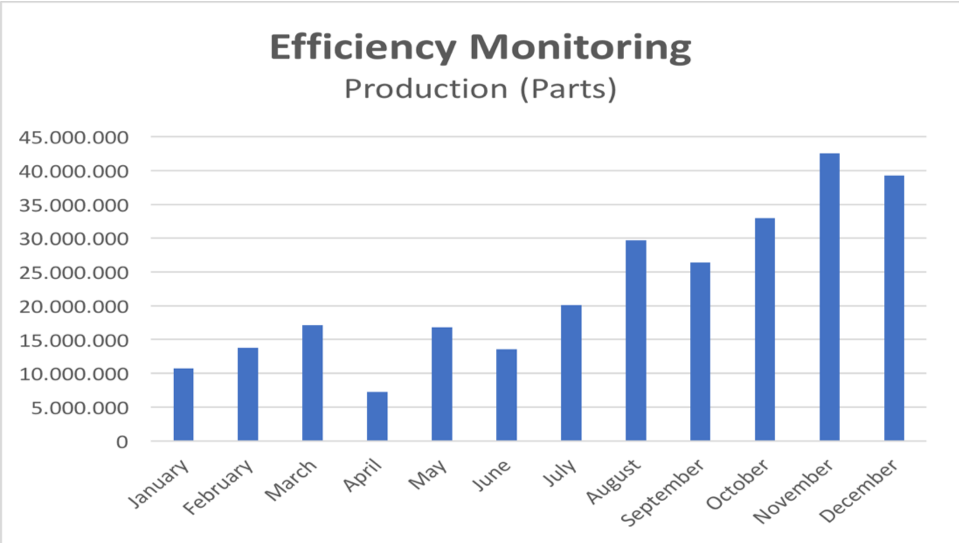



In summary, the evolution of global productivity is represented in the next graph, reaching final values very close to the goal of 95% established by the company and quite acceptable to the global competitiveness standards.

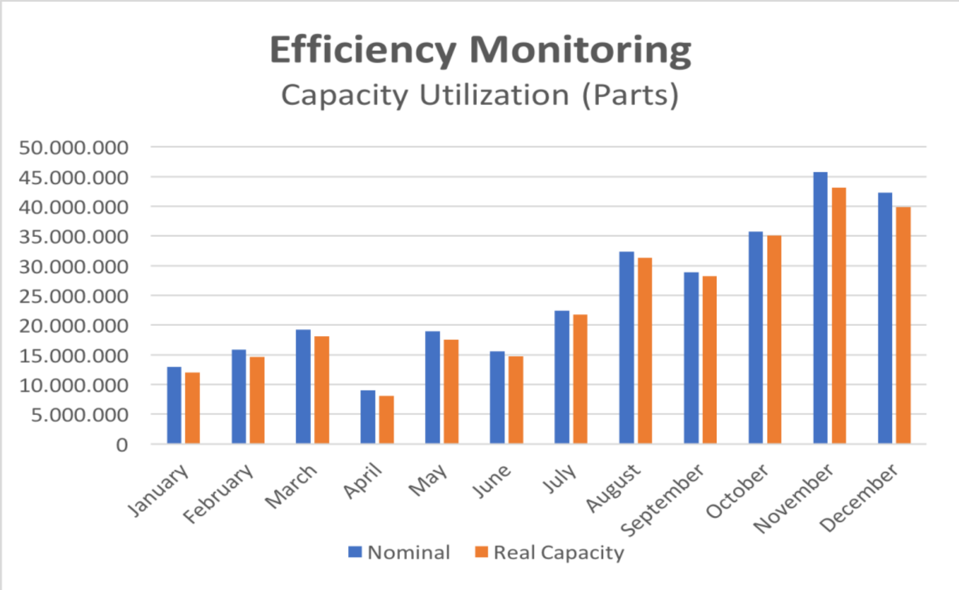
| | January | February | March | April | May | June | July | August | September | October | November | December | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Production (Parts) | 13.180.981 | 8.949.027 | 13.580.152 | 11.046.685 | 12.836.059 | 17.467.184 | 14.933.717 | 16.723.092 | 21.354.217 | 18.820.750 | 20.610.124 | 25.241.249 | 194.743.238 |
| Nominal | 15.767.897 | 10.917.219 | 16.003.121 | 12.997.848 | 14.948.983 | 20.034.885 | 17.029.612 | 18.980.747 | 24.066.649 | 21.061.375 | 23.012.511 | 28.098.413 | 222.919.260 |
| Real Capacity | 14.744.784 | 9.860.003 | 14.952.017 | 12.140.411 | 13.805.029 | 18.897.043 | 16.085.437 | 18.150.055 | 23.042.069 | 20.030.463 | 21.895.081 | 26.587.095 | 210.189.486 |
| Productivity | 89,39% | 90,76% | 90,82% | 90,99% | 92,98% | 92,43% | 92,84% | 92,14% | 92,67% | 93,96% | 94,13% | 94,94% | 92,65% |




ficiency, the relation between input resources and the parts of the products produced indicates an influence of the seasonality of demand, however, a residual evolution is observed with an average increase of 266%. There is also less influence of the parties' compositions on final products, which has an impact on the quantity of parts produced in the month.

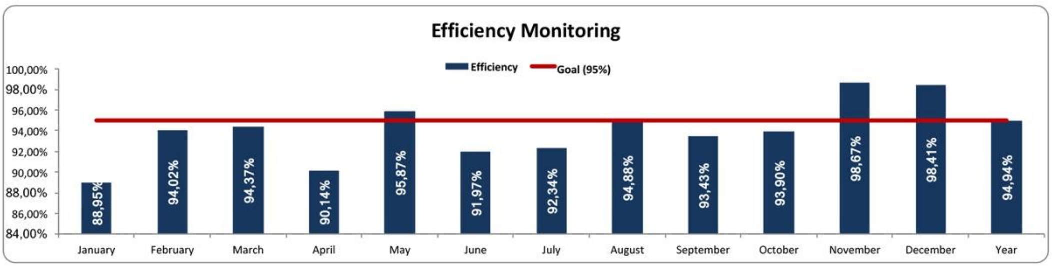



Within the concept of inputs and outputs, capacity utilization showed a strong correlation with the quantity of parts of products produced, considering the almost total reuse of the process wastes, dispensing only equipment and personnel hours. That the most relevant part refers to the equipment hours. Likewise, capacity utilization has always been close to its maximum utilization, since the production lines operate uninterruptedly every day and during the twenty-four hours.

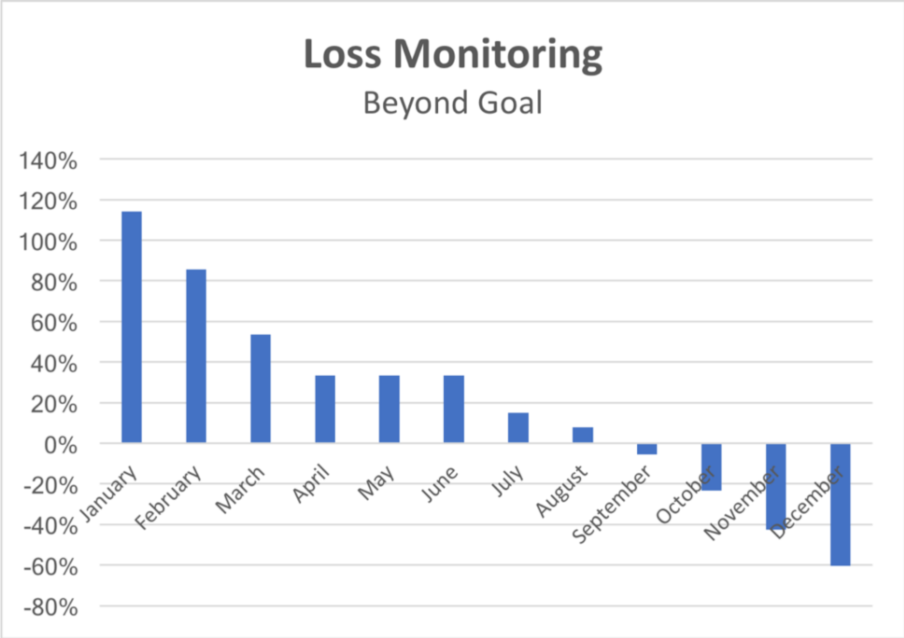



As a consequence, efficiency increased by 9.47% over the year, which is quite representative, in addition to maintaining the monthly indexes above the initial reference. Actual capacity fluctuated around an average of 95% of nominal capacity throughout the period, which demonstrates a stable and judicious maintainability. The maintenance stops were scheduled and followed the formal procedures, with few exceptions.

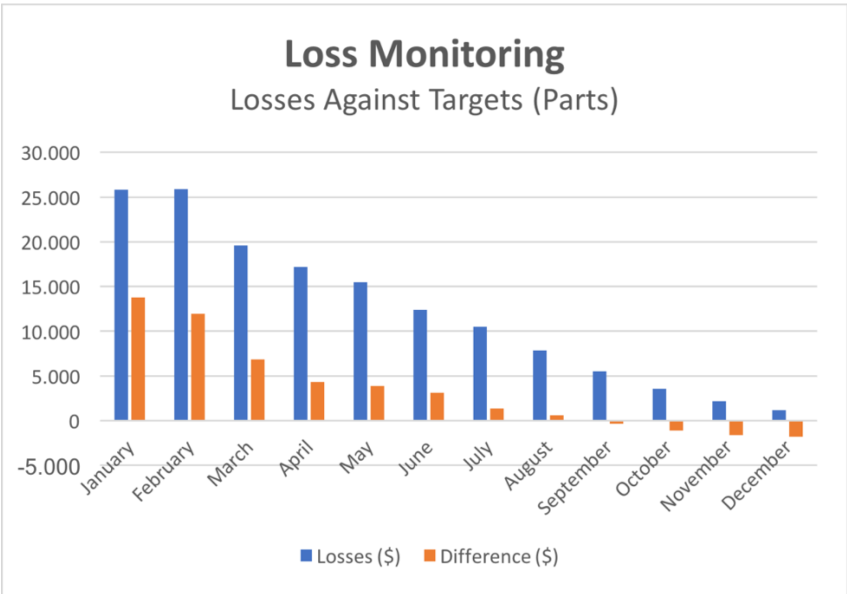
| | January | February | March | April | May | June | July | August | September | October | November | December | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Production (Parts) | 10.724.932 | 13.809.120 | 17.089.059 | 7.249.242 | 16.826.352 | 13.546.413 | 20.106.291 | 29.683.402 | 26.403.463 | 32.963.341 | 42.540.451 | 39.260.512 | 270.202.579 |
| Nominal | 12.918.502 | 15.843.740 | 19.262.813 | 9.005.594 | 18.966.792 | 15.547.719 | 22.385.865 | 32.347.064 | 28.927.991 | 35.766.137 | 45.727.336 | 42.308.263 | 299.007.816 |
| Real Capacity | 12.057.653 | 14.686.932 | 18.109.261 | 8.042.274 | 17.551.668 | 14.729.339 | 21.773.997 | 31.283.631 | 28.261.302 | 35.105.960 | 43.115.595 | 39.893.265 | 284.610.879 |
| Efficiency | 88,95% | 94,02% | 94,37% | 90,14% | 95,87% | 91,97% | 92,34% | 94,88% | 93,43% | 93,90% | 98,67% | 98,41% | 94,94% |




The monitoring of losses was also an important aspect to be observed. Since the volumes of the parties take up a lot of space in the warehouses, any amount saved has a big impact on sales, since demand has been growing for several years. Any reduced space in storage, decreases the opportunity cost and increases actual gains. Initially, the targets for losses were over 50%, reaching this level in exact five months. The target for losses was revised each month, analyzing the behavior of the indexes over the previous months. Beginning in the eighth month, even setting bold targets, the factory floor performed better than the target for losses. After twelve months, the losses became practically insignificant, about 4.5% of the losses at the beginning of operations interventions.

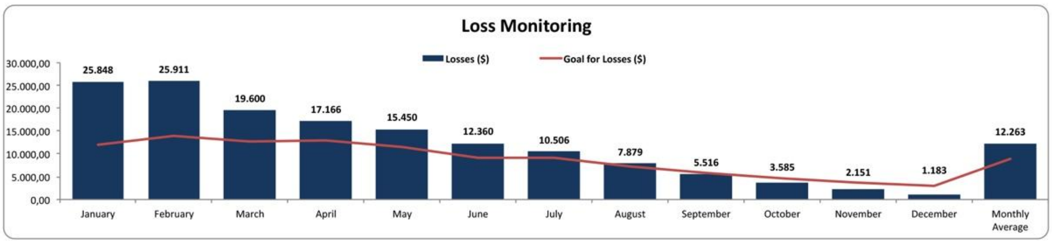



It was observed that the losses were reduced each month in an almost linear way, except in the first month due to adaptation issues and in the last two months due to the proximity of the optimum point in the optimization process. On the other hand, the differences in losses against the targets had a strong reduction in the first three months, but then stabilized, reducing almost linearly until the end of the annual period of analysis. This demonstrates the rapid suitability of the model in the optimization process since the resulting procedures were adjusted in real time in the company's operations system. The operations system is integrated, involving all the production lines and its monitoring is carried out via WEB in real time, which greatly facilitated the interaction with the optimization process.




In practice, losses have been controlled, foreseeable and their origin identified, directing the actions to small final adjustments that have been translated into preventive actions in the production lines in order to totally eliminate the losses arising from the production process.

| | January | February | March | April | May | June | July | August | September | October | November | December | Monthly Average | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Goal for Losses ($) | 12.070 | 13.957 | 12.767 | 12.863 | 11.577 | 9.262 | 9.125 | 7.300 | 5.840 | 4.672 | 3.738 | 2.990 | 8.847 | 106.161 |
| Losses ($) | 25.848 | 25.911 | 19.600 | 17.166 | 15.450 | 12.360 | 10.506 | 7.879 | 5.516 | 3.585 | 2.151 | 1.183 | 12.263 | 147.155 |
| Difference ($) | 13.778 | 11.955 | 6.833 | 4.303 | 3.873 | 3.098 | 1.381 | 579 | -325 | -1.087 | -1.587 | -1.807 | 3.416 | 40.995 |
| Beyond Goal | 114,15% | 85,66% | 53,52% | 33,45% | 33,45% | 33,45% | 15,13% | 7,93% | -5,56% | -23,27% | -42,45% | -60,43% | 38,62% | 38,62% |




The database analysisincluded the four production linesof this company, all production lines with approximately1,700 product types, considering the variables described in this article. A large database was created to obtain more substantial and more representative indexes regarding the behavior of operations on the shop floor.

## V. CONCLUSION

The optimization process has proven to be an important tool to focus on the production system. The results indicate that effective management of manufacturing processes promotes significant cost savings and increases production levels, therefore, increasing competitiveness and profitability.

We obtained higher gains from reduced setup times and the increased availability of the machines. As this indicator considers resources available for production, it was possible to improve production with machines in parallel, fewer unnecessary stops, less waste in the exchange of pigment and even improvement in the quantity of defective products manufactured.

Choosing the best product mix greatly reduces time wasting and restrictions. However, we tried to meet the demands focusing on time optimization, also including the logistics involved, thus increasing the production time of some products. In short, the method much improved the sequencing of production.

By knowing what the time required for processing a request and this sequence will be, the setup times were greatly reduced or, in some cases, were null. The optimization focused on the bottleneck of the production lines, especially analyzing changes of moulds, pigment (impacting the volume produced to clean the internal system of each machine), the lost time and the number of setups. The sequencing of production orders became organized so that similar requests were put together. As a result the method, reduced setup times and unnecessary duplications were avoided.

Greater care was taken in reprogramming the production sequence when the orders entered the queue again so as not to cause delays in relation to other requests. In these cases, when reprogramming was made and resulting in delay, a new program would come to correct this problem. The lead-times, operating expenses, inventory investment declined noticeably, while the quality, performance, delivery times and production speed increased.

As the restrictions significantly affected the overall result of the production system, it is vital to make the machines work considering the restrictions. At the end of the implementation of the new method, the company managed to increase its production 4% on average without increasing their fixed costs, number of employees and machinery sequence. For a turnover of approximately US$ 400 million per year, we are estimating US$ 16 million a year more in sales.

A preliminary analysis of the data, identified that thirteen machines accounted for 16% of the annual turnover of the plant. An optimization plan for increased productivity by 10% would result in an increase of US$ 158,000 per month. Any improvement activity held on other machines would give a lower return. Some conditions were considered:

a) goods manufactured in the last three years;
b) types of products that machines usually produce;
c) sales of each product in relation to the total turnover of the plant.

The optimization process considered the efficiency of the machines for the optimum productive capacity in relation to maintenance costs, energy costs and value of the product. This research analyzed the potential increase in the efficiency of machines, production processes and operations management.

Regarding the increased efficiency of the machines, idleness was analyzed, the level of utilization, performance, quality, mass balance and energy balance. Increased process efficiency had the dimensions: time of activities, process maps, value stream maps, activity and standard time for each activity and the layout process.

Increased efficiency in the management improved the company's business, brought greater reliability to meeting demands, improved cash flow, enabling more investment and profitability.

Regarding the extent of this research, it could be improved by exploring the hierarchy of production optimization criteria further. We also plan for the future to take into account logistics, business strategy, further validating the method and expanding to other market segments.

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