Research Article

Systems Theory and Evidence-Based Decision-Making as Keys for Arbitrating between Optimal Production and Efficient Maintenance: A Case Study

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Organizations in the 21st century operate in evolving and highly competitive environments—such environments are catalysts for deviation in organization-planned operations, including production and maintenance. The differences between maintenance and production, in general, are well known, given the several studies found in the literature regarding industrial engineering. However, the differences between maintenance and production are becoming less significant as a result of increased understanding of the systemic approach to organizations where the whole matters more than the sum of the parts. The aim of this study was to maximize the productivity of a manufacturing factory by applying mathematical programming methods while simultaneously considering the requirements of efficient maintenance. A case study is used to show how systems theory can be used as the basis for evidence-based decision-making in a factory manufacturing line in Morocco. Despite the potential for conflict between optimal production objectives and efficient maintenance in high-performance factories, the four-month case application suggests that systems theory is a key for arbitration. Research implications are presented along with future research directions.

1. Introduction

Equipment maintenance is crucial in any production [1]. Maintenance and production scheduling are two essential and interactive activities in production systems [2]. However, maintenance plans and production plans are usually considered two independent activities to be carried out independently in the manufacturing process [3]. The opposition between maintenance and production is documented in the literature [3, 4]. Production and maintenance should be viewed from a more holistic view, often presented as systems thinking and its tools [5]. Systems theory emphasizes laws, theorems, and principles characterizing the natural character that ensures the equilibrium for any system, whatever its nature and structure [6, 7]. It gave the system’s concept its deserved value by releasing it from limitations created by reductionists (the Cartesians) towards openness to its environment [8]. Systems theory (i.e., General Systems Theory) [9, 10] is an instantiation of the systems approach [11]. According to
Rosnay [10], its ultimate goal is to describe and encompass in a mathematical form all systems encountered in nature.

From an organizational point of view, maintenance is a support process for production. The previously mentioned opposition between maintenance and production originates in part from a lack of evidence-based decision-making. In other words, that opposition is strongly justified by the silo-mentality because of the bureaucracy and the reductionist management (or classical thinking-based management), which limits communication within a company and enhances barriers and ambiguity between its processes or services, including maintenance and production. Operational research, specifically mathematical programming, can be used for evidence-based decision-making to optimize manufacturing systems.

“Since the success of operation research applications in the military during the 2nd World War, it has become increasingly present in the day-to-day activities of managers such as manufacturing planning, personnel assignment, inventory management, transport problems (road, rail, air, and sea transport), schedule development, etc. All these problems implicitly or explicitly call for operational research techniques. The interest in this discipline has grown considerably in the last decades with advances in computing technology” [12]. Furthermore, according to Benadada and Alaoui [12], mathematical programming regroups several classes of problems; for instance, linear programming has been used for studying the optimization problems of linear functions under linear constraints [13]; non-linear programming has been applied in studying non-linear optimization problems with or without constraints [14]; integer programming is used for optimization problems where the variables are constrained to take only integer values [15]; dynamic programming is a general approach dedicated to the optimization of dynamic problems [16]. According to Nakhla and Moisdon [17], operational research tackles management and decision-making problems in economic organizations and considers combinatorics and uncertainty.

In the framework of systems theory and evidence-based decision-making, many research works have recently emphasized the efficiency of mathematical programming methods in enhancing (i.e., maximizing) production in various fields, such as the petroleum industry (e.g., [18]), small mechanical-based industry (e.g., [19]), and energy (e.g., [20, 21]). However, they do not consider the constraints of efficient maintenance (e.g., maintenance department’s objectives, maintenance conditions for high-performance, maintenance KPIs, etc.) facing production optimization in actual operation. This study aims to address this gap in the literature. Therefore, this paper applies mathematical programming to a case study in the aeronautical industry to maximize the productivity of a manufacturing process while optimizing the planned production time and respecting the conditions and requirements expressed by the objective of an efficient maintenance function within the factory. Furthermore, this study aims to avoid deviations from objectives due to common causes, i.e., management and decision-making-related causes.

This paper is organized as follows. Materials and methods are described in Section 2. The problem statement formulation is described in Section 3. The problem statement (Section 3.1) is based on the data analyzed and extracted from the monthly performance reports over a three-month period. The bottleneck element of the productivity of the manufacturing line is then modeled using a linear mathematical program (LMP) (Section 3.2). Discussion and results are presented in Section 4. Conclusions and future work are presented in Section 5.

2. Methodology

This study utilized both qualitative and quantitative approaches. The methodology involved an extensive review of the literature on systems theory and the production of manufacturing systems to identify key issues. Some keywords of interest include “Systems theory and manufacturing systems optimization,” “Mathematical programming,” “Manufacturing and maintenance management,” and “Manufacturing system bottlenecks” (Figure 1). After a further examination to determine the relevance to this study, over 100 initially identified papers were narrowed down to 32 papers.

In addition to the comprehensive literature review, a key aspect of this research is the analysis of the monthly performance data of an industrial manufacturing process as well as modeling a manufacturing maximization problem using linear mathematical programming (Section 3). The methodology uses defined steps to incorporate the various elements in order to achieve the research goal. The aim is to provide clarity by presenting the perspective of the research that justifies the harmony of its immersed and active parts [8, 9, 22, 23]. Therefore, the research methodology employed in this study considers interacting sub-contexts of systemic thinking applied to manufacturing systems and their maintenance (Figure 1).

Operational research tackles management and decision-making problems in economic organizations and considers combinatorics and uncertainty [17]. All classes of optimization problems related to industrial activities in general and organization-planned operations, including production and maintenance, more particularly, know an extensive application of mathematical programming as a discipline of operational research. Indeed, mathematical programming methods such as linear programming, non-linear programming, integer programming, and dynamic programming are widely used to assist operations management in making decisions relating to assembly line configuration [24]; to support decision-making in optimizing maintenance [25–28]; in addition to aiding decision-making in optimizing manufacturing planning or even strategic capacity planning in manufacturing [29–32], transport, and supply chain problems [33, 34], control plans in manufacturing [35], safety in manufacturing [36], and many other activities in the industry. Moreover, the recent mathematical programming literature has long recognized the centric role of mathematical programming methods in maximizing production in diverse
areas, notably the petroleum industry (e.g., [18]), small mechanical-based industry (e.g., [19]), and energy (e.g., [20, 21]). However, no work considered the constraints of efficient maintenance (e.g., maintenance department’s objectives, maintenance conditions for high-performance, maintenance KPIs, etc.) constraining the production optimization in real operation. The novelty of this work relies on addressing this research gap by applying mathematical programming to a case study in the aeronautical industry to maximize the productivity of a manufacturing process while optimizing the planned production time and respecting the conditions and requirements expressed by the objectives of an efficient maintenance function in the factory, besides avoiding productivity deviations from objectives due to common causes (i.e., management and decision-making-related causes).

3. Optimization of Productivity of a Parts Manufacturing Line in the Aeronautical Industry

3.1. Problem Statement. Organizations are increasingly operating under the characteristics of volatility, uncertainty, complexity, and ambiguity (VUCA) [37]. These conditions challenge the economic performance of companies in a context of diversified constraints imposed by their macro-system, and indeed, by their environment [38], which is a competitiveness and pressure source for companies around the world to commit to optimization and continuous improvement projects. In the framework of a productivity optimization policy applied to a company operating in the aeronautics sector, this paper focuses on performance improvement projects for the factory’s manufacturing lines. Based on the objective of motivating the work team on improvement work sites, this study targets the most available and maintainable manufacturing line in the company, according to the monthly performance reports for August, September, and October 2021 (Figure 2). It is a workshop (Figure 3) dedicated to the production of two distinguished types of special plastic parts (type A and type B), but the production bottleneck is the work position called “handling and manufacturing chain.” According to the monthly performance reports, the daily mean manufacturing rates are often lower than the target even in the absence of special causes of malfunctioning (or breakdowns) of the manufacturing activity within the workshop and in the case of 100% daily mean availability rates of the manufacturing line (Figures 2 and 4). This indicates the existence of a major common cause at
the handling and manufacturing chain level, generating considerable deviations in the productivity of the manufacturing line.

Based on the daily mean manufacturing rates with significant deviations from the fixed daily manufacturing objective during and before August-October 2021, we highlighted the “unplanned production time” for each team that works on the handling and manufacturing chain (Figure 5).

The line must run for two shifts of 8 hours per day. At the level of this workshop, there are:

(i) A handling and manufacturing chain of a capacity of 345 molds of parts: 200 molds of parts of type A and 145 molds of parts of type B.

(ii) Each team of operators must work on producing both types of plastic parts simultaneously, knowing that each team’s total available time is 8 hours a day.

(iii) A handling conveyor for moving the plastic parts from the handling and manufacturing chain towards the machining stations of the two types of parts by material removal.

Figure 2: Manufacturing line mean availability rate during the unplanned production time and monthly availability rate averages compared to the maintenance objectives in matters of the manufacturing line availability over August, September, and October 2021.

Figure 3: Simplified diagram of the manufacturing process of plastic parts of types A and B within the factory’s line.
(iv) Storage carts of both types of parts, each with a capacity of 90 plastic parts.

daily availability rate higher or equal to 97% and maintainability of 99% during the optimal planned production time are needed for the maximum productivity of the line. Therefore, to achieve a monthly availability rate average that is higher or equal to 99% for the handling and manufacturing chain (Figure 2), indeed, for the manufacturing line: we take into account the line preparation time, the time necessary for a site meeting or sensitizing the work team to safety, the time of cleaning the line, the preventive maintenance time, and planned downtime for a break of fewer than 30 minutes during each working shift of 8 hours. We focus on a production spread over a duration of less than or equal to 7 hours as the planned production time.

Through a test carried out at the level of the manufacturing line, we obtained the following data:

(i) The time necessary for manufacturing 1 group of parts of type A is 12 minutes and 40 seconds (the time necessary for setting, indeed, to mobilize a part of type A on the handling and manufacturing chain

![Diagram](image-url)
from the entrance to the exit (Figure 3)). It is with a speed $V_1$ of the chain to ensure the plastic material takes for a part of type A.

(ii) The time necessary for manufacturing 1 group of parts of type B is 12 minutes and 40 seconds (the time necessary to mobilize a part of type B on the handling and manufacturing chain from the entrance to the exit). It is with a speed $V_2$ of the chain to ensure the plastic material takes for a part of type B.

**Questions** Based on the line’s monthly performance reports, the unplanned production time is a consequence and expression of the existing interference between the production and maintenance departments at the level of the factory’s manufacturing line (Figure 3). The unplanned production time fluctuates between 6 hours and 30 minutes and 6 hours and 52 minutes for each working shift of 8 hours. It was a major common cause behind the productivity deviation of the manufacturing line from its manufacturing objectives for the two types of plastic parts before and during the months of August, September, and October 2021. Therefore, to act on the bottleneck element of the manufacturing line, which is the handling and manufacturing chain, some key questions need to be addressed:

(i) What are the quantities to be manufactured for the two types of plastic parts to maximize the productivity of the factory line and the profit given the maintenance function objectives and constraints?

(ii) Is the fixed manufacturing objective for each shift an optimal productivity-related objective for the manufacturing line teams? If not, what is the optimal challenging and achievable manufacturing objective to establish for the manufacturing line that does not impact the efficient maintenance objectives fixed by the maintenance department? The fixed manufacturing objective for each shift of 8 hours during and before the months August, September, and October 2021 was 5488 plastic parts of types A and B, which is equal to 60,98 carts of both types A and B.

3.2. **Mathematical Programming.** The approach to address the formulated problem (Section 3.1) is described as follows:

(i) Problem modeling by a linear mathematical program with integer variables to maximize the quantities of parts to be manufactured in the workshop (Section 3.2.1).

(ii) Solving the mathematical problem (or program) of maximizing the so-called “objective or economic function” under a set of constraints to be extracted from the problem (Section 3.2.2).

### 3.2.1. Modelling the Manufacturing Maximization Problem of the Line’s Chain.

In the handling and manufacturing chain of molds, let $x_1$ and $x_2$ be the main variables of the problem, where:

(i) $x_1$: number of groups of parts of type A.

(ii) $x_2$: number of groups of parts of type B.

Regarding the time, there are:

(i) The time necessary for manufacturing each group of parts (type A and type B) is 12 minutes 40 seconds = 760 seconds. It is the time necessary for the setting of plastic, indeed, to mobilize each part of type A and type B on the handling and manufacturing chain from the entrance to the exit (Figure 3).

(ii) Focus on a production spread over a duration of less than or equal to 7 hours = 25200 as a planned production time (not optimal). We must consider the line preparation time, the time necessary for a site meeting or sensitizing the work team to safety, the time of cleaning the line, the preventive maintenance time, and planned downtime for a break of fewer than 30 minutes, during each working shift of 8 hours.

Profit$_1$ and Profit$_2$ will be gained from the manufacturing of the two groups of plastic parts, Group A and Group B, respectively. Since these profits will not influence the values of $x_1$ and $x_2$, we estimated that Profit$_1 = 380$ USD and Profit$_2 = 300$ USD to model the problem using LMP.

The mathematical model of the problem is the following Linear Program (P):

$$\begin{align*}
\text{Max } z &= 380 \times x_1 + 300 \times x_2 \text{ (objective or economic function)}, \\
\text{Subject to,} \\
(P) \quad & 760 \times x_1 + 760 \times x_2 \leq 25000 \text{ (constraint of manufacturing time, inequality),} \\
& x_1 - x_2 = 0 \text{ (constraint of equality of groups of parts to manufacture),} \\
& x_1, x_2 \in \mathbb{N}_0 \text{ (constraint of integrity).}
\end{align*}$$

### 3.2.2. Solving the Manufacturing Maximization Model (Linear Mathematical Program) of the Line’s Chain.

The mathematical model obtained (Section 3.2.1) is constituted from an inequality constraint and an equality constraint.
Therefore, the two-phase Simplex method is used to solve the problem.

3.3. Phase I. By adding a deviation variable to the inequality constraint of the mathematical model (Section 3.2.1), we obtained the following continuous linear problem (CLP):

\[
\begin{align*}
\text{(P or CLP)} & \quad \text{Max } z = 380 \cdot x_1 + 300 \\
& \quad \text{subject to,} \\
& \quad 760 \cdot x_1 + 760 \cdot x_2 + x_3 = 25000, \\
& \quad x_1 - x_2 = 0, \\
& \quad x_1, x_2, x_3 \in \mathbb{R}.
\end{align*}
\]

(2)

where "\(x_2\)" is a deviation variable allowing to transform the inequality constraint (1st constraint) into an equality constraint in the above mathematical program.

By adding an artificial variable "\(t\)" to the equality constraint (2nd constraint), we obtained the following mathematical program:

\[
\begin{align*}
\text{(p + 1)} & \quad \text{Max } z = 380 \cdot x_1 + 300 \\
& \quad \text{subject to,} \\
& \quad 760 \cdot x_1 + 760 \cdot x_2 + x_3 = 25000, \\
& \quad x_1 - x_2 + t = 0, \\
& \quad x_1, x_2, x_3 \in \mathbb{R}.
\end{align*}
\]

(3)

By the modification of the objective function, the continuous linear problem (CLP) takes the form of the augmented problem called (Pa):

\[
\begin{align*}
\text{(pa)} & \quad \text{Max } za = t \text{ (modified objective or economic function),} \\
& \quad \text{subject to,} \\
& \quad 760 \cdot x_1 + 760 \cdot x_2 + x_3 = 25000, \\
& \quad x_1, x_2, x_3 \in \mathbb{R}.
\end{align*}
\]

(4)

Table 1: The initial Simplex table.

<table>
<thead>
<tr>
<th>Basic variables</th>
<th>(x_1)</th>
<th>(x_2)</th>
<th>(x_3)</th>
<th>(t)</th>
<th>(Z_a)</th>
<th>Right-hand side ((B_i))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x_1)</td>
<td>760</td>
<td>760</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>25200</td>
</tr>
<tr>
<td>(T)</td>
<td>1</td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(Z_a)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Thus, in Table 2, the artificial variable "\(t\)" must leave the base. By changing the base, we obtained Table 3 as the new Simplex table, where all relative (or marginal) costs \(C_1\), \(C_2\), and \(C_3\) are negative or zero (they are zero in this case); this solution is optimal (optimal basic solution) for the problem (Pa), with an optimal solution equal to \(0 = Z_a - Z^\ast\). This solution constitutes an optimal basic solution to the problem (P). This ends phase I and will allow us to build an initial Simplex table of (P) to start phase II (Table 4).

3.4. Phase II (Simplex Algorithm). To start this phase, the column associated with the artificial variable "\(t\)" (Table 3) is deleted to obtain a feasible solution to our problem (P). Before starting the 1st iteration of phase II, it will be necessary to replace the coefficients of the objective function \(Z_a\) (Table 3) with those of the original function "\(z\)." Then replace the relative costs as presented in Table 4, which illustrates the canonical form of problem (P).

3.5. 1st Iteration. In Table 4, \(C_1 = 380 > 0\) is the largest relative cost. Therefore, the variable \(x_1\) must enter the base. Furthermore, by applying the rule of smallest ratio, we obtained:

\[
\min \left\{ \frac{Bi}{A_{ij}} : A_{ij} > 0 \right\} = \min \left\{ \frac{25200}{1520} \right\} = \frac{25200}{1520}.
\]

(5)

Therefore, the variable \(x_1\) in Table 4 will leave the base to obtain Table 5 as the new Simplex table.

3.6. 2nd Iteration. In Table 5, \(C_2 = 300 > 0\) is the largest relative cost. Therefore, the variable \(x_2\) must enter the base. By applying the rule of smallest ratio:

\[
\min \left\{ \frac{Bi}{A_{ij}} : A_{ij} > 0 \right\} = \min \left\{ \frac{315}{19} \right\} = \frac{315}{19}.
\]

(6)

For that, the variable \(x_2\) in Table 5 must leave the base to obtain Table 6, where all relative or marginal costs (\(C_1\), \(C_2\), and \(C_3\)) are negative or zero (they are zero in this case).
can then say that this solution is optimal. The solution to the mathematical problem (P) is the following:

\[ (\text{CLP} - \text{Chain of the manufacturing line} - \text{plastic parts}) = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 315/19 \\ 315/19 \end{bmatrix}, \]  
(7)

4. Discussion and Results

4.1. Treatment of the Mathematical Programming Results.

The linear mathematical problem (or continuous linear problem) results that are productivity maximization model results for the bottleneck element, and the handling and manufacturing chain, within the manufacturing line of plastic parts of types A and B, are described below.

(i) The line can manufacture \( x_1 = x_2 = 315/19 = 16.58 \) groups/shift (where \( x_1 \) and \( x_2 \) are, respectively, the numbers of groups to be manufactured in type A and type B), where:

(i) One group of type A contains 200 parts.
(ii) One group of type B contains 145 parts.

Given that integer values are needed for the number of groups of parts to be manufactured on the manufacturing line’s chain, we can obtain \( x_1 = x_2 = 16 \) groups of plastic parts/shift using the branch and bound method.

(ii) To obtain integer values, the solver tool in Microsoft Excel was used.

(iii) The estimated profit at the maximization of productivity of the line (or the optimal value of the profit) is equal to \( 380 \times 16 + 300 \times 16 = 10880 \) USD/shift.

(iv) The constraint of permissible time for an optimal (maximal) productivity of the line for both types of plastic parts is impacted by:

(i) The need for a break of 30 minutes or less per shift.
(ii) The efficient maintenance function requires planned maintenance and autonomous maintenance during every single working shift of 8 hours per day (24 hours) to prepare the normal operating conditions of the line (including the cleaning time and inspection time of the manufacturing process, in addition to the time necessary for tests, modifications, site meetings,

---

Table 3: The final Simplex table in phase 1.

<table>
<thead>
<tr>
<th>Basic variables</th>
<th>( x_1 )</th>
<th>( x_2 )</th>
<th>( x_3 )</th>
<th>( t )</th>
<th>( Z_a )</th>
<th>Right-hand side (( B_i ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_1 )</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1520</td>
<td>0</td>
</tr>
<tr>
<td>( L_2 )</td>
<td>-</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>25200</td>
</tr>
<tr>
<td>( L_3 )</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>315/19</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4: The canonical form of problem (P).

<table>
<thead>
<tr>
<th>Basic variables</th>
<th>( x_1 )</th>
<th>( x_2 )</th>
<th>( x_3 )</th>
<th>( z )</th>
<th>Right-hand side (( B_i ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_1 )</td>
<td>1</td>
<td>0</td>
<td>1/1520</td>
<td>0</td>
<td>315/19</td>
</tr>
<tr>
<td>( L_2 )</td>
<td>0</td>
<td>1</td>
<td>1/1520</td>
<td>0</td>
<td>315/19</td>
</tr>
<tr>
<td>( L_3 )</td>
<td>0</td>
<td>300</td>
<td>-1/4</td>
<td>1</td>
<td>= 6300 (given it is a maximization problem)</td>
</tr>
</tbody>
</table>

Table 5: New Simplex table with \( x_1 \) as a new basic variable that replaces \( x_3 \).

<table>
<thead>
<tr>
<th>Basic variables</th>
<th>( x_1 )</th>
<th>( x_2 )</th>
<th>( x_3 )</th>
<th>( z )</th>
<th>Right-hand side (( B_i ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_1 )</td>
<td>1</td>
<td>0</td>
<td>1/1520</td>
<td>0</td>
<td>315/19</td>
</tr>
<tr>
<td>( L_2 )</td>
<td>0</td>
<td>1</td>
<td>1/1520</td>
<td>0</td>
<td>315/19</td>
</tr>
<tr>
<td>( L_3 )</td>
<td>0</td>
<td>300</td>
<td>-1/4</td>
<td>1</td>
<td>= 6300 (given it is a maximization problem)</td>
</tr>
</tbody>
</table>

Table 6: Table of the optimal solution to problem (P).

<table>
<thead>
<tr>
<th>Basic variables</th>
<th>( x_1 )</th>
<th>( x_2 )</th>
<th>( x_3 )</th>
<th>( z )</th>
<th>Right-hand side (( B_i ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_1 )</td>
<td>1</td>
<td>0</td>
<td>1/1520</td>
<td>0</td>
<td>315/19</td>
</tr>
<tr>
<td>( L_2 )</td>
<td>0</td>
<td>1</td>
<td>1/1520</td>
<td>0</td>
<td>315/19</td>
</tr>
<tr>
<td>( L_3 )</td>
<td>0</td>
<td>0</td>
<td>-17/38</td>
<td>1</td>
<td>6300 + 315/19 = 11273, 68421 USD (given it is a maximization problem)</td>
</tr>
</tbody>
</table>
and sensibilizations to occupational safety, etc.). The efficient maintenance function is considered within the framework of a systems approach of the optimization of the productivity, maintenance, quality, safety, and sustainability, in fact in the perimeter of an evolved Total Productive Maintenance project, i.e., Sustainable Total Productive Maintenance [39] applied to the manufacturing line making the subject of this study.

(iii) Expectations (or objectives) of the high-performance or efficient maintenance function: manufacturing line availability rate \( \geq 97\% \) and maintainability of 99\% during the optimal planned production time for the maximum productivity of the line in general and its handling and manufacturing chain particularly, for achieving a monthly availability rate average that must be higher or equal to 99\% for the manufacturing line (Figure 2).

We found as a result of solving the optimization problem, that in the 1st constraint of problem (P): 
\[
760 \times x_1 + 760 \times x_2 \leq 7 \text{ hours (25200 seconds),}
\]
through replacing \( x_1 \) and \( x_2 \) by their integer values making the set of optimal solutions of the LMP obtained: 
\[
760 \times 16 + 760 \times 16 = 24320 \text{ seconds (6 hours 46 minutes) \leq 25200 seconds (7 hours).}
\]
We can then maximize the profit to be obtained from manufacturing the types A and B plastic parts. Furthermore, we can maximize the productivity of the line during a planned production time of 6 hours 46 minutes, through a team of operators and with the same resources available in the line.

4.2. Mathematical Programming Results-Based Decision-Making. During the normal operation time of the studied manufacturing line, the daily manufacturing rate constantly fluctuated between 59,01 and 60,98 carts of parts of types A and B per shift (Figure 4); during unplanned production time that can exceed 6 hours 46 minutes/shift (Figure 5).

Based on the manufacturing line’s bottleneck productivity optimization problem results (Section 4.1), from November 2021 onwards, a total of 3200 + 2320 = 5520 parts (type A + type B) must be produced during each shift (8 hours). This requires producing:

(i) An optimal quantity of plastic parts of type A that is equal to \( x_1 \times 200 = 16 \times 200 = 3200 \text{ parts/shift.} \)

(ii) An optimal quantity of plastic parts of type B that is equal to \( x_2 \times 145 = 16 \times 145 = 2320 \text{ parts/shift.} \)

In terms of the number of carts of parts to produce and to be set as a target to be reached in a duration of 6 hours 46 minutes of work of a team within the line: 5520/90 = 61.33 carts of parts = 61 carts and 30 parts of types A and B per shift (per 8 hours).

Furthermore, this new manufacturing objective to be implemented from November 2021 is based on a planned production time of 6 hours and 46 minutes for each shift. That is a decision to raise the manufacturing objective from 5488 plastic parts before November 2021 to 5520 plastic parts/shift from November 2021 onwards (Figure 4).

4.3. Assessment of the Feasibility of the Decision Made during November 2021. The results indicate that the objective of manufacturing 5488 plastic parts of types A and B per shift of 8 hours was not an optimal productivity-related objective. Previously, we summarized the decision of increasing the manufacturing objective for the teams that work on the handling and manufacturing chain (Figure 3) while considering a planned production time of 6 hours and 46 minutes per shift, a manufacturing line availability rate \( \geq 97\% \), and maintainability of 99\% during that optimal planned production time, for reaching a monthly availability rate average \( \geq 99\% \) for the manufacturing line.

To confirm that the recommended manufacturing objective for the manufacturing line teams to be implemented from November 2021 onwards does not impact the efficient maintenance objectives fixed by the maintenance department of the factory and is an achievable manufacturing objective, we assessed its feasibility during November 2021.

To do so, based on the monthly performance report of November 2021, we were able to analyze and synthesize the manufacturing line data. Figures 6 and 7 illustrate the daily mean manufacturing rates compared to the new fixed manufacturing objective during November 2021 and the handling and manufacturing chain availability rates during the optimal planned production time over the same month, respectively. According to Figure 5, by eliminating the major common cause of deviation of the manufacturing line from its objectives in terms of productivity and adhering to a planned production time of 6 hours and 46 minutes, the following were observed:

(i) Significant improvement of the manufacturing line productivity: despite raising the manufacturing target from 5488 to 5520 plastic parts of types A and B/shift, during November 2021, there are only three deviations for the manufacturing line teams from the new daily manufacturing objective, notably on the 11th, 19th, and 26th of the month (Figure 6). These deviations were all due to special causes, particularly breakdowns. No common cause of deviation from the new manufacturing objective occurred during that period (Figures 6 and 7). In contrast, there were 29 deviations from the former manufacturing objective (i.e., 5488 plastic parts/shift) in August, 28 deviations in September, and 29 deviations in October 2021. Of these deviations, 93.10\% during August, 89.28\% in September, and 86.20\% in October 2021 were caused by unplanned production time.

(ii) Financial benefits are derived from the new manufacturing objective: 10880 USD/shift is the objective related to producing 5520 plastic parts/shift as a new manufacturing objective, except for the 11th, 19th, and 26th of November 2021, where only special causes took place and without
significantly impacting the manufacturing line dependability (availability in particular) (Figure 7). The monthly average of daily mean manufacturing rates for November 2021 is equal to 5507 plastic parts (Figure 6), but it is equal to 5407 parts for August, 5409 parts for September, and 5402 parts for October (Figure 4), which involved benefits of 10855 USD/shift for November higher than 10657 USD/shift for August, 10661 USD/shift for September, and 10647 USD/shift for October.

(iii) Feasibility of mathematical programming (as a tool of the systems theory)-based decision to raise the daily manufacturing objective: the maintenance department’s objectives are achieved over November 2021 (Figure 7). There is a synchronization of achievement of objectives between the factory’s production and maintenance departments. During November, the manufacturing line achieved 99.77% of the new monthly manufacturing objective (Figure 6), in parallel with having a 99.75% monthly availability average which is higher than the 99% monthly availability set by the maintenance department. Furthermore, the handling and manufacturing chain’s daily mean availability rates were always higher than 97% as a minimum objective (Figure 7).

5. Conclusion and Future Research

The paper uses a case study to demonstrate that systems theory is an enabler of evidence-based decision-making for engineering an optimal production. Moreover, systems
theory, as an environment for mathematical programming, allows preventive maintenance for the manufacturing line to be correctly carried out within an optimal amount of time. It is also evident that the production department does not have to interfere with maintenance by eliminating the major common cause, such as unplanned production time/shift. Systems theory has played an arbitration role between production as a company’s operational process and the maintenance as a support process. Utilizing systems approach and its systems theory tools can provide evidence-based decision-making to resolve the conflict between production and maintenance departments.

The issue of increasing productivity using a systems approach transcends the field of the aeronautics industry. Other industries (e.g., chemical industry, building and public works, and energy) can benefit by using the same concept of increasing productivity using a systems approach [40]. Therefore, the suggested planned production time can be used to arbitrate between optimal production and efficient maintenance in other scenarios. Moreover, the concept of arbitrating between optimal production and efficient maintenance can be considered in company philosophy and in the system approach to total productive maintenance. A future work is the development of an innovative maintenance method called the structural systemic method for treating the impact of a part failure on the other neighboring parts on the same mechanical subset. The structural systemic method is an application of systems approach to the structure of equipment to improve performance and productivity as well as dependability of its surrounding production environment.

Data Availability

The data used to support the study are included within the article.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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