Journal of Mechanical Engineering and Manufacturing
https://www.sciltp.com/journals/jmem

Article

Using Systematic Layout Planning together with Analytic Hierarchy Process to Define a New Industrial Layout in the Automotive Industry: A Novel Approach

Rodrigo Lopes [1], Arnaldo G. Pinto [1], Isabel M. Pinto [1,2,*], Maria Teresa Pereira [1,3], Alexandra Gavina [1,2], Isabel Figueiredo [1,2] and Ana Júlia Viamonte [1,2]

1 CIDEM, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249-015 Porto, Portugal
2 LEMA, ISEP, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 4249-015 Porto, Portugal
3 LAETA-INEGI, Associate Laboratory for Energy, Transports and Aerospace, Rua Dr. Roberto Frias 400, 4200-465 Porto, Portugal
* Correspondence: irm@isep.ipp.pt; Tel.: +351-22-83-40-500

How To Cite: Lopes, R.; Pinto, A.G.; Pinto, I.M.; et al. Using Systematic Layout Planning together with Analytic Hierarchy Process to Define a New Industrial Layout in the Automotive Industry: A Novel Approach. *Journal of Mechanical Engineering and Manufacturing* **2026**, *2*(1), 6. https://doi.org/10.53941/jmem.2026.100006

Received: 14 September 2025
Revised: 22 October 2025
Accepted: 30 October 2025
Published: 6 January 2026

Abstract: The automotive sector is marked by intense competition, technological innovation, and a continuous need to improve efficiency, cut costs, and ensure responsible operations. In this scenario, industrial layout planning plays a crucial role, as it directly affects internal motion, logistical efficiency, and the ability to adjust to new challenges. This work addresses the requirement for an organization to create a new production area to meet its strategic growth demands. The research incorporated the Systematic Layout Planning (SLP) approach to formulate layout options and the Analytic Hierarchy Process (AHP) to assist in multi-criteria decision-making, taking into account factors such as operational efficiency, adaptability, safety, and sustainability. The data collected demonstrates the effectiveness of using SLP and AHP together as an organized approach to aid strategic decisions in the industrial sector. In addition to providing concrete answers to the company used to validate this approach, this study strengthens the scientific basis that proves that these tools, when used together, form a reliable framework for improving factory layouts in the automotive industry. The novelty of this paper lies in the hybrid application of Lean philosophy and its methods, combined with SLP and the AHP. By applying Lean principles, namely reducing possible waste to each alternative prior to the SLP and AHP comparative analysis across criteria, the approach yields more targeted and impactful results aligned with the main goals of any company. This contribution is especially significant because, unlike most research that focuses on changing existing layouts, the methodologies were successfully implemented in this case in the planning of a new automotive components production unit from the outset, filling an important gap in the literature and highlighting the relevance of economic and environmental sustainability.

Keywords: automotive industry; layout optimization; sustainability; systematic layout planning; analytic hierarchy process; manufacturing planning; industrial engineering

1. Introduction

The automotive industry is one of the most strategic and challenging sectors of the global economy, characterized by intense competition and constant demands for productivity, flexibility, and sustainability. The integration of Industry 4.0 technologies, the digitization of production systems, and growing environmental pressure require automotive organizations to reevaluate their management models and manufacturing structures [1,2]. In this scenario, factory layout planning is a critical factor, as a functional arrangement of resources can significantly reduce internal handling costs, reduce motion, minimize cycle times, and optimize space utilization [3,4]. Recent studies indicate that the adoption of optimized layouts can result in reductions of more than 20% in handling costs and substantial improvements in productivity [5,6].

The Systematic Layout Planning (SLP) methodology, developed by Muther and Hales [3], is widely used to generate structured layout alternatives based on the analysis of material flows, proximity relationships, and spatial constraints [3]. SLP integrates qualitative and quantitative criteria to develop efficient, safe, and adaptable facility layouts that support productivity and continuous improvement. It aims to enhance material flow, minimize handling time, and reduce production costs through the strategic placement of interrelated areas. The method consists of three main phases: Analysis, Search, and Selection. The Analysis phase examines product flows and operational relationships, resulting in a relationship diagram that classifies proximity needs using the semantic scale coded as A, E, I, O, U, and X, to denote degrees of closeness between layouts departments—from "Absolutely necessary" (A) to "Undesirable" (X), often accompanied by numerical reasons for proximity, applied throughout a relationship alternatives matrix. The Search phase identifies layout constraints and explores feasible alternatives that balance efficiency and practicality. Finally, the Selection phase evaluates the alternatives based on flexibility, space utilization, safety, and cost-effectiveness.

To support the selection of the best solution, the Analytic Hierarchy Process (AHP), developed by Saaty [7,8], is one of the most widely applied multicriteria decision-making (MCDM) methods, particularly effective for problems involving subjective judgments, which allows for the weighting of multiple quantitative and qualitative criteria, such as cost, flexibility, or safety [9]. The AHP structures decision problems into a hierarchical model consisting of a goal at the top, followed by decision criteria, and the available alternatives at the bottom. The method relies on pairwise comparisons between criteria and alternatives, using Saaty's 1–9 semantic scale to express relative importance to the goal, meaning 1—equal importance, 3—moderate importance, 5—strong importance, 7—very strong importance, and 9—extreme importance, being the 2, 4, 6, 8 the intermediate values between the above judgments. The comparisons produce priority vectors and consistency ratios that ensure logical coherence in the decision-making process. The priority weights are derived through the computation of eigenvalues and eigenvectors, quantifying the relative influence of each element. A Consistency Ratio (CR) below 0.10 indicates reliable judgments. Although these calculations can be performed manually, specialized software such as RStudio facilitates efficient and accurate analysis in complex decision-making scenarios.

The AHP uses pairwise comparison matrices to assign relative importance among criteria. Each element a_{ij} of the matrix represents the importance of criterion C_i compared to criterion C_{ij}, with reciprocal values $a_{ji} = \frac{1}{a_{ij}}$. After constructing the comparison matrix, normalization is performed by dividing each element by the sum of its column. The weight of each criterion is then obtained through the priority vector λ, calculated as the arithmetic mean of the normalized values [7]. To ensure logical coherence, a Consistency Index (CI) is computed based on the maximum eigenvalue λ_{max} of the comparison matrix: $CI = \frac{\lambda_{max} - n}{n-1}$, where n number of compared alternatives. The Consistency Ratio (CR) assesses whether judgments are acceptable: $CR = \frac{CI}{RI}$. Here, RI is the Random Consistency Index proposed by Saaty [7]. The matrix is considered consistent if $CR < 0.10$.

The integration between SLP and AHP supported by Lean Principles in increasing the economic and environmental sustainability has demonstrated theoretical robustness and practical application, with gains in layout selection efficiency of up to 30% compared to traditional methods [9,10]. In the literature, several practical cases with concrete quantitative impacts stand out, which are fundamental for future comparison, such as: A study by Qamar et al. [11] at a light vehicle manufacturer in Jordan presented a model with five layout alternatives generated via SLP and evaluated by AHP, revealing a significant reduction in the total distance traveled by materials, with a consistency matrix of 6.918%; A study in micro and small industries (MSME) reported that the use of SLP reduced material handling costs by 67.8% and daily handling time by 69.19% [12]; A comparative investigation between SLP, Automated Layout Design Program (ALDEP), and Computerized Relationship Layout Planning (CORELAP) concluded that the ideal layout via SLP reduced the distance traveled by parts daily by 32.68% [13]; A study of the restructuring of a glass factory using SLP combined with simulation (Discrete Event Simulation (DES)) resulted in an average reduction of 52% in the distance traveled by operators, increased material flow efficiency, and a relative efficiency of 90% in the selected layout [14]; In a generic industrial context, the application of SLP increased the layout efficiency of a company from 96.7% to 98.5% [15]; Furthermore, a study applying SLP to a loudspeaker industry managed to reduce handling costs by 11.63% [16]; A study in a furniture factory used different layout modeling techniques (Graph Theory, CRAFT, Genetic Algorithm, etc.) and compared alternatives via AHP. The final layout reduced handling costs and increased flow efficiency [17]; An integrated methodology of AHP with nonlinear programming (NLP) was proposed and applied to a real case, allowing quantitative and qualitative criteria, such as costs, distances, and flexibility, to be considered simultaneously [18]; A study on the optimization of an automotive air conditioning component production line, based on Standard Work and Lean Thinking, increased the average OEE by 16%, from 70% to 86% [19]; The application of Lean tools (PDCA, 5S, 5W2H) in a trimmings factory resulted in a 10% increase in available working time per operator, demonstrating an impact on sectors supplying the automotive industry [20]; A case study at a bus manufacturer showed that reorganizing the layout and applying Lean tools reduced picking time by about 75 min per cycle and decreased operator turnover by 50% [21]; A digital layout optimization tool with 3D simulation, considering ergonomics and human logistics flows, was successfully tested in a real industrial case, reducing implementation times and improving logistics routes [22]; A mathematical model applied to the automotive industry has proven effective in creating hybrid layouts, reconciling distance minimization and resource utilization maximization, with computational results obtained in seconds [23]; A study in an automotive assembly environment designed a collaborative cell layout with an industrial robot, through detailed risk analysis, ensuring both safety and productivity [24]; A mathematical model applied to a just-in-time (JIT) retail warehouse in Portugal reduced the distance traveled by more than 2000 km/month simply by reallocating internal locations [25]; A study on the optimization of a three-dimensional picking warehouse proposed a mathematical model to determine aisle depth, number of storage levels, and lateral and longitudinal width. The results showed that the appropriate choice of these parameters significantly reduced handling and space costs, allowing optimal solutions to be found in terms of total cost for different demand scenarios and operating costs [26].

Despite these promising results, there is a substantial gap in literature: most studies focus on reconfigurations of existing layouts or simulations, with few applying both SLP and AHP in new manufacturing plants in the automotive sector, especially in real-world contexts of facility construction from the initial planning stage.

Moreover, the above-referred methodologies can be deeply supported by Lean tools, reducing the waste in intralogistics operations, as previously reported [19–21], increasing by this way the economic and environmental sustainability. However, depending on the specific needs and complexity of each case, the Lean tools need to be selected and applied in a judicious way.

In this context, the work carried out is particularly important, as it addresses in an integrated manner a real challenge of manufacturing expansion in companies integrated in the automotive sector. Unlike many studies focused on reconfiguring existing layouts, this study deals with the definition of a production unit from its conception, which involves long-term decisions with a direct impact on the company's sustainability, flexibility, and competitiveness. By combining SLP with the AHP, this study not only allows for the structuring of optimized layout alternatives based on objective criteria but also provides a decision-making process based on multiple qualitative and quantitative criteria, involving aspects such as safety, expansion capacity, logistics costs, and energy efficiency. In addition to its applied contribution, the proposed model is also scientifically relevant, as it provides empirical evidence comparable to previous studies and reinforces the applicability of these methodologies in complex industrial contexts, such as the automotive industry, which is characterized by high demands for rigor, technological integration, and competitive pressure.

The novelty of this paper lies in the hybrid application of Lean principles directly related to economic and environmental sustainability, and its methods, combined with SLP and the AHP. By applying Lean principles to each alternative prior to the SLP and AHP comparative analysis across criteria, the approach yields more targeted and impactful results aligned with the company's objectives. Therefore, this study aims to create and structure a management model for the new manufacturing unit, applying SLP to generate layout alternatives that minimize internal distances and logistics costs and maximize space and flexibility. These alternatives are then evaluated using AHP, considering quantitative criteria (cost, distance, space usage) and qualitative criteria (flexibility, safety, sustainability). The main factors taken into consideration to pursue the mains goals of this work are: Flow, Flexibility and Costs, as explained ahead.

This article is organized as follows: after the introduction, the methodology of the work is presented, where the specific problem is introduced and the strategy for solving the problem is defined, establishing the initial data. Next, in the results chapter, it is described how the strategy was implemented and the new results obtained, in the discussion, the results obtained are compared with other solutions mentioned in the literature. Finally, in conclusion, the improvements achieved, their alignment with the objectives, the novelty of the methodology used, and how the application of the methodology can be generalized are highlighted.

2. Methodology

For a new manufacturing unit to be successfully implemented and for a company to make the most of the new layout, it is necessary to consider the methodology that will be used and the steps that need to be followed. It was necessary to outline what would need to be done to achieve this goal, as described in Table 1.

Table 1. Different steps for the Methodology.

Step No	Step Description
1	Review of Lean methodologies applied to flow optimization
2	Review of tools applied to the creation of industrial layouts
3	Analysis of manufacturing processes associated with products manufactured by each company
4	Analysis of the available industrial, manufacturing and storage areas, ceiling heights, interconnections, infrastructures available and needed, handling and storage equipment requirements. Compare alternative design solutions with their initial layouts within each company
5	Analysis of inventory management policy and material flows for each alternative
6	Study, selection, discussion, and simulation of layout alternatives for a new manufacturing facility based on relevant criteria to achieve the previously defined goals
7	Development of the selected layout
8	Monitoring the equipment transfer operation
9	Analysis of the economic impact of the implementation of the new manufacturing facility
10	Future proposals to be implemented in each case

All these steps are directly or indirectly important for achieving results, starting with the review of Lean practices, an approach that allows companies to reduce costs, increase efficiency, reduce execution times, reduce all types of waste, and maintain low inventory levels. All these factors contribute to customer satisfaction and, consequently, increased profit margins for the organization [27].

Moving on now to the definition of layouts, a layout consists of the organized spatial dispersion of various elements that make up a value creation system, composed of various processes and functions, in a given finite three-dimensional space, in which certain elements flow, such as equipment, materials, people, information, security, and communication. The study of layout is extremely important, as it ensures the right choice to streamline the process [28]. The layout arrangement is known to have a significant impact on production costs, Work in Progress (WIP) levels, lead time, and productivity. An appropriate layout contributes to the overall efficiency of operations. Therefore, the structure of a layout influences the performance and operational competitiveness of an organization [21]. One tool used to aid in layout decisions is SLP, which is used to organize the layout, locating high-frequency areas and logical relationships close to each other. The process allows the flow of material needed for product manufacturing to be carried out more quickly, at lower cost, and with less processing/handling [3]. The SLP was implemented based on Figure 1.

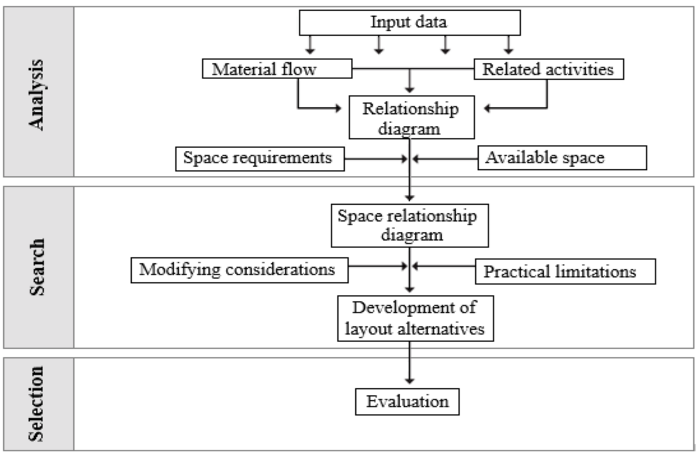
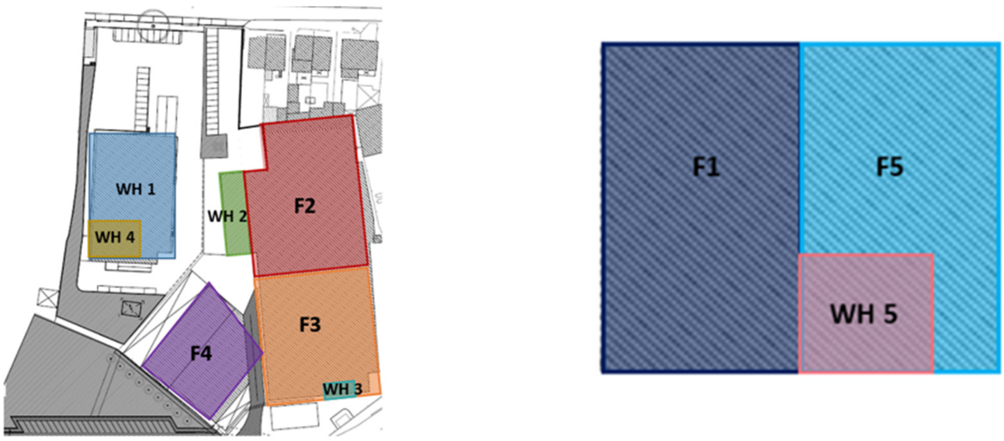


Figure 1. SPL implementation phases.

It is also extremely important to use decision support tools, particularly in problems involving subjective assessments, such are the Multicriteria Decision Aid methods (MCDA) [7]. The choice in this case, was the AHP method, one of the multi-criteria decision support tools with the highest number of practical applications reported in the literature due to existing software leading the users on the method implementation, its improvements, such as the consistency index to overpass its drawbacks, as compensatory method, related to others existing non-compensatory well-known methods such as the Preference Ranking Method for Enrichment Evaluation (PROMETHEE) family, Elimination and Choice Translating Reality for Enrichment Evaluation (ELCTRE) family, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), as well hybrid methodologies combining methods to overpass the drawbacks of each one [29]. The problems addressed by MCDA methods are typically those of selecting and evaluating alternatives [7].

The first phase to implement the methodology is to analyze the company's current layout, identify areas for improvement, materials flows. All related processes were analized and Lean principles coupled to economic and environmental sustainability, applied to increase their performance considering relevant issues and, understand the motivations, objectives, and decision-making criteria that were considered for the layout of the new manufacturing unit, as well as the restructuring of existing ones and imposed constraints. An increase in the space allocated to product manufacturing is necessary, as well as the space available for material storage, due to the usual company's production growth. In the case taken as a case study to validate this work, the company under study has two sectors, located about 1 km apart from each other. Sector 1 contains three production areas and three warehouses, while sector 2 contains two production areas and one warehouse. In sector 1, there are three distinct modules, called F2, F3, and F4, and their respective warehouse areas are also subdivided. Sector 2 is divided into two distinct modules, F1 and F5, and contains a warehouse area. It is possible to see these divisions in Figure 2. In addition to these two sectors, the company has three more rented warehouse areas, which are used to store obsolete lines and equipment, maintenance materials, among others. These areas are located about 3 km from sector 1.



(**a**) (**b**)

Figure 2. Subdivisions of sector 1 (**a**) and sector 2 (**b**).

The description of the company's manufacturing areas is shown in Table 2.

Table 2. Description of the company's manufacturing areas.

Module/Warehouse	Description	Area (m^2)
F1	Spiral manufacturing	2500
F2	Manufacture of a large series of control cables with plastic overmolding	2415
F3	Manufacture of a large series of control cables	2406
F4	Manufacture of comfort systems	1916
F5	Manufacture of a small series of control cables and comfort systems	1700
WH1	Shipping warehouse	1200
WH2	Component warehouse (e.g., spiral terminals, dust covers, grommets, etc.)	400
WH3	Spiral warehouse	60
WH4	Packaging warehouse	685
WH5	Raw material warehouse (e.g., wire coils, cable coils, PL, etc.)	800

https://doi.org/10.53941/jmem.2026.100006

Currently, all these modules and storage areas are interconnected; none are autonomous. According to the SLP method, the analysis phase is followed by the research phase and then the selection phase. One solution for the company is to build a new factory building. The main objective of integrating this new area is to restructure and organize the current operating method of the processes. Faced with the demand for expansion of the manufacturing space, it was decided to construct a new building near sector 1 in order to shorten the distances between production areas to reduce operational costs such as handling and materials movements, saving, as well the environment from excessive energy consumption and larger level of emissions. This strategy optimizes the flow of materials between modules and reduces the amount of equipment and labor required for material transport. As the construction space will be rented, the administration had to comply with the requirements imposed by the owner. Therefore, the owner outlined some features of the space, but always taking into account the needs of the company:

- Gross area of 8000 m^2;
- Support area of 2000 m^2 covering two floors;
- Gross area for production of 6000 m^2;
- Internal production area divided into four buildings measuring 25 m × 60 m;
- Each building is divided by pillars with a span of 5.2 m, totaling 50 pillars;
- Conveyor belts were placed along the pillars;
- Two docks located on one of the side facades, requiring an internal corridor of at least three meters; there is a structure to create a third dock, if necessary;
- Four crane bridges with transverse movement along each nave.

During the research phase, several layout alternatives were developed, but the company chose to analyze only three of them. For each alternative, a quantitative analysis of material flows between the different modules was performed, namely the number of trips performed, and distances traveled, as well as the amount of equipment to be transported under the proposed alternative. Finally, an analysis was performed to determine which areas would be available after the layout restructuring.

Alternative 1

This alternative involves the most significant restructuring of the modules and storage areas. The focus of this alternative was to analyze the impact of material flows, given that the new building will house a completely autonomous production unit, i.e., it will not need to be supplied by or supply the other modules or warehouse areas. The changes presented in relation to the current layout, see Figure 3, are as follows:

- Transfer of the F4 module to the new factory building, also grouping together all the SM lines that were scattered throughout the other modules;
- Creation of an autonomous production unit in module F4, integrating all the processes necessary for the manufacture of comfort systems, as well as storage areas for packaging, raw materials, and finished comfort systems products;
- Transfer the F1 module to sector 1 (where the F4 module was located), and close the location where it was located;
- Elimination of the spiral warehouse (WH3);
- Transfer of the raw materials warehouse (WH5) to sector 1, dividing it into two areas, one located in the new unit and the other in the shipping warehouse (WH1);
- Subdivision of the shipping warehouse (WH1) into three areas: raw materials, control cable shipping, and packaging;
- Transfer of the laboratory located in module F1 to the new building.

After describing the proposed future layout, it is necessary to quantitatively evaluate the same assumptions mentioned above in the description of the current layout:

- Types of equipment used for material transport and their respective transport capacities;
- Amount of material to be transported per day—this calculation was based on the sales budget for the next three years;
- Number of trips made per day/Distances traveled per day—there are no specific trips for returning materials and/or components (pallets, packaging, raw materials). Therefore, it was assumed that all transports are made with a full load; the values presented are rounded up;
- Number of logistics suppliers needed;
- Transport equipment needed.

Table 3 shows the distances, in meters, between the manufacturing modules and the material storage areas for the proposed layout.

(a) **(b)**

Figure 3. Layout alternative 1. Sector 1 (**a**) and sector 2 (**b**).

Table 3. Distance matrix, alternative 1 (in meters).

From/To	F1	F2	F3	F4	F5	WH1	WH2	WH3	WH4	WH5	WH6	WH7
F1	X	X	X	X	X	X	90	X	X	X	X	X
F2	X	X	50	X	X	X	10	X	X	X	X	X
F3	X	X	X	X	X	X	60	X	X	X	X	X
F4	X	X	X	X	X	X	X	X	X	X	X	50
F5	X	X	X	X	X	1200	X	X	X	X	X	X
WH1	X	X	X	X	X	X	X	X	X	X	X	X
WH2	90	10	60	X	1200	90	X	X	X	X	X	X
WH3	100	X	X	X	1200	X	90	X	X	X	X	X
WH4	X	X	X	X	1200	X	90	X	X	X	X	X
WH5	10	X	X	10	X	X	X	X	X	X	X	X
WH6	X	X	X	20	X	X	X	X	X	X	X	X
WH7	X	X	X	X	X	X	X	X	X	X	X	X

Next, considering the same assumptions and the same analysis structure used for the current situation, the quantities of material to be transported were evaluated, see Table 4.

Table 4. Pallet quantity matrix, per shift, alternative 1.

From/To	F1	F2	F3	F4	F5	WH1	WH2	WH3	WH4	WH5	WH6	WH7
F1	X	X	X	X	X	X	12	X	X	X	X	X
F2	X	X	1	X	X	X	16	X	X	X	X	X
F3	X	X	X	X	X	X	19	X	X	X	X	X
F4	X	X	X	X	X	X	X	X	X	X	X	88
F5	X	X	X	X	X	4	X	X	X	X	X	X
WH1	X	X	X	X	X	X	X	X	X	X	X	X
WH2	0.2	16	15	X	3	33	X	X	X	X	X	X
WH3	5	X	X	X	0.2	X	8	X	X	X	X	X
WH4	X	X	X	X	1	X	19.5	X	X	X	X	X
WH5	X	X	X	12	X	X	X	X	X	X	X	X
WH6	X	X	X	15	X	X	X	X	X	X	X	X
WH7	X	X	X	X	X	X	X	X	X	X	X	X

Considering the new manufacturing areas and maintaining the same number of shifts, 2.5 shifts per day. The results are shown in Table 5.

Table 5. Matrix of number of trips per day, alternative 1.

From/To	F1	F2	F3	F4	F5	WH1	WH2	WH3	WH4	WH5	WH6	WH7
F1	X	X	X	X	X	X	30	X	X	X	X	X
F2	X	X	3	X	X	X	40	X	X	X	X	X
F3	X	X	X	X	X	X	48	X	X	X	X	X
F4	X	X	X	X	X	X	X	X	X	X	X	220
F5	X	X	X	X	X	1	X	X	X	X	X	X
WH1	X	X	X	X	X	X	X	X	X	X	X	X
WH2	1	10	10	X	1	21	X	X	X	X	X	X
WH3	13	X	X	X	1	X	20	X	X	X	X	X
WH4	X	X	X	X	1	X	49	X	X	X	X	X
WH5	X	X	X	30	X	X	X	X	X	X	X	X
WH6	X	X	X	38	X	X	X	X	X	X	X	X
WH7	X	X	X	X	X	X	X	X	X	X	X	X

Following the previous analysis regarding the total distance traveled, the same calculation was made (Table 6) for the proposed situation, maintaining the same assumptions.

Table 6. Total distance matrix, alternative 1 (in meters).

From/To	F1	F2	F3	F4	F5	WH1	WH2	WH3	WH4	WH5	WH6	WH7
F1	X	X	X	X	X	X	2700	X	X	X	X	X
F2	X	X	150	X	X	X	400	X	X	X	X	X
F3	X	X	X	X	X	X	2880	X	X	X	X	X
F4	X	X	X	X	X	X	X	X	X	X	X	11,000
F5	X	X	X	X	X	1200	X	X	X	X	X	X
WH1	X	X	X	X	X	X	X	X	X	X	X	X
WH2	90	100	600	X	1200	1890	X	X	X	X	X	X
WH3	1300	X	X	X	1200	X	1800	X	X	X	X	X
WH4	X	X	X	X	1200	X	4410	X	X	X	X	X
WH5	X	X	X	300	X	X	X	X	X	X	X	X
WH6	X	X	X	760	X	X	X	X	X	X	X	X
WH7	X	X	X	X	X	X	X	X	X	X	X	X

In addition to this analysis, this proposal also analyzed the number of equipment transfers required under this alternative, as well as the areas that became available for the possible integration of new equipment. This alternative would involve the following equipment transfers:

- All equipment included in module F4—22 injection machines, 2 heat treatment furnaces, 33 wire cutting and forming machines;
- Three wire extruders that will be removed from module F1;
- Eleven automatic Suspension Mat manufacturing lines that are scattered throughout all modules;
- In addition to these transfers, there is the move from module F1 to the old module F4 building. This corresponds to the transfer of 67 pieces of equipment.

In this layout proposal, it would be necessary to move 138 pieces of equipment. Next, which areas would be available after these layout changes were analyzed, Table 7.

Alternative 2

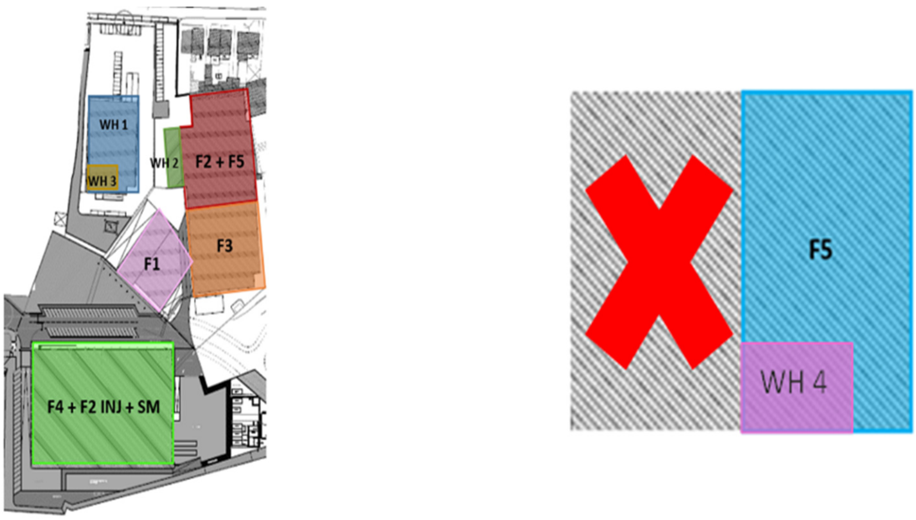
Alternative 2 is based on the concept of unifying the existing plastic injection modules, both in the F4 module and in the F2 module, Figure 4. This analysis was conducted to study the advantages of unifying this injection process and separating it from the F2 module assembly lines. This alternative addresses the following layout restructuring:

- Transfer of module F4 to the new factory building, also grouping together all SM lines that were scattered throughout the other modules;
- Transfer of the injection unit that was integrated into module F2, as well as all equipment that supplied this unit;
- Transfer of module F1 to sector 1 (where module F4 was located), and closure of the location where it was located;
- Elimination of the spiral warehouse (WH3);
- Transfer of some assembly lines from module F5 to module F2 (lines that depend on the plastic injection module);

- Return the component warehouse (WH2) to the interior of the F2 module building;
- Integrated, standardized, and centralized mold metalworking in the new building;
- Transfer the laboratory that was in F1 to the new building.

Table 7. Analysis of areas available for alternative 1.

Module/Warehouse	Available Area (m^2)	Justification
F1	50	Closure of the building located in sector 2. The module went from an area of 2500 m² to an area of 2000 m², but it was decided to remove some equipment from this module that was obsolete, had low production, or was transferred to other modules (extruders case).
F4	500	The F4 module was housed in a 2000 m² building, moving to a building with a production area of 6000 m², although this area also included production lines of other products (occupying around 1800 m², already taking into account the new equipment—4 lines), 3 extruders (occupying around 80 m^2), and a storage area (1200 m^2). The mold workshop was transferred along with the module and acquired an area of around 180 m^2. The remaining areas are distributed between corridor zones and intermediate product storage areas. The available space is intended for the integration of new cutting, forming, and heat treatment equipment, as well as other products' manufacturing lines.
F5	900	With the relocation of the raw materials warehouse to sector 1, this entire area became available to accommodate assembly lines located in modules F2 and F3, which have a low production volume. With the transfer of these lines, it is now possible to relocate the components warehouse inside the building.



(a) **(b)**

Figure 4. Layout alternative 2. Sector 1 (**a**) and sector 2 (**b**).

The same analysis that was performed for alternative 1 was then carried out in order to understand the material flows in this model. First, the distances between the modules were evaluated, Table 8.

Table 8. Distance matrix, alternative 2 (in meters).

From/To	F1	F2 LM + F5	F3	F2 INJ + F4 + SM	F5	WH1	WH2	WH3	WH4
F1	X	X	X	400	1240	X	90	X	X
F2 LM + F5	X	X	X	X	X	X	10	X	X
F3	X	X	X	X	X	X	60	X	X
F2 INJ + F4 + SM	X	X	X	X	1630	600	510	X	X
F5	X	X	X	X	X	1200	X	X	X
WH1	X	X	X	X	X	X	X	X	X
WH2	30	10	60	510	1200	90	X	X	X
WH3	X	X	X	600	1200	X	90	X	X
WH4	1230	X	X	1620	10	X	X	X	X

Next, we analyzed the quantities of material to be transferred between the different modules, considering the same assumptions presented for the initial layout, Table 9.

Table 9. Pallet quantity matrix, per shift, alternative 2.

From/To	F1	F2 LM + F5	F3	F2 INJ + F4 + SM	F5	WH1	WH2	WH3	WH4
F1	X	X	X	7	2	X	4	X	X
F2 LM + F5	X	X	X	X	X	X	4	X	X
F3	X	X	X	X	X	X	7	X	X
F2 INJ + F4 + SM	X	X	X	X	1	88	16	X	X
F5	X	X	X	X	X	2	X	X	X
WH1	X	X	X	X	X	X	X	X	X
WH2	1	8	11	15	1	11	X	X	X
WH3	X	X	X	10	4	X	8	X	X
WH4	2	X	X	6	1	X	X	X	X

Next, the number of trips per day was calculated, considering the capacity of the equipment and the quantities of material to be transported, as shown in Table 10.

Table 10. Matrix of number of trips per day, alternative 2.

From/To	F1	F2 LM + F5	F3	F2 INJ + F4 +SM	F5	WH1	WH2	WH3	WH4
F1	X	X	X	18	1	X	10	X	X
F2 LM + F5	X	X	X	X	X	X	10	X	X
F3	X	X	X	X	X	X	18	X	X
F2 INJ + F4 + SM	X	X	X	X	1	37	7	X	X
F5	X	X	X	X	X	1	X	X	X
WH1	X	X	X	X	X	X	X	X	X
WH2	3	5	7	7	1	7	X	X	X
WH3	X	X	X	25	1	X	20	X	X
WH4	1	X	X	2	3	X	X	X	X

After calculating the number of trips to be made per day, the total distances traveled were determined, as shown in Table 11.

Table 11. Total distance matrix, alternative 2 (in meters).

From/To	F1	F2 LM + F5	F3	F2 INJ + F4 + SM	F5	WH1	WH2	WH3	WH4
F1	X	X	X	7200	1240	X	900	X	X
F2 LM + F5	X	X	X	X	X	X	100	X	X
F3	X	X	X	X	X	X	1080	X	X
F2 INJ + F4 + SM	X	X	X	X	1630	22,200	3570	X	X
F5	X	X	X	X	X	1200	X	X	X
WH1	X	X	X	X	X	X	X	X	X
WH2	90	50	420	3570	1200	630	X	X	X
WH3	X	X	X	15,000	1200	X	1800	X	X
WH4	1230	X	X	3240	30	X	X	X	X

As with alternative 1, we also analyzed the number of equipment transfers required for this alternative, as well as the areas that became available for the possible integration of new equipment. This alternative would involve the following equipment transfers:

- All equipment included in module F4—22 injection machines, 2 heat treatment furnaces, 33 wire cutting and forming machines;
- Equipment from module F2 associated with the injection process—18 injection machines; 49 cutting machines, Zamak injection machines, and subassembly stations;
- Two assembly lines located in module F3, which contains the injection process integrated into the line;
- Eleven automatic Suspension Mat manufacturing lines scattered throughout all modules;
- In addition to these transfers, there is the move from module F1 to the old module F4 building. This corresponds to the transfer of 70 pieces of equipment.

Given this layout proposal, it would be necessary to move 207 pieces of equipment. Next, the areas that would be available after these layout changes will be analyzed, Table 12.

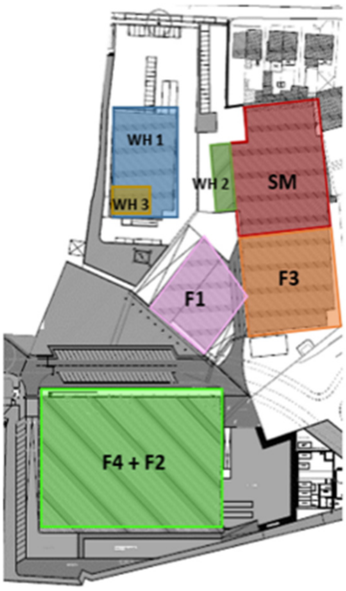
Table 12. Analysis of areas available for alternative 2.

Module/Warehouse	Available Area (m^2)	Justification
F3	250	Transfer of two assembly lines, which integrate the injection process into the line itself, to the new building.
F4	500	The F4 module was housed in a 2000 m² building, moving to a building with a production area of 6000 m², although this area also included other manufacturing lines (occupying around 1800 m², already taking into account the new equipment—4 lines), injection machines from the F2 module, equipment added to the process (800 m²), and the two assembly lines (250 m²). The mold workshop was transferred along with the module and acquired an area of approximately 180 m². The remaining areas are distributed between corridors and intermediate product storage areas. The available space is intended for the integration of new cutting and forming equipment, heat treatment, as well as other manufacturing lines.
F2	400	With the relocation of the injection module, it was possible to move the component warehouse back inside the building (400 m²), leaving 400 m² available to transfer lines from the F5 module to sector 1.

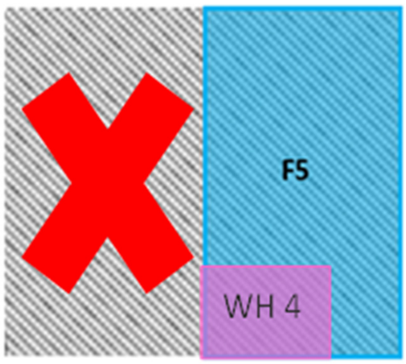
Alternative 3

This alternative was designed similarly to alternative 2, combining the two plastic injection modules, Figure 5. In this case, there is no separation between module F2—module injection and F2—assembly lines, and the possibility of integrating the other existing manufacturing lines into the old module F2 building is being analyzed. This alternative addresses the following layout restructuring:

- Transfer of the F4 module to the new factory building, with the exception of the Suspension Mat lines;
- Transfer of module F2 to the new factory building;
- Transfer of the Suspension Mat lines to the old module F2 building;
- Transfer of module F1 to sector 1 (where module F4 was located), and closure of the site where it was located;
- Elimination of the spiral warehouse (WH3);
- Reintegrate the component warehouse (WH2) inside the F2 module building;
- Transfer the laboratory that was in module F1 to the new building.



(**a**)



(**b**)

Figure 5. Layout alternative 3. Sector 1 (**a**) and sector 2 (**b**).

Similar to the study conducted for alternatives 1 and 2, the same analysis was performed for the distances between modules, amount of material to be transported, number of trips made, and, consequently, the total distances traveled between modules per day. These data are described in Tables 13–16.

Table 13. Distance matrix, alternative 3 (in meters).

From/To	F1	SM	F3	F2 + F4	F5	WH1	WH2	WH3	WH4
F1	X	X	X	400	1240	X	90	X	X
SM	X	X	X	X	X	X	10	X	X
F3	X	X	X	X	X	X	60	X	X
F2 + F4	X	X	X	X	1630	600	510	X	X
F5	X	X	X	X	X	1200	X	X	X
WH1	X	X	X	X	X	X	X	X	X
WH2	30	10	60	510	1200	90	X	X	X
WH3	X	X	X	600	1200	X	90	X	X
WH4	1230	X	X	1620	10	X	1240	X	X

Table 14. Pallet quantity matrix, per shift, alternative 3.

From/To	F1	SM	F3	F2 + F4	F5	WH1	WH2	WH3	WH4
F1	X	X	X	5	2	X	5	X	X
SM	X	X	X	X	X	X	32	X	X
F3	X	X	X	X	X	X	7	X	X
F2 + F4	X	X	X	X	1	23	1	X	X
F5	X	X	X	X	X	3	X	X	X
WH1	X	X	X	X	X	X	X	X	X
WH2	1	15	11	8	2	39	X	X	X
WH3	X	X	X	8	4	X	10	X	X
WH4	2	X	X	4	1	X	2	X	X

Table 15. Matrix of number of trips per day, alternative 3.

From/To	F1	SM	F3	F2 + F4	F5	WH1	WH2	WH3	WH4
F1	X	X	X	13	1	X	13	X	X
SM	X	X	X	X	X	X	80	X	X
F3	X	X	X	X	X	X	18	X	X
F2 + F4	X	X	X	X	1	10	1	X	X
F5	X	X	X	X	X	1	X	X	X
WH1	X	X	X	X	X	X	X	X	X
WH2	3	10	7	4	1	25	X	X	X
WH3	X	X	X	20	1	X	25	X	X
WH4	1	X	X	1	3	X	1	X	X

Table 16. Total distance matrix, alternative 3 (in meters).

From/To	F1	SM	F3	F2 + F4	F5	WH1	WH2	WH3	WH4
F1	X	X	X	5200	1240	X	1170	X	X
SM	X	X	X	X	X	X	800	X	X
F3	X	X	X	X	X	X	1080	X	X
F2 + F4	X	X	X	X	1630	6000	510	X	X
F5	X	X	X	X	X	1200	X	X	X
WH1	X	X	X	X	X	X	X	X	X
WH2	90	100	420	2040	1200	2250	X	X	X
WH3	X	X	X	12,000	1200	X	2250	X	X
WH4	1230	X	X	1620	30	X	1240	X	X

As with alternatives 1 and 2, the number of equipment transfers required for this alternative was analyzed, as well as the areas that became available for possible integration of new equipment. This alternative would involve the following equipment transfers:

- All equipment included in module F4—22 injection machines, 2 heat treatment furnaces, 33 wire cutting and forming machines;
- All equipment included in module F2—18 injection machines, 49 cutting machines, Zamak injection machines, and subassembly stations, 22 assembly lines;
- Two assembly lines located in module F3, which contain the injection process integrated into the lines;
- Eleven automatic Suspension Mat manufacturing lines that are scattered throughout all modules are transferred to module F2;

- In addition to these transfers, there is a change from module F1 to the old module F4 building. This corresponds to the transfer of 70 pieces of equipment.

Given this layout proposal, it would be necessary to move 229 pieces of equipment. Next, it will be analyzed which areas would be available after these layout changes, Table 17.

Table 17. Analysis of areas available for alternative 3.

Module/Warehouse	Available Area (m^2)	Justification
F3	250	Transfer of two assembly lines, which integrate the injection process into the line itself, to the new building.
F4	200	The F4 module was housed in a 2000 m² building and was moved to a building with a production area of 6000 m², which also included the 2500 m² F2 module. The mold metalworking shop was transferred along with the module and acquired an area of approximately 180 m². The remaining areas are distributed between corridors and intermediate product storage areas.
F2	2000	With the relocation of the injection module, it was possible to move the component warehouse back inside the building (400 m²), leaving 2000 m² available for transferring the other existing manufacturing lines.

3. Results—Guidelines/Concept Development

Once the research phase, in which possible layout alternatives were developed, is complete, the selection phase follows. This final phase consists of defining the best layout alternative according to the requirements imposed by management. To this end, the AHP methodology was used to support the selection of the best option. The AHP methodology is used as a decision-making tool to solve the problem of factory layout, due to its practical application. After developing several layout alternatives, the AHP is then applied to provide a multi-criteria assessment, including qualitative and quantitative aspects. Three criteria were selected to evaluate the best layout alternative:

- Maximize flexibility for future expansions—refers to areas that are available for possible acquisitions of new equipment, taking into account the expected business volume. This criterion in the development of the method is referred to as “Flexibility”.
- Minimize material flows—The minimization of flows is related to the distances traveled by materials between different modules during the manufacturing process and motion equipment options. This criterion in the development of the method is referred to as “Flow”.
- Minimize the number of equipment transfers (re-layout)—determines the impact of layout changes, thus enabling the necessary investment costs to be assessed. This criterion in the development of the method is referred to as “Cost”.

In order to facilitate the selection process, a software called R Studio was used, which can streamline all stages of the calculations. The software develops the following hierarchical structure for this decision-making process. Figure 6 shows the diagram produced by the software.

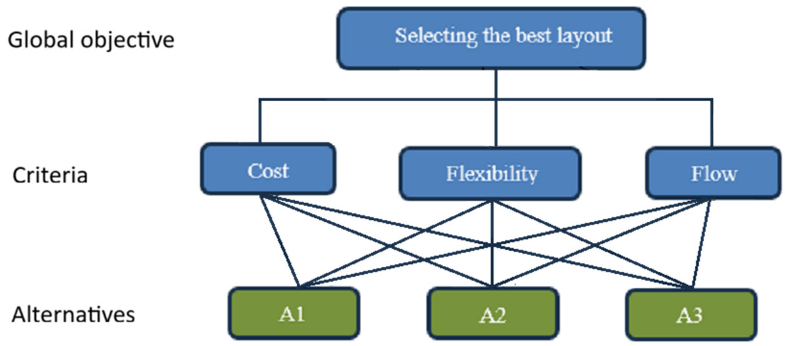


Figure 6. Defined AHP hierarchy.

The application of degrees of importance summarizes the strategy adopted by the company in the implementation of a new manufacturing unit. Flow minimization was chosen by management as the criterion with the greatest impact to consider. The company anticipates that these changes will enable the optimization of existing flows, centralizing all production areas in the same sector, reducing distances traveled, as well as the resources required to transport material between the different manufacturing modules. This will result in improved productivity, increasing the efficiency and effectiveness of the entire production process. However, regarding the methodology, different approaches can be chosen depending on the criteria considered by each company.

Maximizing flexibility, although a factor to consider due to the possibility of integrating new projects and equipment, is the criterion with the least weight compared to minimizing flows and costs, since the new manufacturing unit was designed considering the turnover forecasts for the coming years and the consequent acquisitions of new equipment. Therefore, this criterion is not a priority, as the areas necessary for the acquisition of new equipment have already been considered for the near future. However, it is necessary to have areas available for possible unforeseen changes that may arise, both in terms of new equipment and layout changes that optimize the production process.

Another factor is that the company seeks to minimize the costs associated with equipment transfers and building construction/acquisition, although the main decision criterion is the reduction of flows, as defined by management. For any company, the most advantageous strategy is always to carry out the work with the lowest possible investment.

The matrix that describes the degrees of importance applied in the comparison of criteria is represented in Table 18, that after normalization using AHP procedure as in Section 1.

Table 18. Matrix of relationships between criteria and its normalization weights and CR.

	Saaty's Scale Elicitation			**Normalized Values**				
	Flexibility	**Flow**	**Cost**	**Flexibility**	**Flow**	**Cost**	**Weights**	**CR**
Flexibilty	1	1/9	1/2	8.33	8.86	5.88	7.6%	
Flow	9	1	7	75	79.75	82.35	79.3%	1.88
Cost	2	1/7	1	16.67	11.39	11.76	13.1%	
Total	12	1.253968	8.5	7.69	79.03	13.27	100%	

It is necessary to perform a side-by-side comparison matrix between the different alternatives for each criterion, assigning degrees of importance that are classified on a Saaty's scale from 1 to 9 referred in Section 1, see Tables 19–21.

Table 19. Alternatives assessment by criterion Flexibility and normalized values and CR.

Flexibility	**A1**	**A2**	**A3**	**Normalized Value**	**CR**
A1	23.08	21.74	33.3333	26.05	
A2	69.23	65.22	55.55	63.33	3.33%
A3	7.69	13.04	11.11	10.62	

Table 20. Alternatives assessment by criterion Flow and normalized values and CR.

Flow	**A1**	**A2**	**A3**	**Normalized Value**	**CR**
A1	74.47	78.95	63.64	72.35	
A2	14.89	15.79	27.27	19.32	5.7%
A3	10.64	5.26	9.09	8.33	

Table 21. Alternatives assessment by criterion Cost and normalized values and CR.

Cost	**A1**	**A2**	**A3**	**Normalized Value**	**CR**
A1	65.22	69.23	55.55	63.33	
A2	21.74	23.08	33.33	26.05	5.7%
A3	13.04	7.69	11.11	10.62	

Comparison matrices were developed between the alternatives to be entered into the software, letting them proceed with the calculation of the optimal solution. Once created, these matrices were entered into the software and calculated using the AHP method with RI = 0.58 for 3 alternatives [7]. It is possible to see the results obtained in Table 22.

Table 22. Results obtained by RStudio software in solving the AHP method.

Select Best Layout	Weight	A1	A2	A3	CR
Result	100%	67.6%	23.6%	8.8%	1.88%
flexibilty	7.6%	26.0%	63.3%	10.6%	3.33%
flow	79.3%	72.4%	19.3%	8.3%	5.7%
cost	13.1%	63.3%	26.0%	10.6%	3.3%

Given these data, it can be concluded, as mentioned above, that the flow minimization criterion has a higher weight than the other criteria, equivalent to 79.3%. Therefore, the alternative that corresponds to the optimal solution, with a result of 67.6%, which was subsequently implemented by the company, is alternative 1. By each criterion, all alternatives assessed have a consistency index lower than 0.1, thus, it can be said, according to Saaty et al. [7], that the matrix comparisons are not inconsistent and the evaluations are valid. Alternative 1, as it is the alternative corresponding to the lowest flow as previously calculated, and the flow minimization criterion was defined as the criterion with the highest weight to be considered, it can be concluded that the results obtained reflect consistent data.

After evaluating the best layout for the industrial area structure, a relationship diagram was drawn up based on current data in order to understand the relationships between the different manufacturing processes and facilitate the development of a layout proposal, see Figure 7. The evaluation scores for the selection criteria are as follows:

1. Internal flows—represents the movement of material between different production processes;
2. Technical synergies—represents specialized labor resources, namely maintenance technicians, tuners, among others; Supply Chain—represents resources related to logistics, that is, dedicated to internal and external transportation of material;
3. Safety—Ensuring that there are no material exchanges, given that the raw material for the manufacture of cushions and Suspension Mat is the same.

In this preferential interrelationship diagram, the reason for the proximity can also be indicated, usually represented in numerical form. Based on Figure 7, it is possible to identify which production areas must be located close to each other and which should be kept apart, preventing potential failures in internal material flow, such as reference mix-ups. The requirements set by management for layout development considered the dependencies among processes and machines, thus demanding a rigorous layout criterion to optimize internal flows without affecting the current operational methodology.

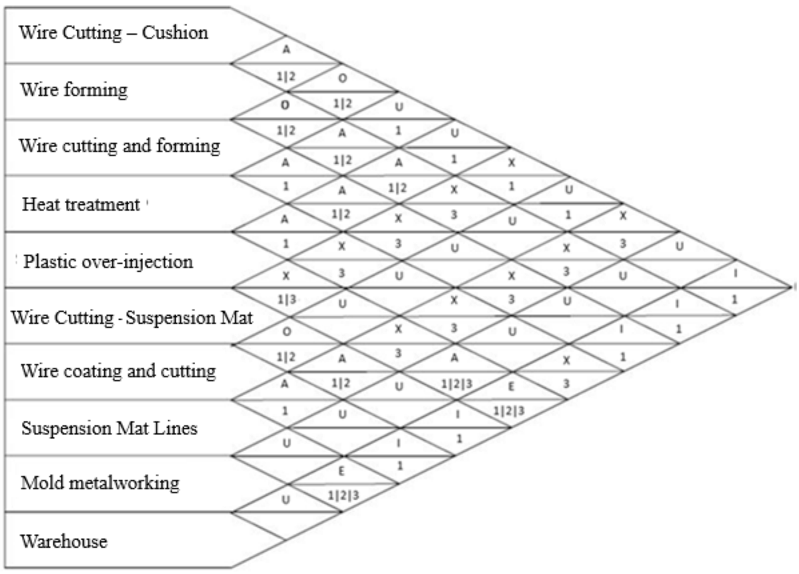


Figure 7. Relationship diagram among processes selected for transfer to the new module.

It is important to observe which production areas need to be close to each other and which should be kept apart in order to prevent possible failures in the internal flow of materials, such as mixing of references. The requirements imposed by management for the layout design took into account the dependencies between processes and machines, thus requiring strict layout criteria in order to optimize internal flows without impacting the current operating methodology. Some important restrictions were also imposed to make the most of the layout. After this entire process has been evaluated and all requirements imposed, the proposed layout can be analyzed in Figure 8.

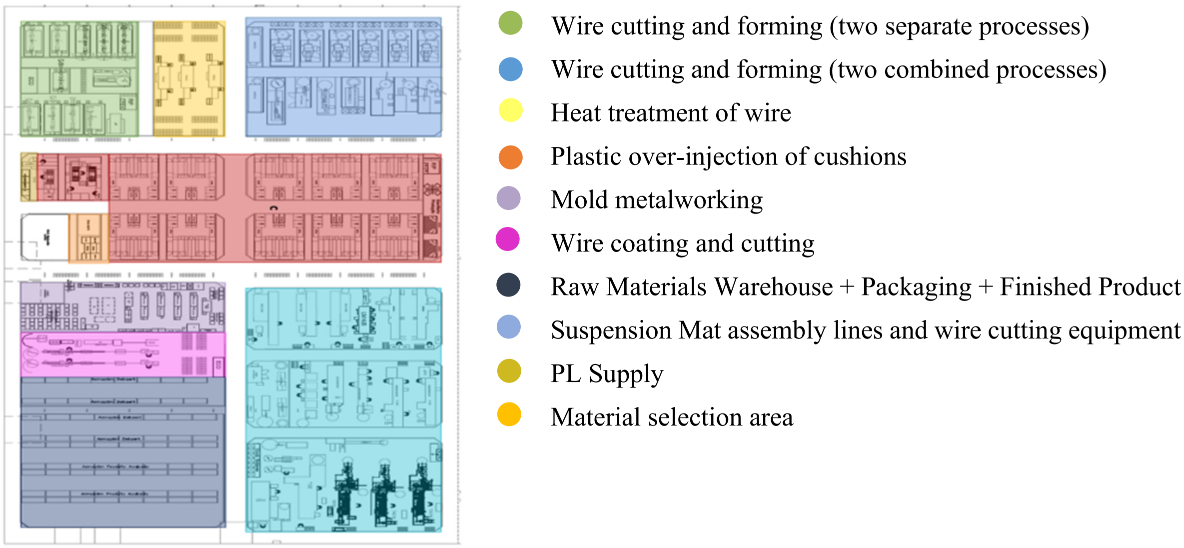


Figure 8. Layout of the new manufacturing unit according to the selected alternative.

The internal material flows are described in Figure 9, which contains all the processes necessary to produce comfort systems, cushions, and suspension mats.

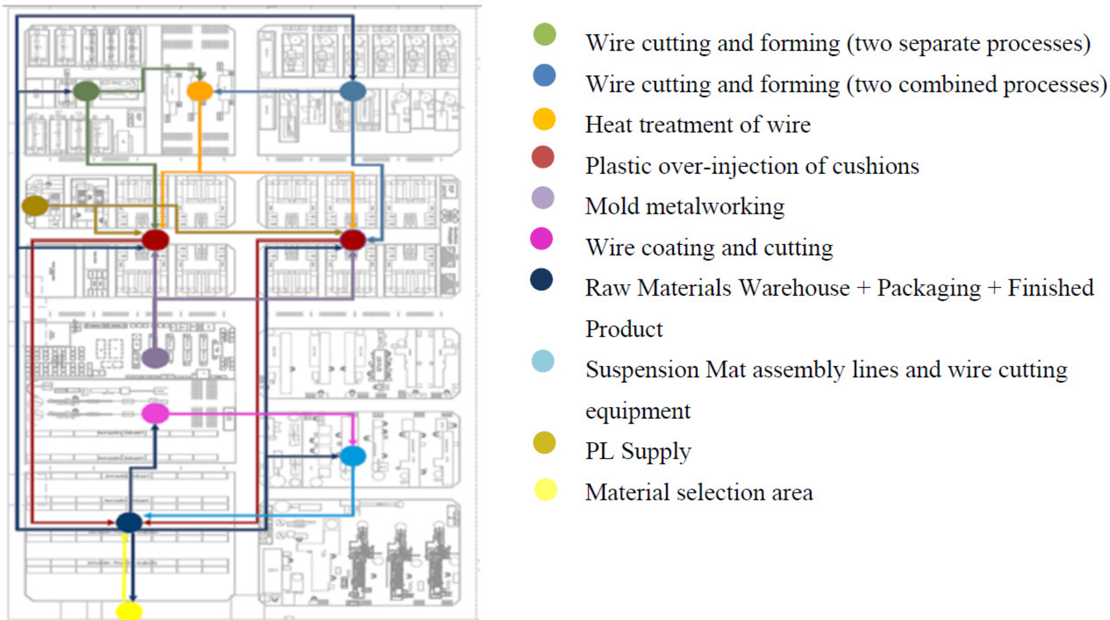


Figure 9. Internal flow diagram for the layout of the new manufacturing unit.

This layout of the equipment allows for improved internal flows, as all intermediate processes are close to the end customer. Although the storage space is not close to all processes, it is close to the dock, which facilitates the loading and unloading of materials, which can be transported internally by a logistics train. This space is reduced for the preparation of loads. Due to the high number of items of this type of product to be shipped each day, a warehouse area was integrated to relieve the flow of material from the shipping warehouse and thus reduce movement between modules. In addition to this warehouse area dedicated to finished products, it was decided to integrate a raw material and packaging warehouse area that supplies the module into this same area. For this flow, a storage space of five racks with three levels of height was considered, with 3.7 m between racks, which is equivalent to three pallets with two levels per zone. Each space contains eight zones, meaning that the storage space can hold up to 720 pallets. Regarding the raw material that supplies this module, with this layout arrangement it will be stored inside it, i.e., the wire that supplies the wire cutting and forming process, as well as the wire that supplies the wire coating machines that were moved from module F1, is stored in the module. Three racks are reserved for this material, which can hold approximately 234 pallets of material. Figure 10 shows the final layout of the equipment and the relationships between them, according to the existing designs. In the diagrams, each color corresponds to a different design.

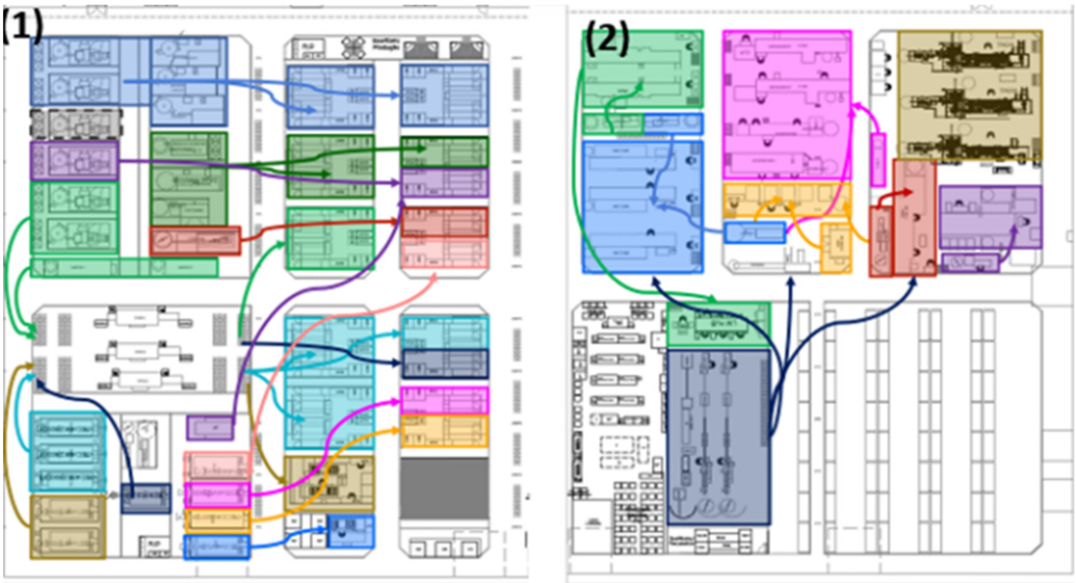


Figure 10. Diagram showing the relationships between equipment by project for the manufacture of cushions (**1**) and SM (**2**).

Once the decision had been made on the appropriate factory layout, the next step was to implement these solutions. A plan was then drawn up for the transfer of equipment, and a checklist was created to involve all the teams concerned in the transfer, informing them of the transfer plan, with each manager assessing whether the necessary conditions were in place for the transfer to take place. After defining the planning method, a schedule was drawn up to begin transferring the equipment. To draw up the schedule, it was necessary to define the priorities in the transfer process and meet with all stakeholders to determine the estimated time for each transfer.

After defining the layout of the new building, it is necessary to assess the economic impact resulting from the implementation of the new manufacturing unit. As the building was constructed on leased land, most of the investment costs were borne by the landowner, as was the definition of the building's structure. However, in addition to the costs of constructing the building's front, there were other installation costs that were borne by the company. It can be concluded that the company had a strategy to minimize costs, managing to reduce them by 10% compared to the estimated amount. To estimate the cost of transportation, it was evaluated the relationship between each piece of equipment to be transported and the need for specialized labor, maintenance, and rental of equipment to support the transfer. It should be noted that for the cost of specialized labor, a value of 20 cost units/hour was considered, with a maximum of 8 h per day. For the cost of equipment rental, a cost of 30 cost units/hour was considered, and for each maintenance intervention by an external supplier, a value of 250 cost units/maintenance was estimated. In addition to the costs of transferring equipment, the costs of transferring warehouse areas were also considered. It was concluded that the investment associated with the transfer of equipment was approximately 41,160 cost units.

The adopted solution is strongly aligned with Lean principles of cutting waste and avoiding unnecessary logistics operations by studying how to shorten necessary trips between workstations. This contributes to economic sustainability by reducing time and, consequently, costs. It also contributes to environmental sustainability, as fewer trips lead to lower energy consumption and less pollution (when using gas-powered forklifts or *Mizusumachi* system. Implicitly, spaghetti diagrams were also drawn, which resulted in the aforementioned distance maps.

Some warehouses were closed, and others were installed, and it is important to analyze the economic impact on rents with the changes made. Table 23 shows the values of before and after. It should be noted that not all rents were evaluated, only those of the buildings involved in these changes were effectively considered.

Table 23. Costs associated with building rents.

Building	Current Income (cost unit/month)	Future Income (cost unit/month)
F1 Module	5700	-
New Building	-	27,200
External warehouse 1	1800	-
External warehouse 2	1200	-
External warehouse 3	1000	1000
Total	9700	28,200

With the proposed changes, rents would be 28,200 cost units, as the rental value of the new building has a significant impact, but at the same time, with the reduction in the number of storage spaces, there was a monthly reduction in rent costs of 8700 cost units, as two external warehouses and the F1 module warehouse were reduced.

The current and proposed layouts were developed to analyze possible flow optimizations that could arise with the implementation of the new factory building and restructuring of existing areas. With the data already obtained, it is possible to assess the economic impact in relation to material flows. However, as distances have been reduced, the impact of the amount of transport equipment to be used and the change in their type was assessed. Currently, all equipment is rented from an external supplier. As such, this assessment presents a favorable economic impact for the company. This reduction in distances also impacts the number of skilled laborers required, i.e., with the reduction in distances to be traveled, it is possible to optimize the number of workers needed, as each supervisor will be able to transport more material. Table 24 shows the total costs associated with the material flow for the current layout and the costs associated with the material flows for the selected layout.

Table 24. Total costs associated with material flow for the current layout.

	Labor Required	Cost per Person/Month (Units per month)	No. of Equipment	Equipment Cost/Month (Units/month)	Total (Units per month)
Current layout	28	33,600	29	7600	41,200
Future Layout	21	25,200	25	6200	31,400
Gains	7	8400	4	1400	9800

In summary, analyzing the data obtained, material handling costs were reduced by approximately 23%, corresponding to a gain of 117,600 cost units/year.

4. Discussion—Validation of the Concept through a Case Study

To support and contextualize the results achieved in this study, it is important to compare them with similar situations already documented in the literature. A notable example is the study conducted by Qamar et al. [11], which investigated layout optimization in a passenger car factory in Jordan. In this study, five layout options were created using SLP, based on material flows, proximity between sectors, and physical constraints of the existing facility. The best option was chosen using the AHP, considering factors such as the total distance traveled by materials, the effective use of available space, and the functional interactions between production sectors. The research findings showed significant advances. The layout option considered ideal resulted in a notable decrease in the distance that materials need to travel, resulting in lower logistics costs and increased production efficiency. The robustness of the decision-making process was enhanced by calculating the AHP consistency matrix, which showed a maximum *CR* value of only 5.7%, well below the maximum limit *CR* of 10% indicated in the literature, ensuring the reliability and consistency of the assessments made. In addition, the authors demonstrated that the combination of the two methodologies (SLP + AHP) not only improved the performance indicators of the industrial plant but also provided a systematic tool that assists industrial managers in highly complex situations. The relevance of this example to the current work is evident. As in the study conducted in Jordan, the methodology used here combines SLP with AHP, focusing on the definition and choice of factory layout. However, there are important differences that highlight the uniqueness of this study. While Qamar et al. [11] focused on reconfiguring an existing facility, this case deals with the creation of a new manufacturing unit from scratch. This differentiation is crucial, as decisions made at this stage have a long-term impact on aspects such as costs, flexibility, and sustainability of the operation.

When examining the two scenarios, it can be observed that the benefits mentioned in the research by Qamar et al. [11], such as reduced distances and more effective use of space, serve as a relevant parameter for measuring the goals expected to be achieved in the solution developed in this work. Thus, while significant reductions in logistics indicators were observed in the Jordanian context, this study seeks to determine whether these benefits can be replicated or even expanded when the methodology is applied from the outset of a facility. In this context, comparative analysis will help to recognize not only similarities (in the effectiveness of the methodologies) but also differences (in the numerical results) resulting from the varying characteristics of industrial environments. Another relevant point of comparison is the consistency index of the AHP. The value of 6.918% obtained by Qamar et al. [11] serves as a direct reference for the present work, in which it was aimed to ensure that the process of assigning weights and criteria is robust and consistent. In addition to these indicators, the authors also found notable improvements in terms of productivity and operational efficiency—for example, increases of up to 88% in productivity were reported in areas originally affected by bottlenecks and overlapping flows.

Thus, the ensuing debate demonstrates that the research by Qamar et al. [11] serves as an appropriate international standard for the present study. By comparing the results, it will be possible to strengthen the scientific and practical credibility of the model created, in addition to emphasizing its usefulness in new scenarios of factory expansion. Ultimately, this comparative analysis helps to prove that the combination of SLP and AHP not only effectively addresses the challenges of reorganization in established factories but also proves to be an effective tool for guiding planning from the ground up for new production units.

Another relevant example can be found in the work of Antoniolli et al. [19], who studied the optimization of an automotive component production line in Portugal. In this case, the application of Lean tools and work standardization was decisive in improving the overall efficiency of the system. The reorganization of the layout, combined with the standardization of procedures, resulted in a significant increase in OEE, which rose from 70% to 86%, as well as a reduction in waste associated with irregular cycles and unnecessary movements. The similarity with the present study lies in the emphasis placed on the use of structured methodologies to optimize production performance in the automotive context. The main difference, however, lies in the starting point: while Antoniolli et al. [19] intervened in an existing line, the current work deals with the design of a new manufacturing unit from scratch, requiring more comprehensive decisions with long-term impact.

In addition, it is worth highlighting the research conducted by D'Antonio et al. [23], who proposed a mathematical model for optimizing hybrid product-process layouts, applied to practical cases in the automotive industry. The study demonstrated the feasibility of generating, in a few seconds, optimized layout proposals that reconcile the minimization of internal distances with the maximization of the use of available resources. The relevance of this comparison to the present work is evident: both studies deal with highly complex and demanding industrial environments, where layout definition plays a strategic role. However, while the model D'Antonio et al. [23] favors a mathematical approach to solving combinatorial layout problems, the present study adopts an integrated SLP + AHP methodology, which allows qualitative criteria such as flexibility, safety, and sustainability to be included in the decision-making process.

5. Conclusions

This work successfully demonstrated the effectiveness of combining Lean practices, Systematic Layout Planning (SLP) and the Analytic Hierarchy Process (AHP) for the initial planning of a new industrial plant within the automotive industry. This integrated approach allowed for a comprehensive evaluation of various layout options, considering both qualitative and quantitative aspects crucial for optimizing production processes, and using Lean principles, trying to reduce waste of time and costs, increasing the economic and environmental sustainability. The use of AHP as a decision-making tool facilitated the selection of the best alternative by providing a multi-criteria assessment based on management requirements. Three key criteria were established for evaluating layout alternatives: maximizing flexibility for future expansions, minimizing material flows, and minimizing the number of equipment transfers (re-layout), namely costs. Among these, minimizing material flows was identified as the criterion with the highest weight (79.3%), reflecting its significant impact on operational efficiency, which also matches with the environmental sustainability required, reducing energy consumption and emissions. The chosen layout, Alternative 1, achieved a 67.6% optimal solution, primarily due to its alignment with the flow minimization objective, which is in line with the waste reduction, as well as economic and environmental sustainability needs. The consistency of the AHP matrices, with consistency indices below 0.1, validated the reliability of the evaluations.

The implemented new layout led to substantial improvements in operational efficiency and significant cost reductions. Specifically, the chosen solution resulted in an approximate 23%, corresponding to a gain of 117,600 cost units/year. The reduction in the distances traveled by material flows translates to shorter handling times and reduced logistical issues, contributing by this way to better economic and environmental sustainability.

Furthermore, the centralization of processes and more efficient use of available space contributed to a notable reduction in costs related to leased areas, resulting in lower logistics costs and increased production efficiency, contributing to wasted time reduction, as well as economic and environmental sustainability. The use of rationalization strategies during implementation also resulted in a 10% reduction in the initially projected investment, thereby confirming the financial viability of the project.

Beyond the immediate economical and structural advantages, the developed layout provides a more adaptable arrangement that supports future expansion. This flexibility is particularly important in the rapidly evolving automotive sector, allowing for the integration of new projects and equipment.

The study's findings align with previous research, such as the study by Qamar et al. [11], and validates the effectiveness of the strategy used demonstrating that the SLP + AHP combination, when properly supported by Lean principles, is an efficient resource for complex industrial decisions. However, the current study differentiated from that one particularly by the addition of Lean principles to increase economic and environmental sustainability in the context of new manufacturing unit planning, addressing a gap in existing literature.

This research not only delivered tangible advancements for the company by optimizing its new manufacturing unit's layout but also reinforced the scientific foundation for using SLP and AHP, previously supported by Lean principles focused on increasing economic and environmental sustainability, as a robust, reliable, and financially sound strategy for factory planning in the automotive industry. The methodology's success in achieving significant reductions in material handling costs and reducing energy consumption and emissions by using Lean principles, optimizing space utilization, and ensuring adaptability positions, is a valuable model for future industrial facilities implementations, enhancing competitiveness and promoting efficient production resource management.

Author Contributions

R.L.: writing—original draft preparation, methodology, investigation; A.G.P.: conceptualization, methodology, writing—reviewing and editing; I.M.P. methodology, supervision, writing—reviewing and editing: M.T.P.: data curation, visualization, validation; A.G.: data curation, visualization, writing—reviewing and editing; I.F.: data curation, visualization, writing—reviewing and editing; A.J.V.: data curation, visualization, writing—reviewing and editing. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

References

1. Park, J.; Lee, C.; Oh, S.C.; et al. Multi-objective optimization for layout planning of matrix manufacturing system. *Int. J. Precis. Eng. Manuf.-Green Tech.* **2025**, *12*, 1049–1067. https://doi.org/10.1007/s40684-025-00696-2.
2. Hu, F.; Wang, C.; Wu, X. Generative Artificial Intelligence-Enabled Facility Layout Design Paradigm. *Appl. Sci.* **2025**, *15*, 5697. https://doi.org/10.3390/app15105697.
3. Muther, R.; Hales, L. *Systematic Layout Planning*, 4th ed.; Management & Industrial Research Publications: Marietta, GA, USA, 2015. ISBN-13: 978-0-933684-06-5.

4. Drira, A.; Pierreval, H.; Hajri-Gabouj, S. Facility layout problems: A survey. *Annu. Rev. Control* **2007**, *31*, 255–267. https://doi.org/10.1016/j.arcontrol.2007.04.001.
5. Barnwal, S.; Dharmadhikari, P. Optimization of Plant Layout Using SLP Method. *Int. J. Innov. Res. Sci. Eng. Technol.* **2016**, *5*, 3008–3015. https://doi.org/10.15680/IJIRSET.2016.0503046.
6. Nyati, V.; Jaybhaye, M.D.; Sardar, V. Optimization of facility layout for improvement in productivity. In Proceedings of the 4th International Conference on Industrial Engineering (ICIE 2017) AT: S.V. National Institute of Technology, SURAT, Surat, Gujrat, India, 21–23 December 2017.
7. Saaty, T.L. *The Analytic Hierarchy Process*; McGraw-Hill: New York, NY, USA, 1980.
8. Saaty, T.L. Decision making with the Analytic Hierarchy Process. *Int. J. Serv. Sci.* **2008**, *1*, 83–98. https://doi.org/10.1504/IJSSCI.2008.017590.
9. Arunyanart, S.; Pruekthaisong, S. Selection of multi-criteria plant layout design by combining AHP and DEA methodologies. *MATEC Web Conf.* **2018**, *192*, 01033. https://doi.org/10.1051/matecconf/201819201033.
10. Chen, W.; Liu, C.; Huang, X.; et al. SLP Approach Based Facility Layout Optimization: An Empirical Study. *Sci. J. Bus. Manag.* **2016**, *4*, 172–180. https://doi.org/10.11648/j.sjbm.20160405.15.
11. Qamar, A.; Al Meanazel, O.; Alalawin, A.; et al. Optimization of Plant Layout in Jordan Light Vehicle Manufacturing Company. *J. Inst. Eng. Ser. C* **2020**, *101*, 721–728. https://doi.org/10.1007/s40032-020-00576-5.
12. Hakim, I.; Salsabila, D.; Prajadhiana, K. Layout improvement design to reduce material handling cost by using the systematic layout planning method in the MSME industry. *J. Sist. Dan Manaj. Ind.* **2025**, *9*, 43–54. https://doi.org/10.30656/jsmi.v9i1.9212.
13. Kittipanya-ngam, P.; Sitthibrun, S.; Sirikasemsuk, K. Comparison of Plant Layout Using CORELAP, ALDEP and SLP Methodology: Case Study of Printed Circuit Board Manufacturing Plant. *Eng. Technol. Horiz.* **2022**, *39*, 121–137.
14. Mendoza-Ortega, G.P.; Torregroza-Espinoza, A.; Jaraba-Amaya, A.L.; et al. Strategic Plant Redesign in the Glass Industry: A Case Study Applying SLP and Discrete Simulation. *Appl. Sci.* **2025**, *15*, 7028; https://doi.org/10.3390/app15137028.
15. Maina, E.; Muchiri, P.; Keraita, J. Improvement of Facility Layout Using Systematic Layout Planning. *IOSR J. Eng.* **2018**, *8*, 33–43.
16. Potadar, O.; Kadam, G. Development of Facility Layout for Medium-Scale Industry Using Systematic Layout Planning. In Proceedings of International Conference on Intelligent Manufacturing and Automation (ICIMA 2018), Lecture Notes in Mechanical Engineering, Mumbai, India, 5 November 2018; Springer: Singapore, 2019; pp. 473–483. https://doi.org/10.1007/978-981-13-2490-1_43.
17. Wilsten, J.P.; Shayan, E. Layout Design of a Furniture Production Line Using Formal Methods. *J. Ind. Syst. Eng.* **2007**, *1*, 81–96.
18. Hadi-Vencheh, A.; Mohamadghasemi, A. An integrated AHP–NLP methodology for facility layout design. *J. Manuf. Syst.* **2013**, *32*, 40–45. https://doi.org/10.1016/j.jmsy.2012.07.009.
19. Antoniolli, I.; Guariente, P.; Pereira, T.; et al. Standardization and optimization of an automotive components production line. *Procedia Manuf.* **2017**, *13*, 1120–1127. https://doi.org/10.1016/j.promfg.2017.09.173.
20. Neves, P.; Silva, F.J.G.; Ferreira, L.P.; et al. Implementing Lean Tools in the Manufacturing Process of Trimmings Products. *Procedia Manuf.* **2018**, *17*, 696–704. https://doi.org/10.1016/j.promfg.2018.10.119.
21. Freitas, A.M.; Silva, F.J.G.; Ferreira, L.P.; et al. Improving efficiency in a hybrid warehouse: A case study. *Procedia Manuf.* **2019**, *38*, 1074–1084. https://doi.org/10.1016/j.promfg.2020.01.195.
22. Mårdberg, P.; Fredby, J.; Engström, K.; et al. A novel tool for optimization and verification of layout and human logistics in digital factories. *Procedia CIRP* **2018**, *72*, 545–550. https://doi.org/10.1016/j.procir.2018.03.158.
23. D'Antonio, G.; Saja, A.; Ascheri, A.; et al. An integrated mathematical model for the optimization of hybrid process–product layouts. *J. Manuf. Syst.* **2018**, *46*, 179–192. https://doi.org/10.1016/j.jmsy.2017.12.003.
24. Gopinath, V.; Ore, F.; Johansen, K. Safe assembly cell layout through risk assessment—An application with hand guided industrial robot. *Procedia CIRP* **2017**, *63*, 430–435. https://doi.org/10.1016/j.procir.2017.03.160.
25. Horta, M.; Coelho, F.; Relvas, S. Layout design modelling for a real world just-in-time warehouse. *Comput. Ind. Eng.* **2016**, *101*, 1–9. https://doi.org/10.1016/j.cie.2016.08.013.
26. Rakesh, V.; Adil, G.K. Layout optimization of a three-dimensional order picking warehouse. *IFAC-PapersOnLine* **2015**, *48*, 1155–1160. https://doi.org/10.1016/j.ifacol.2015.06.240.
27. Ribeiro, R.; Silva, F.J.G.; Pinto, A.G.; et al. Designing a Novel System for the Introduction of Lubricant in Control Cables for the Automotive Industry. *Procedia Manuf.* **2019**, *38*, 715–725. https://doi.org/10.1016/j.promfg.2020.01.096.
28. Teles, C. Otimização de Layouts e Fluxos Produtivos. Master's Thesis, Departamento de Engenharia Mecânica, Faculdade de Engenharia, Universidade do Porto, Porto, Portugal, 2017.
29. Oliveira, M.; Fontes, D.B.M.M.; Pereira, T. Evaluating vehicle painting plans in an automobile assembly plant using an integrated AHP-PROMETHEE approach. *Int. Trans. Oper. Res.* **2018**, *25*, 1383–1406. https://doi.org/10.1111/itor.12179.