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Original Article

Where Should the Toilets Be in the Factory? A Case Study in Brazil

Michael David de Souza Dutra

Department of Industrial Engineering, Universidade Federal de Minas Gerais, Minas Gerais, Brazil.

Corresponding Author : michaeldavid@ufmg.br

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Abstract - *Improved sanitation has a significant benefit for both public health and the economy. Sanitation for all is a component of the 2030 Agenda for Sustainable Development. However, the literature reveals that some workplaces reprimand employees for using washrooms outside of formal, scheduled breaks due to the perceived negative impact on productivity. Furthermore, research shows that women often limit their washroom visits in workplaces where the facilities are far from their workstations, influenced by concerns about reprimand. While placing washrooms inside production areas is sometimes discouraged for certain plants based on the products they manufacture, managers may remain resistant to the idea even when no such restrictions apply. As a result, a conflict arises between employee health and productivity. This paper aims to mitigate this conflict and contribute to the literature by presenting, for the first time, a case in which locating washrooms within the production facility, detached from its perimeter walls, and near the department with the highest employee density can be economically beneficial. The case studied involved designing a new plant for a Brazilian garment manufacturer via Systematic Layout Planning. Layout alternatives were evaluated using Discrete-Event Simulation and a Net Present Value analysis. Results showed that having washrooms inside the production area becomes economically viable when the profit per unit surpasses \$7.81 in the case studied. This case suggests that managers should consider placing washrooms within the production area during layout planning, thereby challenging the hegemonic discourse that restrooms should never be inside a production facility.*

Keywords - *Sanitation, Industry, Health, Layout planning, Simulation.*

1. Introduction

For years, the United Nations has called for better sanitation for people. For instance, in 2000, the Millennium Development Goals (MDGs) [1] aimed to decrease the number of people lacking access to "basic sanitation" by 2015. The concept of "basic sanitation" was expected to correspond at least to the definition of "improved sanitation" from the World Health Organization [2], which specifies an improved infrastructure of a physical place to serve as a restroom or a latrine. Another example of a call for better sanitation occurred in 2015, when the United Nations General Assembly proposed a commitment between communities, nations, and countries to promote the equality and dignity of human beings, peace, prosperity, a sustainable planet, and decent work for all through the 2030 Agenda for Sustainable Development [3]. This agenda sets 17 Sustainable Development Goals, including the sustainable management and availability of sanitation for all people [4]. This paper assumes that the sustainable management and availability of sanitation services require at least two features. First, people must have access to a room with adequate infrastructure, ensuring efficient management of water resources, safe waste disposal, and promotion of personal hygiene. Second, the room must be in an environment that does not have policies limiting its usage or create discomfort or negative sentiments in individuals who intend to use it. In light of this assumption, workplaces are environments where sanitation may be unavailable. Rajaraman et al. [5] interviewed women about their access to sanitation facilities at their jobs in Bangalore, India. According to reports from women, some construction workplaces had no sanitation facilities, so they needed to use open defecation areas, leading to embarrassment and discomfort. Within a specific company in Bangalore, Srinivas [6] conducted interviews with 100 workers to assess their health and satisfaction regarding the welfare infrastructure within the company. More than half of employees expressed dissatisfaction with the restroom, citing issues such as poor maintenance of cleanliness, inadequate availability of sanitizers and tissues, and a limited number of toilets. Thus, those workplaces fail to adhere to the first characteristic outlined in the assumption, either because they lack a sanitation facility or because their infrastructure is inadequate. Some workplaces do not satisfy the second assumption feature. Heymann et al. [5] registered a domestic workplace where women workers did not use available restrooms due to their feelings about using them - the authors proposed that these feelings could be attributed to entrenched social hierarchies, where lower-caste individuals may be restricted from using the same toilets as those from higher castes. In a garment factory context, two workers reported being consistently denied access to the toilet during working hours, causing women to hold back the urge to use the toilet [5]. Similar situations in which workers consciously choose to forgo using the toilet despite experiencing biological needs (self-restriction), in an attempt to maximize productivity at work, were also reported by other studies [7], [8]. Choi et al. [9] interviewed 860 cosmetics saleswomen in South Korea to investigate their working conditions and health. Of those participants, 534 reported, for a specific week, being unable to use the toilet during working hours when needed due to its distance (implicitly because of the time required to return to work).

This situation was a possible reason for the number of cystitis cases among the respondents. Distance to the washroom was also cited as a reason for self-restriction in the study of [7]. Reynolds et al. [10] and Camenga et al. [8] not only indicated a close link between Lower Urinary Tract Symptoms (LUTS) and women with limited restroom use, but also suggested that an intense work schedule was the primary cause for this limitation. Workers in the United States [11] are typically allowed to take restroom breaks as needed. However, restroom breaks are strictly regulated in practice, and women are occasionally reprimanded for using the restroom outside the scheduled break times, as highlighted by findings from [7]. In other locations, such as Brazil [12], New Zealand [13], and the UK [14], local laws do not prohibit companies from restricting additional time away from work beyond designated breaks. Hence, in workplaces characterized by mass production systems, such as factories, it is common to limit access to restroom breaks to minimize losses resulting from the production line stop due to an employee's absence at their workstation.

In such systems, during working hours, a management practice is to keep the production line in operation and to enable an employee to leave his workstation by replacing him with another worker. This practice is founded on the principle of "good faith," aiming to compromise a trade-off: provide more restroom breaks to employees while safeguarding the company's interests. It requires suitable replacement employees who can step in and take over the responsibilities of workers in need of restroom breaks. Nevertheless, this practice fails when a substitute is unavailable, leaving a worker without permission to leave their workstation for a restroom break. Reasons for this unavailability may include the small number of replacement employees and the time required for the worker to go and return from the restroom. Depending on the frequency and severity of such unavailability, lawsuits may happen. To avoid potential lawsuits, some companies bear the costs associated with providing additional restroom breaks as needed. As a strategy to maintain uninterrupted production, they introduce intermediate stock between workstations, thereby deviating from the concept of a continuous flow process. To decrease these costs, it is desirable that workers return swiftly to their workstations after taking a restroom break. However, this time constraint is a source of self-restriction [7, 8].

Assuming that the time spent by an employee to leave his workstation for a restroom break and return to it is proportional to the distance between their workstation and the restroom, the facility layout and the positioning of sanitation places within it play a significant role in finding an equilibrium between sanitation needs and the company's productivity. However, finding this equilibrium is a challenge that has not been addressed in the literature, and this is a problem considered in this paper.

To promote health, Hartigan et al. [7, p. 14] proposed that workplace restrooms may be strategically positioned in areas with easy access, which include positioning them close to individuals to provide quick access when needed. However, most companies decide to locate restrooms outside the production facility or at its perimeter walls for several reasons. Firstly, if the production facility processes food products, locating the restrooms outside or at its perimeter walls simplifies compliance with safety and quality codes, such as the Food Safety Code [15], which aim to prevent food contamination. Secondly, the flooring of factories or storage warehouses is constructed using robust materials, such as thick ironwork and concrete, to withstand heavy loads. Hence, if fixed toilets are installed on these floors and plumbing blockages occur, it can result in substantial maintenance costs. Thirdly, facility layout modifications may require the relocation of restrooms, which may be costly. Finally, locating restrooms outside the facility may prevent theft [16, 17]. Even when these reasons do not apply, some managers consider the idea of locating washrooms inside the production facility and disconnecting them from its perimeter walls unusual. This naturally brings up the following research question: Is there a case where locating washrooms inside a production facility, disconnected from its perimeter walls, is economically profitable?

The literature does not provide an analysis that addresses this question. Consequently, there is a lack of discussion about the possibility of locating washrooms inside a production facility, disconnected from its perimeter walls, while preserving profits. Answering this question is important because, if managers recognize this possibility, they may consider placing washrooms within the production area during layout planning. This would situate washrooms closer to workers, resulting, as suggested in the literature [7], in better sanitation. Therefore, this study is motivated by the need to fill this gap. Additionally, one contribution of this paper is to question existing forms of knowledge production, especially hegemonic discourses that take restrooms outside a production area as absolute. In addition, this work also contributes to society by providing ways to improve sanitation for people at work. Specifically, this work contributes to the literature by describing a case of modular washrooms located within the facility, disconnected from its perimeter walls. The case involves designing a new plant for a Brazilian garment production company. Systematic Layout Planning (SLP) is applied to design plant layouts, taking into account both washroom locations and plant operational processes. In the evaluation step of SLP, Discrete-Event Simulation is employed to assess the hourly output of the plant, while Net Present Value (NPV) is adopted to determine the economic feasibility of placing washrooms inside the production area. The results indicate that profitability is dependent on the unit profit per product. The remainder of this paper is organized as follows. Definitions are presented in Section 2. Related works are revised in Section 3. A review of the Systematic Layout Planning method and Discrete-Event Simulation is presented in Sections 4 and 5, respectively. Section 6 provides computational results. Finally, conclusions are provided in Section 7.

2. Definitions

In this paper, “toilet” is defined as the equipment people use for urination or defecation. “Restroom” is defined as a room in which there are toilet(s), sink(s), and maybe shower(s). A washroom is a room that has toilet(s) and hand-basin(s) with sink(s). A “bathroom” is defined as a room in which there is a toilet, a bathtub, and a sink. In this paper, the term ``sanitation facility" means a set that may include restrooms or washrooms, as bathrooms are less commonly found in workplaces. According to Muther and Hales [18], the term “facility” refers to the physical assets required for an enterprise to function. This encompasses various components such as land or real estate, buildings or structures, process machinery, and both stationary and mobile support equipment. Additionally, facilities also encompass storage warehouses, offices, laboratories, service areas such as maintenance shops and boiler rooms, as well as auxiliary features like car parking, cooling ponds, and water towers. In this paper, the term “facility” refers only to a physical location, such as a warehouse, service area, or factory.

A “facility layout” refers to the interconnections and arrangements between different sanitation facilities and process machinery, along with both stationary and mobile support equipment, within a facility space. Facility layout planning is the process of proactively determining the facility layout that should be implemented to achieve a desired outcome, i.e., an arrangement that meets acceptable standards and promotes optimal efficiency and functionality.

3. Related Work

While there are some papers about how to optimize the number and position of bathrooms in public spaces [19, 20], there is a literature gap for the theme of how to optimize facility layout considering the washroom position in it. For instance, Table 1 shows the number of peer-reviewed journal papers written in English, indexed in the Web of Science (WoS) and Scopus databases as of September 2025 that contain in their titles, abstracts, or keywords terms related to washroom and layout separately, as well as the combination of these terms. As a result, the number of papers on the topics related to layout and sanitation facilities separately is high. However, the number of papers related to layout optimization considering sanitation facility location is limited to four, and none of these papers address an optimal facility layout that incorporates a sanitation facility.

Table 1. Peer-reviewed papers in WoS and Scopus databases

Theme	Research Protocol	Number of papers in WoS	Number of papers in Scopus
Washroom	toilet OR bathroom	11,677	17,619
	OR restroom		
	OR lavatory		
	OR washroom		
Layout	"systematic layout planning"	6,192	7,113
	OR "layout optimization"		
	OR "layout design"		
	OR "facility layout"		
Washroom and layout	(toilet OR bathroom	4	4
	OR restroom		
	OR lavatory		
	OR washroom)		
	AND		
	("systematic layout planning"		
	OR "layout optimization"		
	OR "layout design"		
	OR "facility layout")		

To the best of the author's knowledge, this is the first paper to address the problem of facility layout planning that considers the possibility of incorporating sanitation facilities into the production or storage area. Focusing on the Systematic Layout Planning (SLP) method, on which this paper's method is based, the literature has applied it in various fields, as shown in Table 2.

4. Methodological Review of Systematic Layout Planning

Systematic Layout Planning (SLP) [18] steps are illustrated in Figure 1 and are detailed below.

4.1. Obtain Data: P, Q, R, S, T

According to Muther and Hales [18], layout planners need to acquire information on five key elements: Products (P) encompassing raw materials, purchased parts, finished goods, product families, models, or services offered by the plant; Quantity (Q) representing the number of goods or services produced; Routing (R) detailing the manufacturing process, operations, flow, and equipment involved; Supporting Services (S) comprising auxiliary activities like maintenance, tool rooms, restrooms, and cafeteria; and Time (T) indicating production schedules, including batch frequency, urgency, or seasonality.

4.2. P-Q Chart Analysis

Products and their corresponding quantities enable a volume-variety analysis, often represented using a P-Q Chart [18]. This chart helps identify the most suitable layout type for each product. Some products lean towards mass production, favoring a product-oriented layout, while others may require a fixed position layout at the opposite extreme. Additionally, the volume-variety analysis often leads to the division of layout areas into “fast-movers” (high-volume, low-variety) and “slow-movers” (low-volume, high-variety) [18, p. 3-6]. Routing, supporting services, and time can also influence this division process [18, p. 3-8].

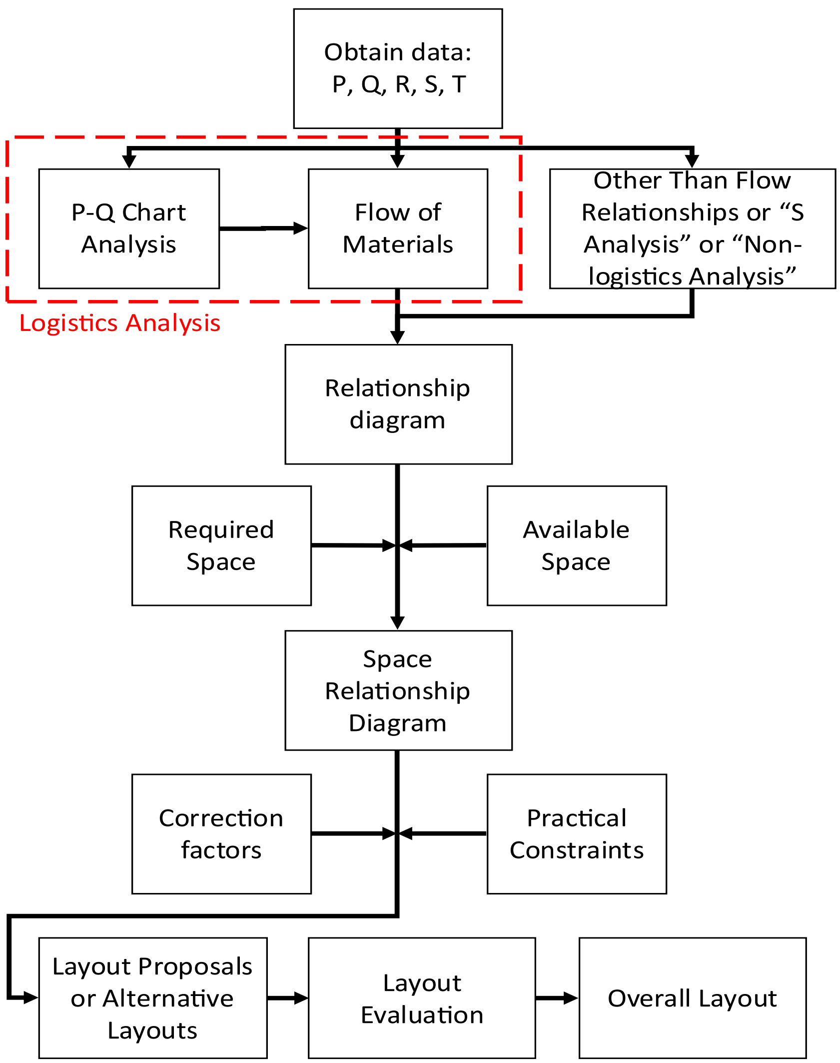


Fig. 1 Systematic layout planning steps

Table 2. Summary of the literature on systematic layout planning

Ref.	Method for layout generation	Method for layout evaluation	Ref.	Method for layout generation	Method for layout evaluation
[21]	SLP	not mentioned	[37]	QFD + SLP	AHP
[22]	SLP	expert analysis	[38]	SLP + GA	AHP
[23]	SLP + SPA	weighted scenario analysis	[39]	SLP	expert analysis
[24]	GA + TS	expert analysis	[40]	SLP + Lean	AHP
[25]	SLP	AHP	[41]	TDPN + SLP	DES
[26]	SLP + Lean	minimization of material flow	[42]	SLP	AHP
[27]	SLP	experts interview	[43]	SLP + GA	AHP
[28]	SLP	Fuzzy-AHP	[44]	SLP	expert analysis
[29]	SLP	expert analysis	[45]	SLP + GA	not mentioned
[30]	SLP	expert analysis	[46]	SLP + GA vs. GAN	expert analysis
[31]	SLP	fuzzy linguistic variable + DES	[47]	SLP	not mentioned
[32]	SLP	expert analysis	[48]	SLP + Lean	expert analysis
[33]	SLP	expert analysis	[49]	SLP	fuzzy AHP + VIKOR
[34]	SLP	DES + Promethee	[50]	SLP	AHP
[35]	SLP + QP	expert analysis	[51]	SLP + MP	FCT
[36]	SLP	FCT	[52]	SPL	fuzzy-TOPSI
			This	SPL + Corelap	DES + NPV

Legend: SPA - Shortest path algorithm; GA - Genetic Algorithm; TS - Tabu Search; QP - Quadratic Programming; TDPN - Time Delay Petri NET; GAN - Generative Adversarial Network; MP - Mathematical Programming; AHP - Analytical Hierarchy Process; FCT - Fuzzy Constraint Theory; DES -Discrete-Event simulation; NPV - Net Present Value.

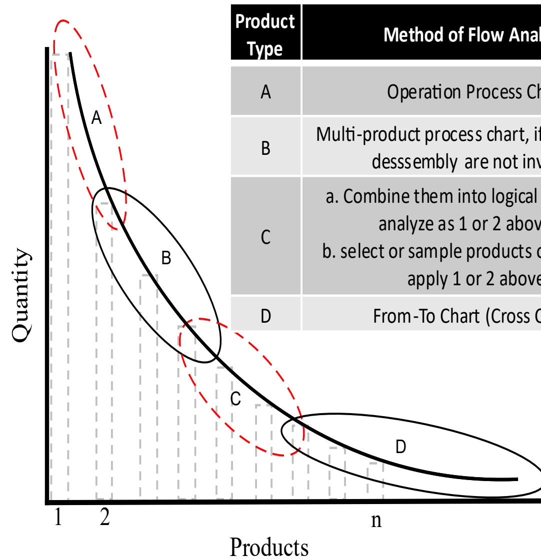
It is worth noting that authors [18] also recommend considering the company's product portfolio in the medium and long-term planning. This is important because, as products approach the end of their life cycle, certain facilities associated with them may be removed from the process. On the other hand, as new products are introduced into production, new facilities may need to be added, which can impact the overall plant layout.

4.3. Flow of Materials

After obtaining routing information, the material flow within the process is examined. The flow of materials refers to the sequence of material movement between different activities and the intensity or magnitude of this movement [18]. Typically, this intensity is computed as the number of pieces moved for a specific period multiplied by the unit measure per piece.

From a flow of materials perspective, the best layout will be the one that minimizes route distances times their intensities. Muther and Hales [18] have suggested that the P-Q Chart can serve as a guide for determining the appropriate chart for flow analysis based on the quantity of each product, as shown in Figure 2.

Figure 2 illustrates the quantity produced for *n* products. Depending on this quantity, products can be classified into four types: A, B, C, or D. Each product is associated with a specific method for analyzing the material flow. Section 6 explains the Operation Process and Multi-Product Process charts. From-To charts are commonly used to represent the intensity of multiple items in a two-way flow between activities and complement other layout planning charts. Figure 3 represents an example of a From-To chart for 3 operations (or activities). In this figure, as an example, the flow from the "Receiving" operation to the "Cutting" operation is 200 units over a certain period of time.



Product Type	Method of Flow Analysis
A	Operation Process Chart
B	Multi-product process chart, if assembly or desssembly are not involved
C	a. Combine them into logical groups and analyze as 1 or 2 above; or b. select or sample products or items and apply 1 or 2 above.
D	From-To Chart (Cross Chart)

Fig. 2 Method for the flow analysis based on the P-Q Chart
Source: Based on [18, Chapter 4]

Another chart that shows time and product process is the Process Flow chart, as exemplified in Figure 4. In this chart, from the sixth line onwards, each line represents an activity. By coloring one icon in any of the columns from the third to the seventh per activity, the sequence of colored icons outlines the process flow. In this example, the process flow is as follows: first, an operation; second, a transportation activity; third, the product is stored; and finally, it joins a queue (delay).

Operations or activities		TO		
		Receiving	Cutting	Painting
FROM	Receiving	x	200	100
	Cutting	0	x	0
	Painting	0	50	x

Fig. 3 From-to chart example

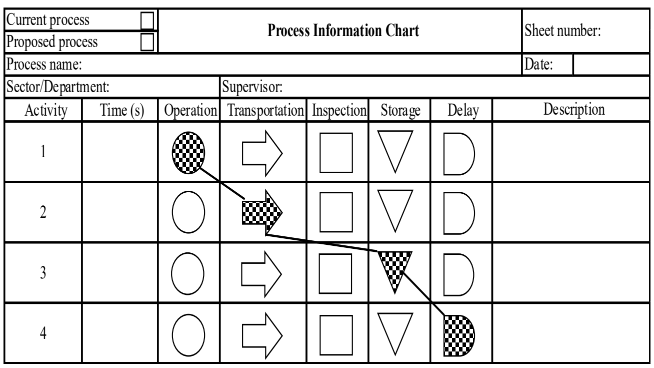


Fig. 4 Process flow chart

Muther and Hales [18] mention the grouping strategy for products of types C and D, but this strategy can also be applied to other product types without any loss. Grouping or clustering products into families is a common practice in the industry, especially when dealing with a large number of products.

Group Technology (GT) [53] provides a way to facilitate this grouping process, and its benefits have been discussed in the industry for years [54]. Moreover, GT can serve as a precursor to adopting Cellular Manufacturing (CM) [55] or as a basis for developing algorithms to optimize CM formation [56].

4.4. Other Than Flow Relationships

In Figure 1, "Logistics-Analysis" refers to the combination of P-Q Chart and Flow of Material analyses. The term "Other Than Flow Relationships" is used in the literature to describe a set that encompasses "Non-Logistics Analysis" and "S Analysis". The concept "Other Than Flow Relationships" captures how close the operations participating in the material flow should be to supporting activities (non-logistics activities) such as pallet rack storage areas or washrooms, as well as to elements such as natural lights or eye contact from a specific position. To represent these relationships, a Relationship Chart, as proposed by Muther and Hales [18], is used, with an example shown in Figure 5.

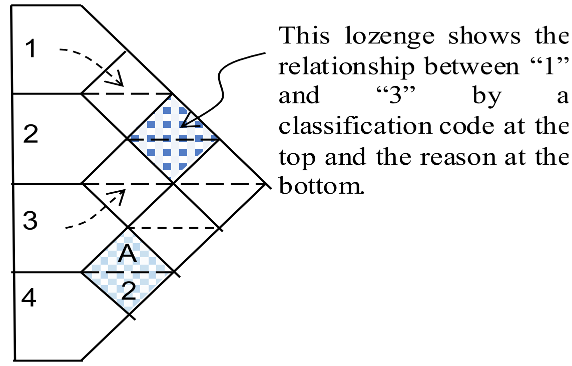


Fig. 5 Relationship chart considering 4 activities or things

The Relationship Chart identifies the activity or element being analyzed for proximity in the first column. Each activity or element i is related to another activity or element j, with their relationship represented by a lozenge that links their diagonal paths on the chart. Each lozenge is divided into two triangles: the top specifies the classification code, and the bottom triangle displays the reason code associated with that classification. For example, in Figure 5, the relationship between activities or elements "3" and "4" is classified as "A" due to reason "2". Muther and Hales [18] proposed six classification codes for proximity. The reasons for these classifications can vary depending on the project. Examples of these classifications, along with their corresponding reasons, are provided in Figure 6.

Code	Proximity
A	Absolutely necessary
E	Especially important
I	Important
O	Ordinary closeness ok
U	Unimportant
X	Not desirable

Code	Reason
1	convenience
2	Share same personnel
⋮	⋮
N-1	Reception of visitors
N	Natural light

Fig. 6 Classification codes and their reason for a relationship chart

When constructing the Relationship Chart, it is essential to exclude activities that overlook the importance of non-material flow activities or other elements. As a consequence, the intensity of material flow activities should be translated to the classification codes and then combined with the Relationship Chart, resulting in a Combined Relationship Chart. Further details on this process can be found in [18, Appendix IV].

4.5. Relationship Diagram

Using an illustrative Combined Relationship Chart as input, the construction of the Relationship Diagram is demonstrated in Figure 7. In this figure, the first step lists separately all A, E, I, O, and U relationships from the Combined Relationship Chart. Each relationship involves two nodes (activities or elements) connected by at least one edge. The number or format of the edges represents classification codes. The second step is to construct a connected graph with only the A relationship. From the third step onward, E, I, O, U, and X relationships are sequentially added to this graph. At each addition, the resulting graph should be adjusted to minimize edge crossings without altering the existing connections. The final graph, obtained after the sixth step, is the Relationship Diagram.

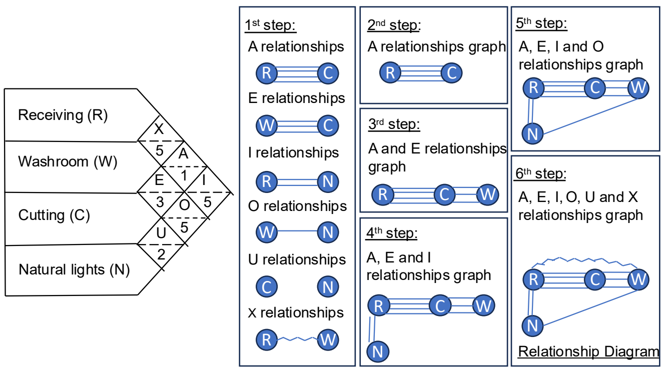


Fig. 7 Relationship diagram construction process

4.6. Required and Available Space

Once operational activities and supporting services are defined, their required resources must be specified. This step is crucial for determining the infrastructure required to support those activities and services. For example, washrooms will accommodate people, require water and electricity, and generate sewage. Therefore, infrastructure considerations must include plumbing, electrical wiring, and appropriate door access. Additionally, the dimensions (length, width, and height) of each area must be defined. Similarly, for a machinery and equipment area, both the entry and exit of products must be accounted for. This may require aisles and maneuvering space for transportation equipment, such as forklifts or conveyors. Additionally, machinery may need electricity or water, which requires the appropriate infrastructure. The floor in this area must be designed to support heavy loads. If ventilation or exhaust systems are necessary above the machinery, space for these systems must also be planned. Looking to the future, the need for new facilities should be considered, along with the flexibility for potential layout changes and the expansion of the production plant.

Thus, the required space must be defined for each operational or supporting area, taking into account physical features and restrictions. This includes space for each physical instrument itself (such as machines, toilet, rack pallet, etc.), the space for operator(s) or user(s), space for maintenance access, space for movement of parts during the operation or usage, space for intermediate inventory and tool(s) used in the process, and the space for receiving and dispatching products.

This paper utilizes a spreadsheet template illustrated in Figure 8 to record information about the required space. The first column of this template identifies the operational or supporting area, with its main function selected among the options in the second to eighth columns. The column "Space needed [m x m]" contains nine blocks per line, as indicated by the arrow pointing to them in the first line of Figure 8. The center block contains the dimensions of the physical instrument, while the eight surrounding blocks specify the required space dimensions in front, behind, beside, and at the corners of the instrument.

As an example, the second line of the template in Figure 8 indicates that the fictitious process "Drill over table" has 3 units of a drill, each with a height of 1.2 meters, a weight of 20 kg, and is categorized as "Machine or Equipment". The space required for each unit of this equipment is as follows: itself, 0.5m x 1m; at its front, 1m x 0.5m; at its right, 0.7m x 0.7m; at its left, 0.6m x 0.5m. No space is required at corners 2 and 3, nor at the back of this equipment. Available space is determined by the dimensions of the perimeter of a given area.

Name and description	Main function							Quantity	Height [m]	Weight [kg]	Space needed [m x m]			Obs.
	Machine or Equipment	Workstation	Storage	Transporter	Production service	Workers service	Other							
											corner 2	right	corner 1	
											back	physical instrument itself	front	
											corner 3	left	corner 4	
Drill over table	x							3	1.2	20		0.7x0.7	0.5 x 0.5	
												0.5 x 1	1 x 0.5	
												0.6 x 0.5	0.5 x 0.5	

Fig. 8 Space needed for a given process

4.7. Space Relationship Diagram

In this step, the information obtained about the required space will be integrated with the Relationship Diagram to create the Space Relationship Diagram. As an example, consider the Relationship Diagram shown in Figure 7. Let us assume the total space required for activity R is 1m x 1m, for activity C is 1.5m x 1m, for supporting service W is 1.2m x 2m, and for feature N is zero (only proximity to a window is required). In this case, a Space Relationship Diagram could be represented in Figure 9.

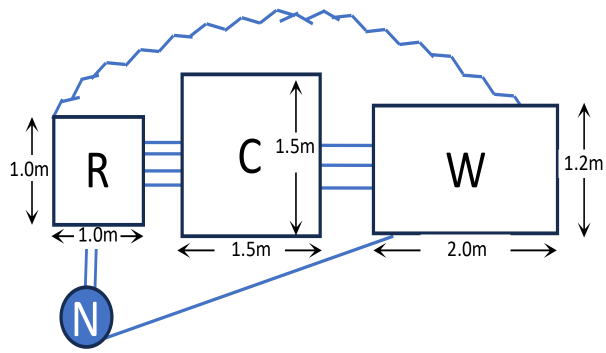


Fig. 9 Space relationship diagram example

4.8. Correction Factors, Practical Constraints, Layout proposals, or Alternative Layouts

Initially, based on the Space Relationship Diagram, some alternative layouts can be created. Various algorithms for layout generation or layout optimization are available in the literature [57, Ch. 7, Section 4], [58]. Once the initial layouts are generated, correction factors and practical constraints are applied to them.

Correction factors consider features such as the desired natural light for certain areas (as shown in the examples of Figure 7 and Figure 9) or the rotation of specific areas.

Practical constraints include the existence of walls or columns in the facility, adherence to codes and regulations, aisle requirements, and other factors. Layout alternatives that incorporate these factors and constraints are then proposed for further evaluation.

4.9. Layout Evaluation and Overall Layout

Layout alternatives are evaluated according to specific criteria, and the one that best meets these criteria is selected for implementation in reality. A list of 20 possible criteria (factors) can be found in [18], Appendix XII.

In the literature, a common method for evaluating these factors is the weighted sum approach, referred to as "factor analysis" in [18, pp. 10-7]. A metric for the weighted sum approach is represented by Expression (1).

$$\sum_{i \in I} (w_i \times f_i) \tag{1}$$

where I is the set of criteria, w_i and f_i are the weight and rate, respectively, of the criterion $i \in I$. Both weight and rate are subjectively chosen. Frequently, material flow is one of the most important factors considered by managers [18, pp. 10-17]. In this context, Simulation Modeling and Analysis [60] can be used to assess the productivity of the entire facility's operation process for each layout alternative. With the profitability of the operation projected, alternative layouts can be compared based on their initial investment and projected profitability using Net Present Value (NPV) [18]. NPV represents the sum of all future cash flows, both negative and positive, over the lifetime of an investment, discounted to their present value.

An investment with a positive NPV indicates profitability, while a negative NPV suggests a net loss. Considering D^p as the project duration in months, C_t as the net cash inflow during the month t, C_o as the total initial investment costs, and r as the required rate of return, the Net Present Value (NPV) is given by Equation (2).

$$NPV = \sum_{t=1}^{D^p} \frac{C_t}{(1+r)^t} - C_o \tag{2}$$

5. Methodological Review of Discrete-Event Simulation

The methodological steps of Discrete-Event Simulation (DES) are represented in Figure 10 and summarized below. For a detailed explanation of DES, the reader is referred to [59, 60].

5.1. System Definition

In Figure 10, the starting point for building a discrete-event simulation model is to define the system - whether real or hypothetical - that will be modeled. A system could be, for instance, some processes within a manufacturing system or the services provided in a hospital. A set of processes that could represent a system in which a client enters a bakery, orders bread, pays for it, and then leaves could be represented by the flowchart in Figure 11.

Decision-makers often use simulation to test scenarios and evaluate system characteristics, such as client waiting times in queues or daily productivity. This need guides the objective of the simulation study itself. After defining the simulation's objective, the system elements to be modeled are chosen.

A manufacturing system model, for example, would incorporate workers, machines, and product components. In the example of Figure 11, the bakery clerk, the client, and the cashier could be the selected system elements.

5.2. Conceptual Model Creation

The conceptual model represents a system in a physical medium (paper, digital file, etc.) using flowcharts or diagrams. According to [61, p. 36], the conceptual model is the result of conceptual modeling, a process that captures the essential features of the system under study. Thus, the representation of how the selected system elements interact with each other, as shown in Figure 11, is a Conceptual Model.

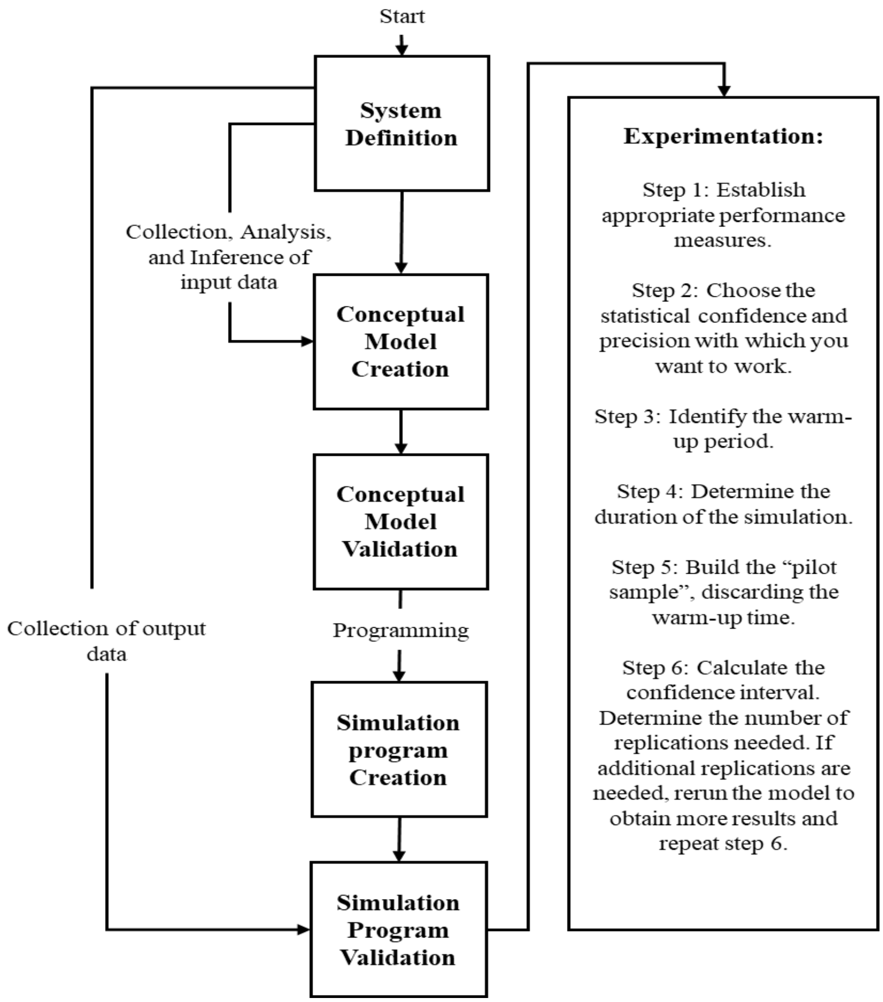


Fig. 10 Discrete-Event Simulation steps.
Source: Based on [60]

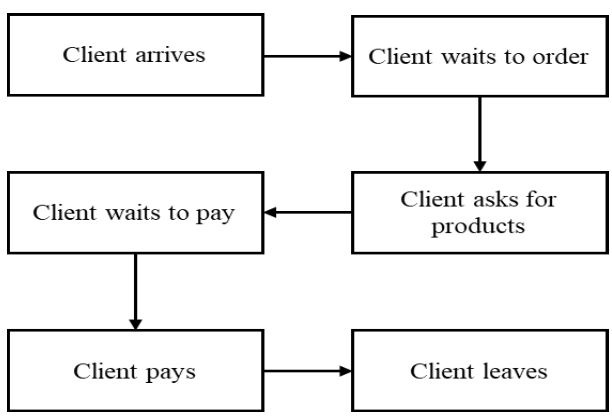


Fig. 11 Example of a set of processes representing a system

Input data for activities in the simulation model must be collected from the system. For instance, input data is necessary to represent the duration of a given process. In most cases, systems involve random phenomena, such as the service time the bakery clerk needs to serve breads, cakes, and other products to a client. Thus, the activity duration is a random variable - a function that associates each possible outcome of a random experiment with a real number. Inferring the probabilistic behavior of random variables associated with the system's random phenomena needs data collection, analysis, and inference. Details about data collection, analysis, and inference are available in [62].

Thus, after inferring the input data, the probability distribution for each random variable will be fitted and used to complement the conceptual model. For example, using Figure 11, if the activity "client enters a bakery" is fitted to an exponential distribution with mean μ, EXP(μ), and the remaining activities are fitted to a log-normal distribution with mean μ and standard deviation σ, L(μ,σ), the final conceptual model could be updated as per Figure 12.

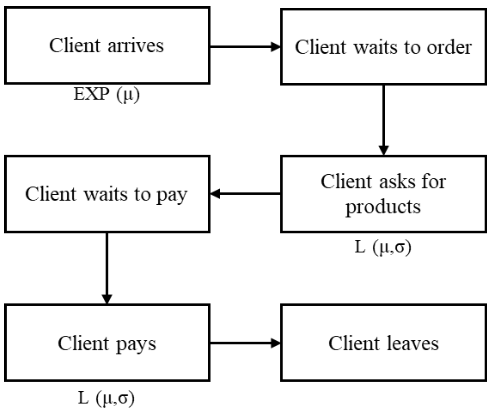


Fig. 12 Conceptual model with distribution probabilities for the duration of activities

5.3. Conceptual Model Validation

The conceptual model must be validated using the system's features. Various validation techniques are discussed in the literature [59, 60]. One such technique is "face-to-face validation," which involves one or more experts who are familiar with parts of the system. The experts validate whether the conceptual model, in terms of flow and logic, adequately represents the system's processes.

5.4. Simulation Program Creation

The conceptual model serves as input to the process of implementing a simulation program, or in other words, a computational model. Programming languages or simulation software may be used for that purpose.

5.5. Simulation Program Validation

The validation of the implemented computational simulation model, named "operational validation", is the process in which one evaluates how properly inputs and outputs of the computer model are mapped onto the inputs and outputs of the real system for a specific study objective, in such a way that it is operational for experiments. Let us define μ^r as the parameter representing a performance measure from the system, the estimator of this parameter may be the sample mean. $\overline{x^r}$, and the system output data will be observations of this estimator. For instance, if the performance measure is the hourly throughput, at each hour i, the throughput value will be an observation $\overline{x_i^r}$ of the performance measure. These observations must be collected from the system in a steady-state, to be compared with output data from the simulation model. From the simulation program model, performance measures are estimated. Banks et al. [60, p. 415] state that when random number generators are used to provide input data for a simulation model, the resulting performance measures will also be random, thus requiring statistical analysis. Let μ^s be a parameter representing a performance measure from the simulation model. Thus, the estimator sample mean, $\overline{x^s}$, has accuracy measured by a standard error ($s^s/\sqrt{n}$, where s^s is the standard deviation and n is the sample size) or by the length of confidence intervals for μ^s [60, p. 421].

Let x_j^s be the random variable representing the performance indicator $j \in J = \{1,2,\dots,m\}$. If $x_1^s, x_2^s, \dots, x_m^s$ composing a stochastic process, the values of their observations will not be independent and will be identically distributed in a single replication of the simulation model. For this case, Law [60] proposes using multiple replications of the simulation model in such a way as to have x_{ij}^s as the performance indicator $j \in J$ for the replication $i \in I = \{1,2,\dots,n\}$ of the simulation model. Thus, the parameters $\overline{x_i^s}$ and s_i^{s2} are estimators for the population mean and the population variance, respectively, regarding the performance indicators for replication $i \in I$ when Equation (3) and Equation (4) hold.

$$\overline{x_i^s} = \frac{1}{m}\sum_{j=1}^{m} x_{ij}^s \tag{3}$$

$$s_i^{s2} = \frac{1}{m-1}\sum_{j=1}^{m}(x_{ij}^s - \overline{x_i^s})^2 \tag{4}$$

Both $\overline{x_i^s}$ and s_i^{s2} are random variables, since each replication uses input data obtained via random number generators. Thus, estimators for the mean and variance of $\overline{x_i^s}$ are given by Equation (5) and Equation (6), respectively.

$$\overline{x^s} = \frac{\sum_{i=1}^{n} \overline{x_i^s}}{n} \tag{5}$$

$$s^{s2} = \frac{1}{n-1}\sum_{i=1}^{n}(\overline{x_i^s} - \overline{x^s})^2 \tag{6}$$

A $(1-\alpha)\%$ confidence interval for $\overline{x_i^s}$ is given by Expression (7).

$$\overline{x^s} \pm H \tag{7}$$

where H is the precision as per Equation (8)

$$H = t_{\alpha/2,n-1}\,\frac{s^s}{\sqrt{n}} \tag{8}$$

And $t_{\alpha/2,n-1}$ is the $(1-\alpha/2)$ percentile of the Student's t-distribution with $n-1$ degrees of freedom. A way to validate the simulation program model is to create a Confidence Interval (CI) for $\mu^r - \mu^s$. If this CI includes the value of zero, that means the difference between μ^r and μ^s may not be significant, which validates the simulation program model as a source of reliable output data. The execution of replications of the simulation model follows the instructions of block "Experimentation" displayed in Figure 10, as discussed in the next subsection.

5.6. Experimentation

There are six steps to use the simulation program for operational validation purposes or to test scenarios. The first step is to obtain output data from the simulation. Therefore, one must establish the performance measures.

In general, they are related to the objective of the simulation study, which was defined in the system definition step. Since statistical estimation will be performed, statistical confidence, α, and precision, H^*, are chosen by the decision-maker in the second step.

In the third step, the warm-up period is identified. By definition, a warm-up, or transient period, is the name given to the period of time during which the system is in a "transient state". During the transient state, the system's performance is strongly related to its initial conditions. In opposition, "steady state" is the period of time during which initial conditions no longer influence the system's performance estimates.

When the study focuses on the steady state, as in the case study presented in this paper, data from the simulation model and the system during the transient state are not used to construct confidence intervals. The identification of the warm-up period implies identifying data that belongs to the transient state and then eliminating it from further analysis.

One way to identify the warm-up period is the graphical method [60, p. 437]. It involves visually identifying when a performance measure approximately converges to an average within a certain variation. For instance, in Figure 13, the warm-up period was defined as 8 minutes because, by this time, the performance measure appeared to converge within the specified limits from 55 to 65.

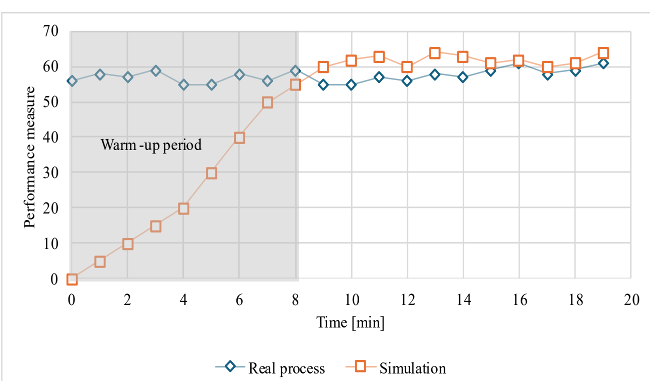


Fig. 13 Warm-up period definition via graphical method

The fourth step is to define the duration of the simulation, which Banks et al. [60, p. 444] propose to be at least 10 times the warm-up period. The fifth step is to build a pilot sample, discarding data from the warm-up period. The pilot sample will consist of executing the simulation model for n times, which gives the number of initial replications of the simulation model. Each replication will provide an observation of the performance measure. During this process, the sample mean, sample variance, and precision H are computed. If the confidence interval achieves the desired precision H^*, step six is skipped. Otherwise, the sixth step is performed. The sixth step is repeated in a loop until the confidence interval achieves the desired precision, which is achieved by the approximate number of replications, n^*, determined using Equation (9).

$$n^* = \left\lceil n \left(\frac{H}{H^*}\right)^2 \right\rceil \tag{9}$$

where $\lceil x \rceil$ results in the first integer greater than x.

6. Results and Discussion

In this section, a case study is presented to support the analysis of positioning a washroom within a production plant. As the object of study, this work examines a Brazilian garment production company that plans to construct a new plant spanning an area of 45 m × 45 m. This plant will be located in a plot of 55m x 125m, as shown in Figure 14, in the city of Senador Canedo, state of Goiás (Brazil). The nearest weather station to the city reports that the average hourly temperature during working hours exceeds 24^{o}C for most of the time [63]. Between 2022 and 2024, the company maintained an average of 30 employees per year and several outsourcing contracts. As part of its strategic plan, the company aimed to hire an additional 70 employees.

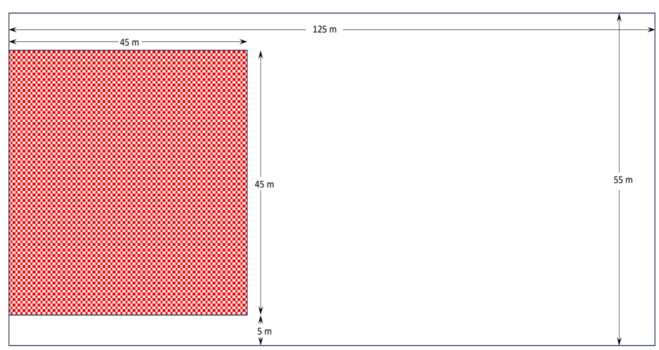


Fig. 14 Plant location in the plot

In the following subsections, the application of SLP to this company's case is described.

6.1. Obtain Data: P, Q, R, S, T; and Perform Logistic Analysis

The company comprises seven main departments: storage, paper printing, Layering and Cutting (LC), sublimation printing, sewing, silk screen printing, and finishing. The company's product portfolio comprises 148 items produced according to a make-to-order policy, i.e., after a customer's order is received. The products were categorized into families using Group Technology. Figure 15 illustrates the P-Q Chart displaying these product families with a zoomed-in view of the third to ninth families.

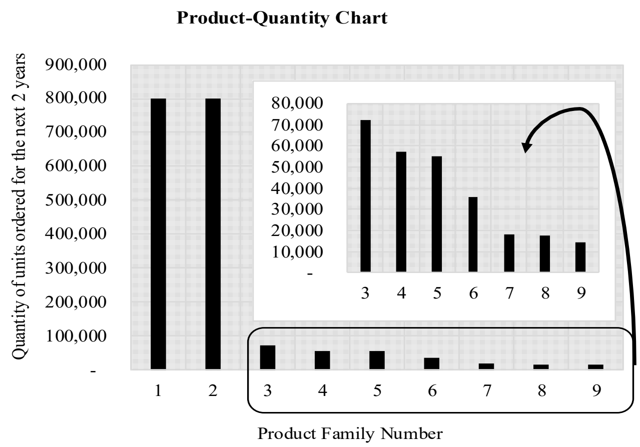


Fig. 15 P-Q chart

Flow Process Charts for the first two families are shown in Figure 16. According to Muther and Hales [18], an operation process chart typically employs symbols denoting "operation" and "inspection," as specified in the legend of Figure 16. Conversely, if the chart utilizes other symbols, it is considered a flow process chart. In either case, the assembly work begins in the upper right corner, indicating the introduction of the initial component in the production process. Additionally, horizontal lines represent the material feeding into the process, while vertical lines indicate the chronological sequence of process steps.

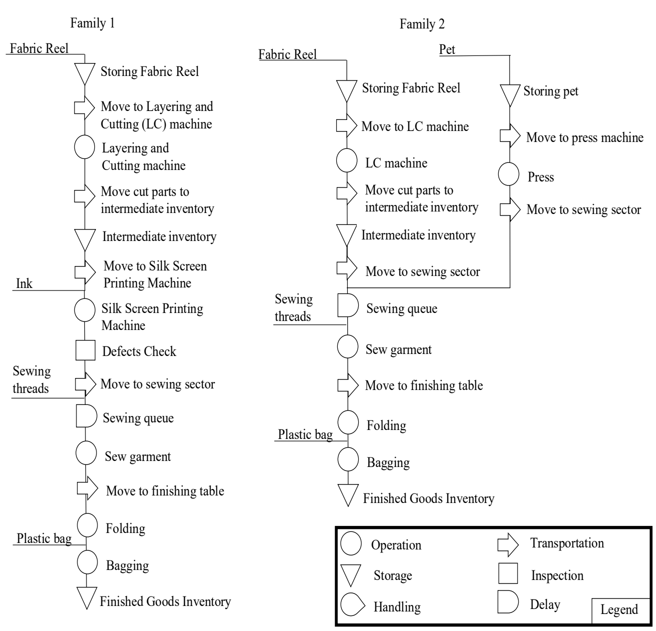


Fig. 16 Flow process charts for product families 1 and 2

The multi-product process chart shown in Figure 17 provides an overview of the material flow for the remaining product families.

Operation	Product Family 3	4	5	6	7	8	9
Layering and Cutting	1	1	1 1	1	1	1 1	1
Paper Printing			2			2	
Sublimation Printing			2 3			2 3	
Silk Screen Printing		2					2
Sewing	2	3	3	2		3	3
Folding	3	4	4	3		4	4
Bagging	4	5	5	4	2	5	5

Fig. 17 Multi-product process chart for product families 3 to 9

In this chart, the first column illustrates the operations that may be common across products. Each subsequent column represents the ordered sequence of operations for a specific product family. For products in family 7, the sewing operation is currently outsourced but could potentially be integrated into the material flow within the new plant in the future. For products in families 5 and 8, an additional flow is introduced for sub-components that undergo paper printing and are later integrated with the main product at the sublimation printing stage. The time spent on bagging without folding is negligible. Therefore, from this point forward, the term "finishing" will refer to the combined processes of bagging and folding.

The From-To Chart for the company's production processes is presented in Figure 18, with flows measured in thousands of units. For example, the flow from storage to the layering and cutting process is $1872.316 \times 1000 =$ 1,872,316 units. The flow data is derived from the P-Q Chart, which covers two years of planned production, with proportions assumed for shorter time periods.

Operations or activities		TO: Storage	Layering and Cutting	Paper Printing	Sublimation Printing	Silk Screen Printing	Press	Sewing	Finishing	Shipping
FROM	Storage	x	1872.316	72.989	-	-	800	-	-	-
	Layering and Cutting	-	x	-	72.989	872.792	-	908.299	18.236	-
	Paper Printing	-	-	x	72.989	-	-	-	-	-
	Sublimation Printing	-	-	-	x	-	-	72.989	-	-
	Silk Screen Printing	-	-	-	-	x	-	872.792	-	-
	Press	-	-	-	-	-	x	800	-	-
	Sewing	-	-	-	-	-	-	x	1854.08	-
	Finishing	-	-	-	-	-	-	-	x	1872.316
	Shipping	-	-	-	-	-	-	-	-	x

Fig. 18 From-to-chart for the production processes in thousands

The company's production schedule consists of large batches, each taking a few days to complete. The only seasonal factor affecting production occurs in the two months preceding governmental elections and ends on the day of the election. During this period, the production of normal contracts is paused to focus on election-related products, a cycle that repeats every two years. The data used in this paper were collected over a five-month period, during which no elections took place. Supporting services include a storage area for raw materials, a manager's office, cleaning tanks, and washrooms. The cafeteria and restroom were previously planned outside the facility and were therefore removed from the scope of this work.

6.2. Other Than Flow Relationships

The "Other Than Flow Relationships" analysis highlighted two key desires of the managers. The first is to place a workstation within the paper printing department to allow visibility of the entire back of all printers. The second is to place washrooms as close as possible to the sewing and finishing processes, as approximately 70% of the company's workforce is involved in these processes, and 99% of those employees are women, who, for biological reasons, need to visit the washroom more frequently than men. An aggravating factor for the frequency of these visits is the facility's internal temperature, which can exceed 30^oC. In such high temperatures, employees tend to drink more water to stay hydrated, leading to more frequent trips to the washrooms. Although the company always permits these visits, the time employees spend away from their workstations has a negative impact on production. To estimate this impact, a Monte Carlo Simulation (MCS) was conducted using the metric in Equation (10).

$$
\begin{aligned}
&O = \sum_{i \in I} \left(l_i \times n_i \times t_i \right) \\
&t_i = d_i / s \times x_i \ \forall\, i \in I
\end{aligned}
\tag{10}
$$

where O is the total daily opportunity cost [\$], l_i represents the assumed average opportunity cost per hour for each paused workstation in process $i \in I$ [\$/h], the decision variable n_i represents the number of employees assigned to process $i \in I$, t_i refers to the time a workstation at the process $i \in I$ is paused [s], the decision variable d_i represents the two-way distance from the workstation in process $i \in I$ to the nearest washroom [m], $s = 0.8$ is the assumed average walking speed [m/s], and the random variable x_i refers to the number of washroom visits per person in process $i \in I$, and I is a set containing two elements, c and f, representing the sewing and finishing processes, respectively.

Two hypothetical washroom locations were tested: one outside the facility, near the main entrance, with distances, $d_c = 33$ and $d_f = 74.6$, and another inside the facility, near the center, with $d_c = 11$, $d_f = 24$. With assumed values of $l_c = l_f = 100$, $n_c = 40$ and $n_f = 10$, locating the washroom outside the production area resulted in an average daily opportunity cost of \$ 226.76. In contrast, placing the washroom inside the production area led to an average daily opportunity cost of \$ 72.78. Thus, the opportunity cost differed by a factor of about three, depending on the washroom location. Although the washroom location was not a priority compared to the placement of the production process, it could become significant if space allows.

The Relationship Chart shown in Figure 19 was developed by combining the "Other Than Flow Relationships" and "Flow Relationship" analyses done by the managers of the company. For each department considered in the Relationship Chart, the required space was determined. For example, Appendix Figure 25 contains the template for the required space of the Silk Screen Printing process.

6.3. Relationship Diagram

Combining the required space and the Relationship Chart resulted in the Relationship Diagram in Figure 20. In this diagram, some edges display the bi-directional flow intensity between the connected departments, based on data from Figure 18. It is important to note that material flow was not the only factor considered by managers. For example, even though the flow intensity between "paper printing - sublimation printing" is the same as that between "sublimation printing - layering and cutting", the former is regarded as more important because paper printing exclusively serves sublimation printing. Similarly, while the flow through the "silk screen printing" process is comparable to the flow between "sewing, layering, and cutting", it is considered less critical. As one manager explained, "*paint can splash around the silk screen printing process, so it is preferable to maintain some distance*".

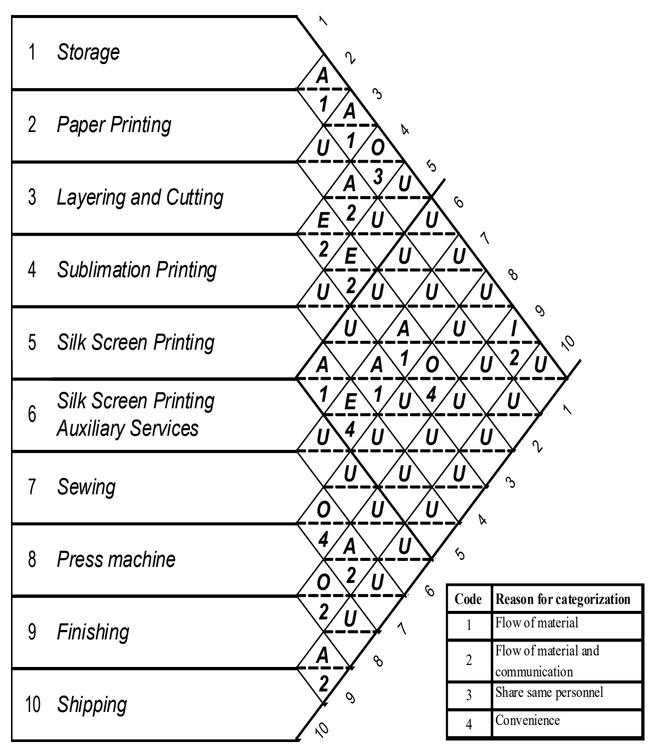


Fig. 19 Relationship chart for the case study

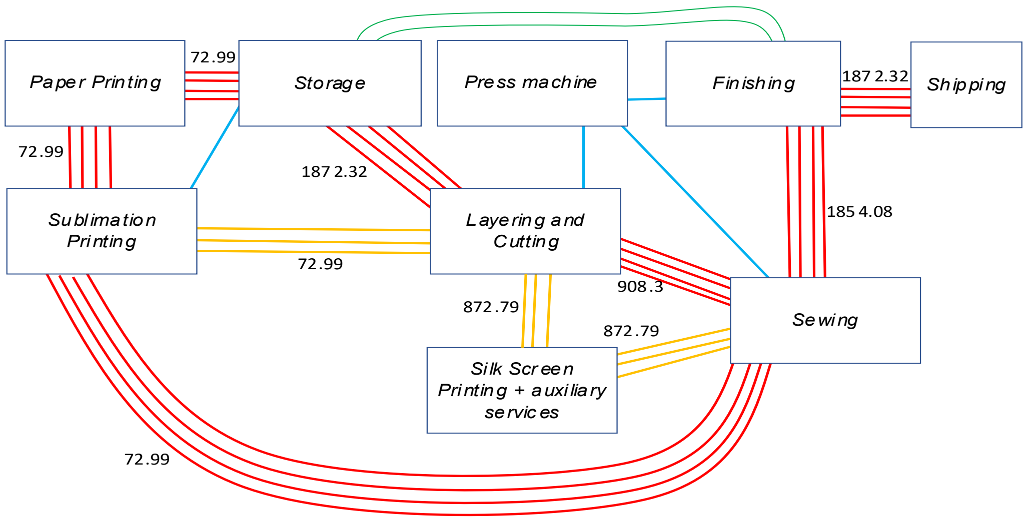


Fig. 20 Relationship diagram for the case study

6.4. Correction Factors, Practical Constraints, Layout Proposals, or Alternative Layouts

Practical constraints were identified: a) the paper printing process must be isolated from other processes to maintain proper temperature and humidity control for the printers; b) the only plant wall that can accommodate docks is the left one; c) the employee restroom will be located on the plant's left side, requiring an entrance on that wall; d) some auxiliary services for Silk Screen printing can be located outside the facility, connected to its wall; e) two columns are located in the center of the facility; f) Silk Screen Printing should have a mechanism to contain its dirtiness; and g) in future expansions, machines should be relocated as minimally as possible. Based on the required and available space, initial alternative layouts were created using CORELAP and manually adjusted with input from company operators and managers. Layouts that were impractical due to real-world constraints were eliminated from further analysis. Two alternative layouts, illustrated in Figure 21, remained for quick adjustments and evaluation. In the figure, the hatched area represents space for future expansion with the current infrastructure. Both layouts share several similarities: they feature a U-shaped design for product flow; in the storage area, they accommodate either pallet trucks with three rows of pallets or forklifts with two rows of pallets; they include perimeter aisles in compliance with Brazilian regulations. Additionally, both layouts allow for future expansion on the first floor beyond the hatched areas by moving the left wall outward, and on the second floor with mezzanines. The sewing, finishing, and shipping areas are highly flexible, allowing for various configurations. Both layouts are designed to facilitate easy supervision.

6.5. Layout Evaluation and Overall Layout

Layout A has some disadvantages compared to layout B: a) Without splitting departments, layout A does not allow for expansion of the layering and cutting department without disrupting other processes, whereas in the layout B, shifting the left wall outwards allows for that expansion with no disruption; b) The sublimation printing process in layout A is more expensive to install due to the need for an exhaust fan and vapor drainage piping, which is simpler in layout B; c) the aisle from cutting department to sewing department is narrower in layout A, which may cause congestion and impact negatively productivity. On the other hand, a serious drawback of layout B is that one of the layering and cutting machines may conflict with the plant's columns or pose a safety risk for workers operating near them under normal conditions.

For a more accurate assessment, both layouts have been refined and adjusted, as shown in Appendix Figure 26 and Appendix Figure 27. The evaluation criteria chosen by the company's managers consist of five factors: safety, installation cost, cost of future expansion, average daily output (linked to revenue), and storage effectiveness.

By "safety", managers were concerned about the risk of danger to people or equipment, although it is worth noting that pilferage or theft was not a concern for the managers. By "storage effectiveness", managers were referring to the limited space for intermediate inventory, which would increase the need for outsourcing and, consequently, raise costs.

Regarding safety in detailed layout B, the workstation for one of the layering machines must be adapted to prevent accidents involving the plant's column. This adjustment is necessary to eliminate the risk of the operator moving into the column, but it may affect the machine's productivity. In terms of installation cost, the primary difference between the layouts stems from the length of the piping required for steam drainage in the sublimation printing process. Local quotation estimates indicate that layout A is $10,700 more expensive per pair of sublimation printers than layout B.

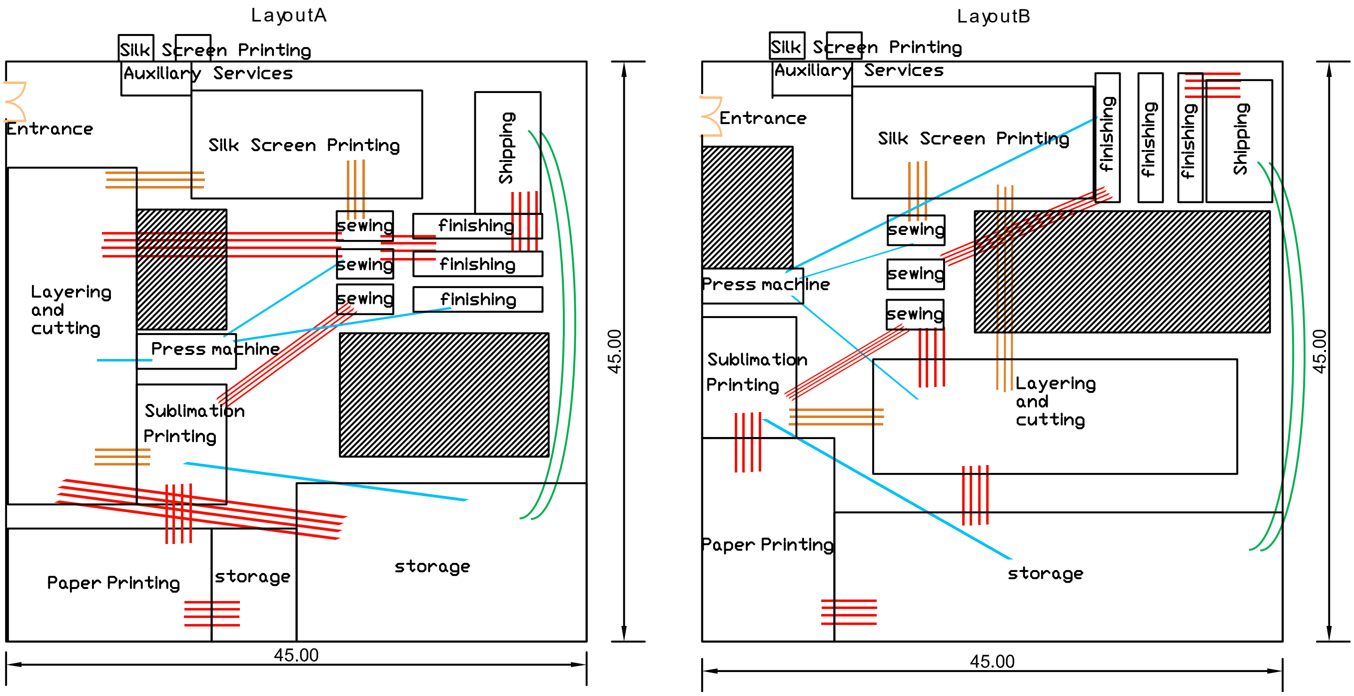


Fig. 21 Space relationship diagram for the two proposed layouts

An advantage of layout A over layout B is the larger expansion hatched area: layout A offers 311 m^2, whereas layout B provides a hatched area totaling only 187 m^2. Without requiring infrastructure changes, both layouts can easily accommodate either one additional silk screen printer, a few sublimation printers, or up to 70 sewing workstations in layout A and 42 in layout B. Aside from the higher installation costs for sublimation printers in layout A, the expansion costs without altering the infrastructure are quite similar for both layouts.

Expansion in the paper printer or layering and cutting departments requires infrastructure expansion in the building. In this case, the expansion must occur on the first floor of the plant by extending it 45 meters to the left, at an estimated cost of approximately \$5 million. A cutting machine is capable of moving and processing materials from parallel layering machines. In layout A, the expanding layering department requires the acquisition of a layering machine for each layering line, whereas in layout B, the line itself can be expanded without the need for any additional layering machines. The acquisition and installation of a layering machine costs approximately \$200,000 per unit.

In terms of operation, the product flow for the two product families with the highest intensities (Families 1 and 2, as illustrated in Figure 16) was overlaid on each layout, as shown in Figure 26 and Appendix Figure 27. Family 1's flow distance is 122m in layout A and 130m in layout B. Family 2's flow distance is 119m in layout A and 117m in layout B. It is important to note that these flows originate from the farthest position of the pallet rack and terminate at the storage area for finished products. To assess whether these differences, along with uncertainty conditions, significantly impact daily output, both layouts were modeled and evaluated using Discrete-Event Simulation (DES) Modeling and Analysis.

6.5.1. Discrete-Event Simulation (DES) Modeling and Analysis

In the following subsections, we detail the application of DES to this company's case, following the step-by-step procedure illustrated in Figure 10.

System Definition

The study objective of the simulation was to assess the daily output of product families. The system elements included scaled layouts, machines, operators, transporters, product families, and other resources.

Input Data

To simulate the processing and setup times of each production department, input data were collected for the following operations: paper printing, layering, cutting, sublimation printing, silk screen printing, pressing, sewing, and finishing. Eight weeks were randomly selected from a five-month period for sampling, ensuring that all operations for the product families were covered, except for families 6, 8, and 9, which were not in production at the time. The Kruskal-Wallis hypothesis test did not reject the null hypothesis of homogeneity for samples from the same process and product family, at a 95% significance level. The setup time for pressing involves heating the press machine, a process with a constant duration of 7 minutes. The finishing processing time for product family 7 is simply the task of bagging a batch of hundreds of pieces, taking less than 1 minute. Box plots for other processing and setup times are shown in Appendix Figure 28. Representative distribution functions were selected using R's fitdistrplus library, based on the lowest standard error. The sample size and distribution function for each of these random times are summarized in Appendix Table 5 and Appendix Table 6.

Conceptual Model - Creation and Validation

The conceptual model was represented through a series of flowcharts, such as those shown in Figure 16, and validated via the face-to-face technique by company managers in terms of material flow.

Simulation Program - Creation and Validation

After the validation, the models were implemented computationally using AnyLogic software. Initial verification was successfully conducted using constant input data.

In the company's old plant, the layering, cutting, and silk screen printing departments were located in a separate building from the rest of the departments. As a result, operational validation of the simulation model was conducted on a department-by-department basis. Hourly output from the real system was collected over 5 days of production (40 hours of working time). Similarly, simulation results were generated for 40 working hours, considering the real production schedule and Work-in-Process (WIP) levels equivalent to those of the real system.

Let us define the mean hourly output for the real system as $\overline{\mu_r}$ (estimation represented by $\overline{x_r}$) and the mean hourly output for the simulation as $\overline{\mu_s}$ (estimation represented by $\overline{x_s}$). The sample variances for the hourly output of the simulation and the real system are denoted as s_s and s_r, respectively. For each process, a 95% Confidence Interval (CI) was constructed to determine the difference between the mean hourly output of the real system and the mean hourly output of the simulation. The results are summarized in Table 3.

Table 3. Descriptive statistics and IC for hourly output

Process	$\overline{x_s}$	$\overline{x_r}$	s_s	s_r	**IC** $\overline{\mu_s} - \overline{\mu_r}$
Sublimation Printing	337.5	342.3	43.5	43.2	[-23.8 ; 14.2]
Layering	2.6	2.6	0.64	0.64	[-0.3 ; 0.3]
Cutting	2.6	2.6	0.5	0.5	[-0.2 ; 0.2]
Silk Screen	942.5	944.1	13.3	11.0	[-6.9; 3.8]
Pressing	78.1	76.9	3.7	3.3	[-0.3 ; 2.8]
Sewing	411.5	412.5	4.5	3.6	[-2.7 ; 0.9]
Finishing	205.8	206.3	4.0	3.9	[-2.2; 1.2]

All these confidence intervals included the value of 0, indicating that the simulation satisfactorily represents the real system in terms of the hourly output performance indicator.

Experimentation

Using the validated model, layouts A and B were compared in terms of hourly output at the Finishing department. To do this, 10 pilot replications, each lasting 100 hours, were conducted. The average hourly output is displayed in Figure 22.

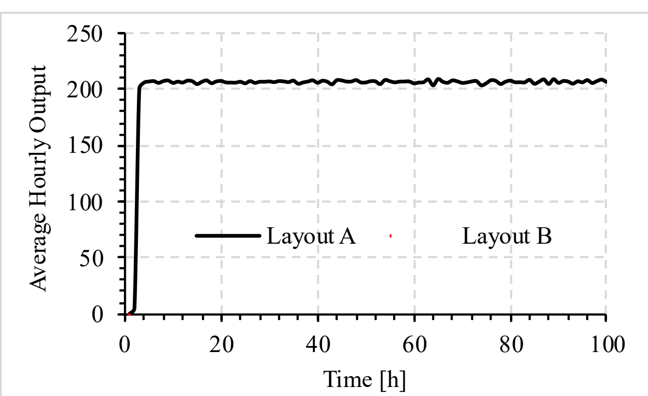


Fig. 22 Average hourly output at the finishing department

There is almost no difference between the average hourly output of Layouts A and B. One contributing factor to this result is that material transfers between departments are conducted in batches, which mitigates the impact of departmental distance on the hourly output performance indicator. Another reason for this result is the high level of WIP, which causes departments to operate with a high utilization factor, as shown in Figure 23. The graphical method in Figure 22 was applied to identify the warm-up period, and it was set to 10 hours. As recommended by [60, p. 444], the total simulation duration was set to 10 times the warm-up period, resulting in 100 hours of simulation time. The number of replications was determined using a precision level of $\pm 1\%$ of the hourly output average within a 95% confidence interval. Excluding the warm-up period, the required number of replications was found to be $n = 2$. As a result, the confidence interval for the mean hourly output in both layouts was $[204; 208]$, with a mean estimate of 206. However, the estimated variance for Layout A was 1.378, while for Layout B it was 1.437. Nevertheless, from the managers' perspective, the difference in daily output averages was not considered significant between Layout A and Layout B. Considering the features of both layouts, managers preferred Layout B.

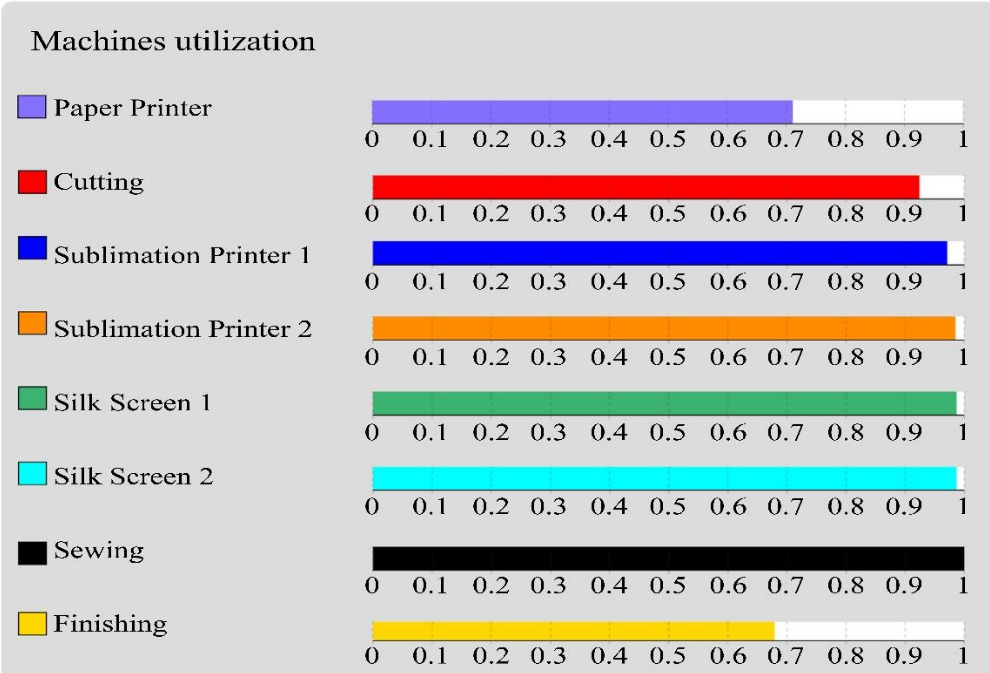


Fig. 23 Utilization factor for some departments

6.5.2. Washroom Location

Considering Layout B, two options for washroom locations were proposed. In the first option, washrooms would be located outside the facility and built with cement and bricks. The results for this option correspond to those previously presented for Layout B.

The second option includes the first, but adds ten prefabricated modular washrooms to be installed in the center of the facility, as shown in Appendix Figure 29.

The modular design of the washrooms would prevent damage to the concrete floor of the warehouse in the event that the washroom locations need to be relocated in the future. Local quotations for the investment in the modular washrooms were $\$60{,}000$, with interest-free monthly payments for 1 year.

Discrete-Event Simulation was used to evaluate the difference in hourly output based on the positions of the washrooms. The warm-up period, number of replications, and simulation duration remained unchanged from previous tests. The duration spent in the washroom is the same for both layout alternatives. A walking speed of 0.8 m/s was assumed, and the time taken to reach the washroom and return was based on the distance within each layout.

As shown in Figure 24, locating the washrooms inside the facility increases the expected hourly output by 4 units, or approximately 1.94%, compared to the scenario where washrooms are only outside the facility. The 95% confidence interval for the mean hourly output when washrooms are located inside the facility was $[206; 214]$.

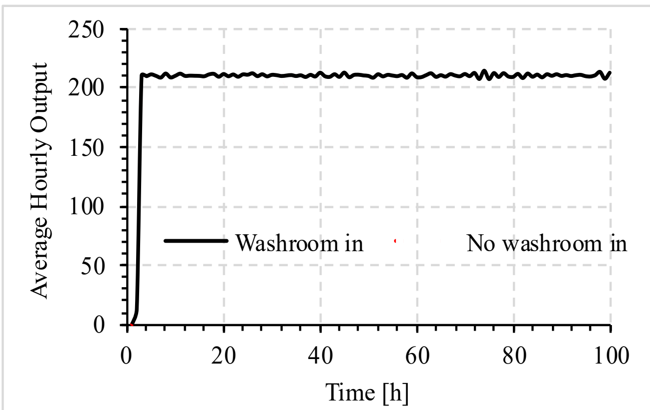


Fig. 24 Average hourly output at the finishing department of Layout B

To determine whether placing the washrooms inside the facility would be advantageous, the Net Present Value (NPV) method can be applied.

To protect confidential information about the company's profitability, NPV was calculated for different profit margins per product unit, over a 12-month period, and assuming a required rate of return of 1% per month, which corresponds to conservative investments in private Brazilian banks. The monthly cash flow is given by Equation (12).

$$cashflow = 4 \times d \times p - 60000/12 \qquad (12)$$

where d represents the number of working hours in a month [h], and p the profit per unit [\$/unit]. With $d = 160$ h, the results are summarized in Table 4 as a function of p.

Table 4. NPV for different unit profits

p [$/unit]	NPV [$]
5	-11,149.87
6	-7,185.47
7	-3,221.07
7.81	-9.91
7.82	29.73
8	743.32
9	4,707.72
10	8,672.12
11	12,636.52
12	16,600.92
13	20,565.32

As shown in Table 4, if the profit per unit exceeds $7.81, having washrooms inside the facility would be economically advantageous for this company. Beyond the economic perspective, having washrooms inside the facility would strategically place them closer to employees [7], potentially improving workplace sanitation conditions.

7. Conclusion

Sanitation for all is a key component of the 2030 Agenda for Sustainable Development. However, the literature highlights that some workplaces reprimand employees for using washrooms outside of formal, scheduled breaks, as such visits are perceived to negatively impact production. Additionally, studies have noted that women often self-restrict their needs in workplaces where washrooms are located far from their workstations, compounded by the fear of reprimand. Although placing washrooms inside production areas is discouraged or restricted for certain types of plants, depending on the products, managers are often resistant to the idea even when no such restrictions apply. The research question proposed in this paper, which has not been answered in the literature, is as follows: Is there a case in which locating washrooms inside a production facility and disconnecting them from its perimeter walls is economically profitable?.

This paper contributes to the literature by presenting a case where locating modular washrooms inside the production facility, disconnected from its perimeter walls, and near the department with the highest concentration of employees, can be economically profitable depending on the unit profit per product. The case studied involved designing a new plant for a Brazilian garment production company. Systematic Layout Planning (SLP) was employed to generate and evaluate alternative layouts. Hourly output was evaluated using Discrete-Event Simulation. Then, a Net Present Value (NPV) analysis demonstrated that having washrooms inside the production area becomes economically viable when the profit per unit exceeds $7.81. As actionable recommendations for management, during layout planning, managers could consider including modular washrooms inside the facility, closer to workstations, as this option may be economically feasible and promote better sanitation compared to distant washrooms. To extend this work, a comparison of workplace productivity in hot environments, where employees are properly hydrated and have unrestricted access to clean washrooms, could provide new managerial insights into the restrictions on washroom usage and their implications for health and morale.

Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to the Brazilian General Data Protection Law, but are available from the corresponding author upon reasonable request.

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Appendix 1

Required space for the Silk Screen Printing process														
Name and description	**Main function**							**Quantity**	**Height [m]**	**Weight [kg]**	**Space needed [m x m]**			**Obs.**
	Machine or Equipment	Workstation	Storage	Transporter	Production service	Workers service	Other							
Silk screen machine	x							2	1.8	1200		7.2 x 7.2		manual access
Screen recording room					x			1	2.6	-		2.5 x 3.0	0.5	manual access
Screen washing tank					x			1	1.5	-		0.5 1.40 x 1.20 0.5	0.5 0.5 0.5	manual access
Screen emulsifying tank					x			1	1.5	-		0.5 1.40 x 1.20 0.5	0.5 0.5 0.5	manual access
Industrial scales	x							1	1.5	500		2.5 x 3.0	0.5	manual access
200 liter barrel			x					10	1	>200		0.57 x 0.57	0.5	manual access
Paint mixer	x							1	3.04	250		0.9 x 0.9	1.27	manual access
Compressor	x							1				0.6 x 1.5		
Steel shelf for paint storage			x					1				0.9 x 0.4	0.5	manual access
screen	x		x					51	0.15	-	0.2	1.10 x 0.05	0.5	manual access

Fig. 25 Required space for the silk screen printing process

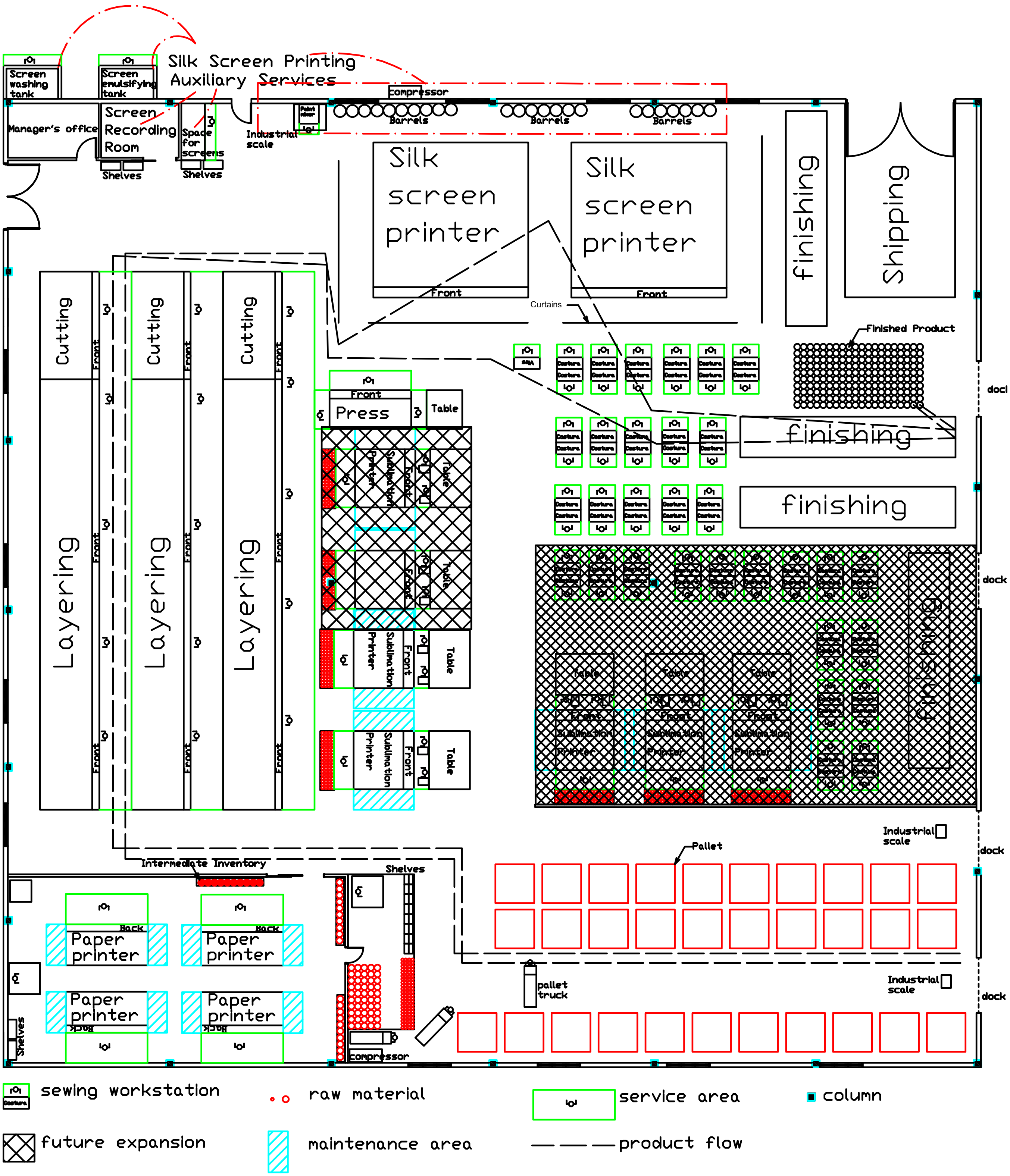

Fig. 26 Layout A

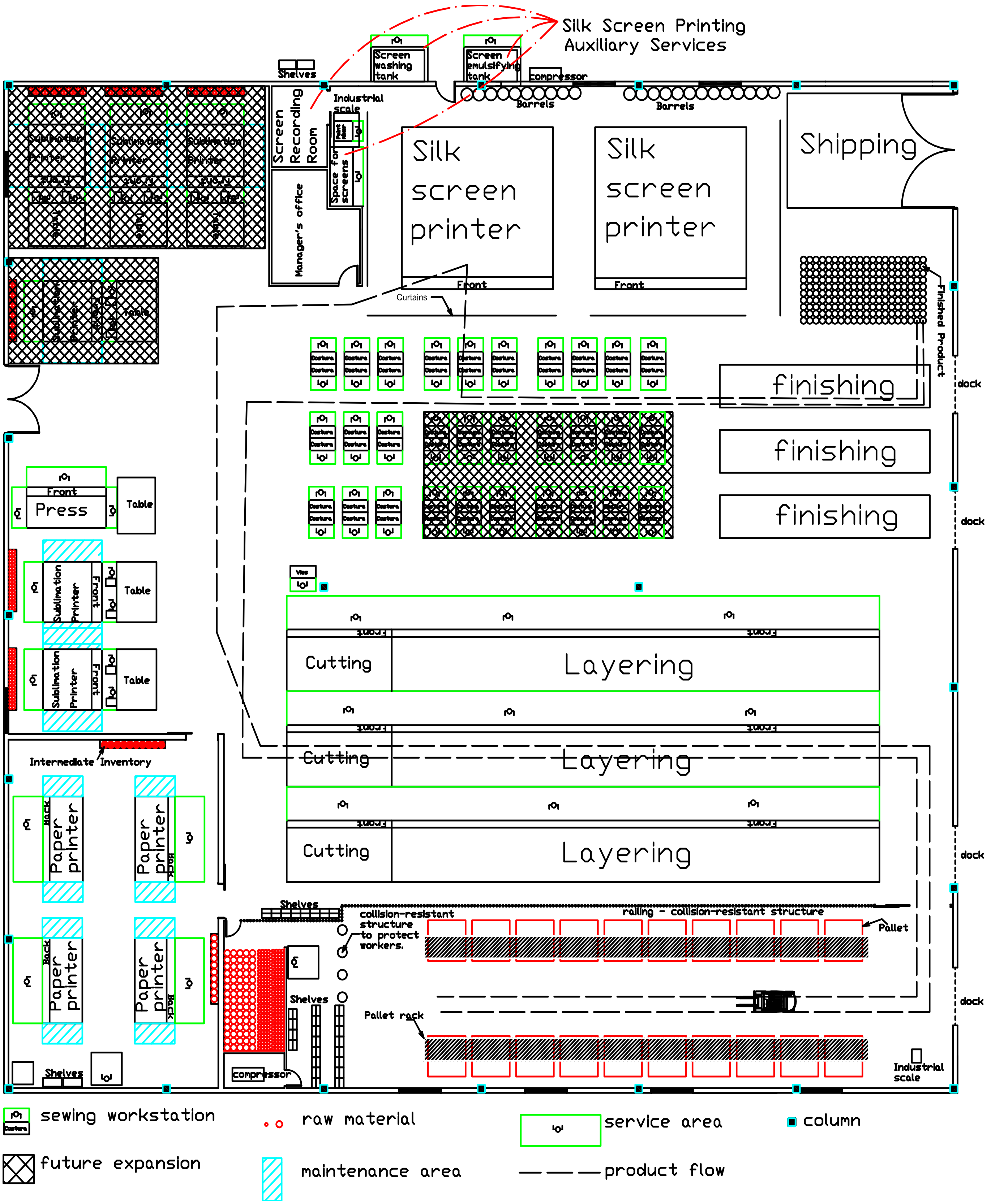

Fig. 27 Layout B

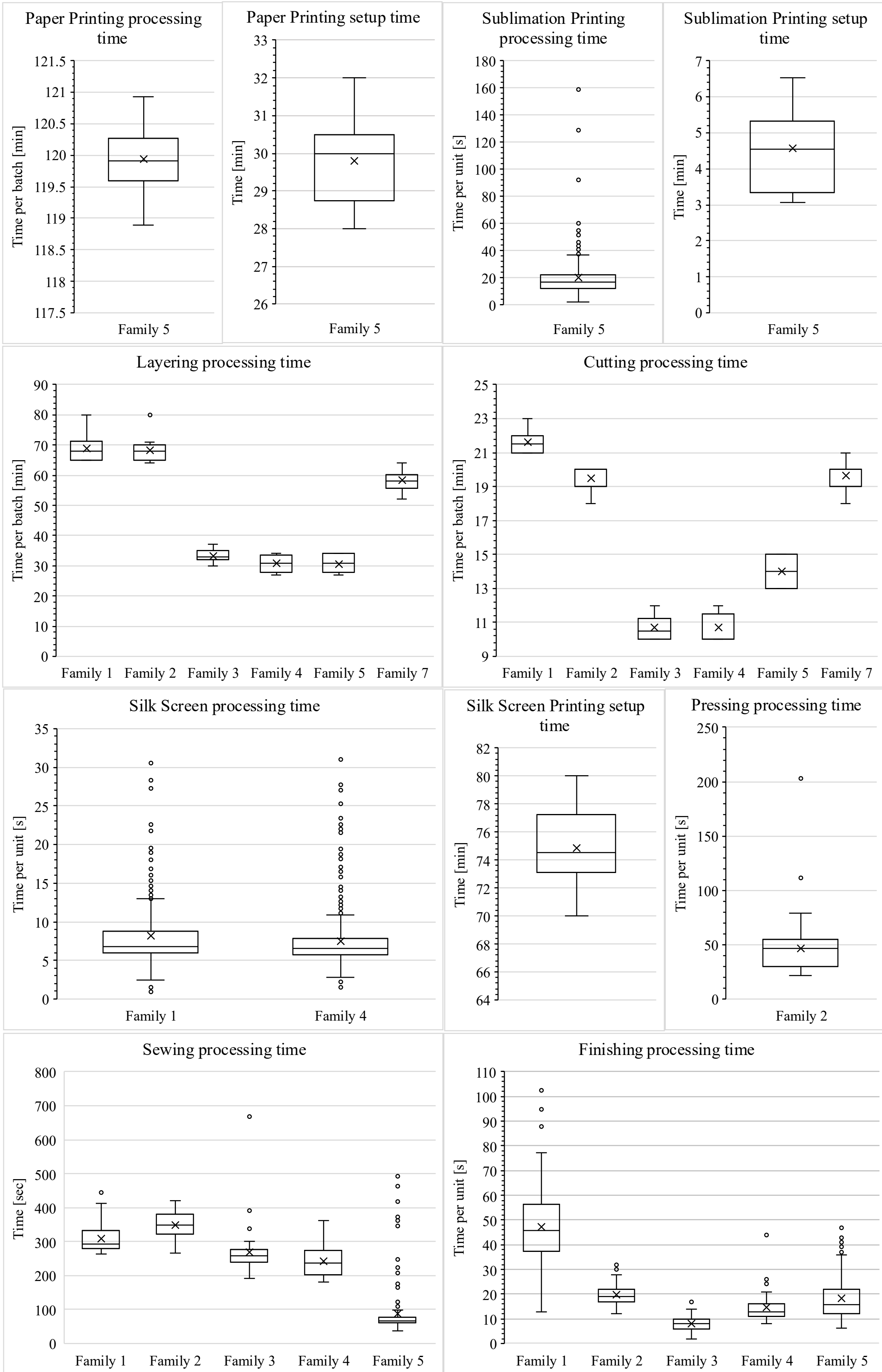

Fig. 28 Processing and setup times for different processes

Table 5. Sample size and fitted distributions for random variables related to the production departments of product families 1, 2, and 3

sample size -> distribution	**Family**		
Random Variable	1	2	3
Layering processing time	80 -> L(4.232 ; 0.063) min	80 -> L(4.222 ; 0.053) min	40 -> L(3.499 ; 0.061) min
Cutting processing time	80 -> N(21.6 ; 0.663) min	80 -> N(19.50 ; 0.6123) min	40 -> N(10.722 ; 0.803) min
Silk Screen processing time	409 -> L(1.998 ; 0.431) sec	-	-
Silk Screen setup time	70 -> T(70 ; 80 ; 75)	-	-
Pressing processing time	-	300 -> L(3.768 ; 0.387) sec	-
Sewing processing time	400 -> L(5.727 ; 0.128) sec	400 -> L(5.848 ; 0.120) sec	400 -> L(5.564 ; 0.208) sec
Finishing processing time	400 ->L(3.7870 ; 0.370) sec	400 -> L(2.965 ; 0.231) sec	400 -> L(1.983 ; 0.458) sec

Table 6. Sample size and fitted distributions for random variables related to the production departments of product families 4, 5, and 7

sample size -> distribution	**Family**		
Random Variable	**4**	**5**	**7**
Paper Printing processing time	-	84 -> N(120 ; 2) min	-
Paper Printing setup time	84 -> L(3.386 ; 0.039) min		
Sublimation Printing processing time	-	350 -> L(2.714 ; 0.789) sec	-
Sublimation Printing setup time	-	63 -> L(1.491 ; 0.244) min	-
Layering processing time	40 -> L(3.421 ; 0.088) min	40 -> L(3.417 ; 0.094) min	25 -> L(4.064 ; 0.052) min
Cutting processing time	40 -> N(10.705 ; 0.823) min	40 -> N(14.000 ; 0.894) min	25 -> N(19.666 ; 0.745) min
Silk Screen processing time	661 -> L(1.944; 0.356) sec	-	-
Silk Screen setup time	70 -> T(70 ; 80 ; 75)	-	-
Pressing processing time	-	-	-
Sewing processing time	400 -> L(5.472 ; 0.186) sec	400-> L(4.282 ; 0.370) sec	-
Finishing processing time	400 -> L(2.630 ; 0.300) sec	400 -> L(2.814 ; 0.411) sec	-

In Table 5 and Table 6, the first column lists the random variables, while the remaining columns display, for a given random variable, the sample size used and the fitted distribution function. The following notations are used for the distribution functions: $N(\mu, \sigma)$ – Normal with mean μ and standard deviation σ; $L(\mu, \sigma)$ – Log-normal with mean μ and standard deviation σ; and $T(a, x, m)$ – Triangular with minimum a, maximum x, and mode m. For example, the random variable "Layering processing time" related to family 1 had a sample of *80* observations, and its distribution function was inferred to be Log-normal with a mean of *4.232* and a standard deviation of *0.063* minutes.

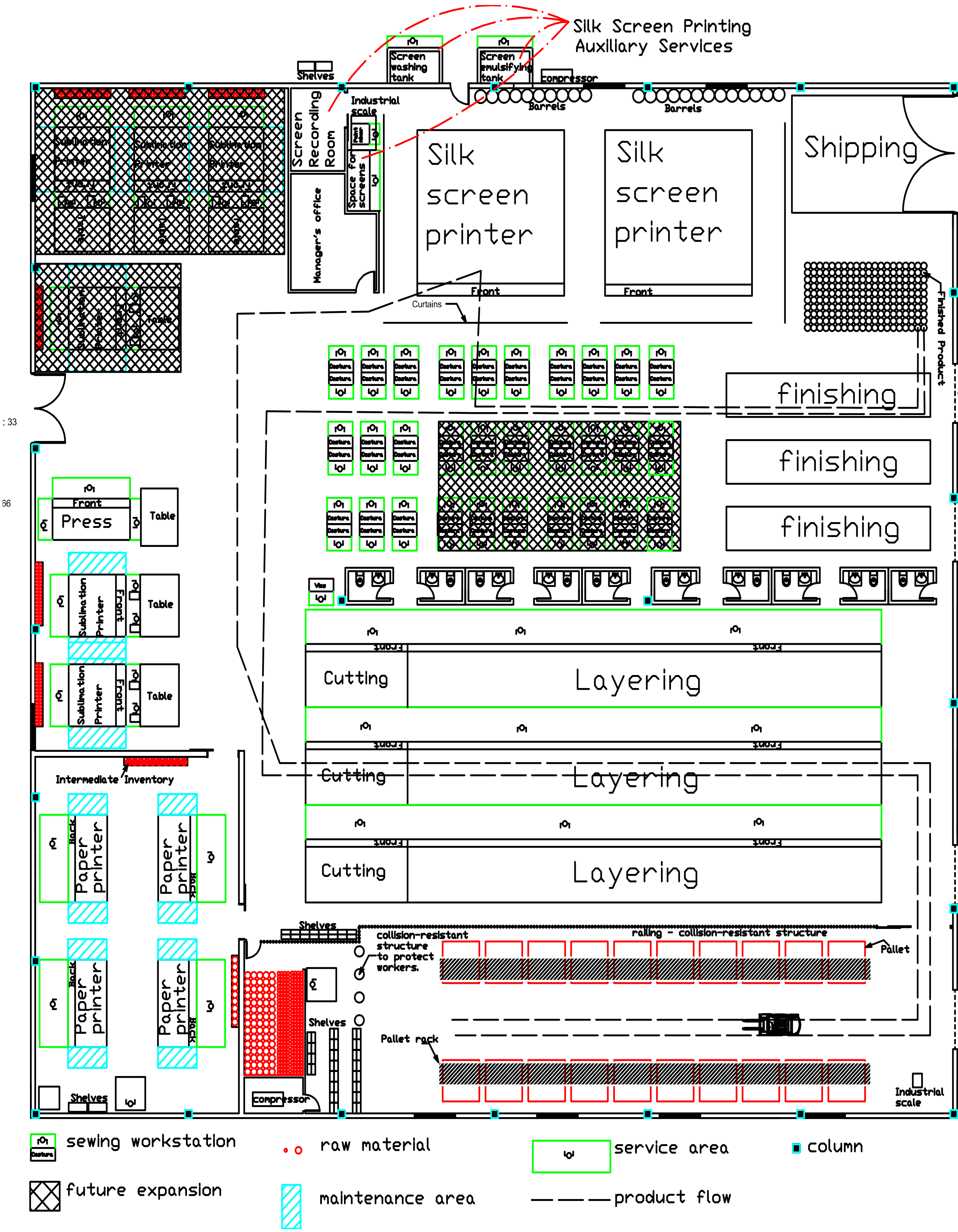

Fig. 29 Layout B with internal washrooms