sustainability

Article

A Revised Systematic Layout Planning to Fit Disabled Workers Contexts

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Abstract: Some people may be disadvantaged on the labor market because of their lower productivity; still, they have the same right to be employed as any other citizen. Social cooperatives employ disabled workers who are trained and supported in developing their abilities through individualized paths and targeted techniques. For the cooperatives to survive on the labor market, an improvement of management procedures and internal organization is required. To achieve this result, an optimal arrangement of activities must be determined to streamline the production processes, which is why Systematic Layout Planning (SLP) has been modified and adapted to fit disabled workers contexts. The factors of social cooperatives influencing the layout study have been determined and introduced into the classic SLP; the new methodology has been applied at L'Iride, a social cooperative developed through the years. The new layout has shown an improvement in space saturation of 219.2% and 197.5% considering the years 2019 and 2020. This paper provides social cooperatives with a revised SLP, including social factors, to enhance the disabled workers situation.

Keywords: layout study; systematic layout planning; social cooperative; disabled workers; production process optimization; reconfigurability

Citation: Micheli, G.J.L.; Rampoldi, A.; Baccanti, F. A Revised Systematic Layout Planning to Fit Disabled Workers Contexts. *Sustainability* **2021**, *13*, 6850. https://doi.org/10.3390/su13126850

Academic Editor: Lucian-Ionel Cioca

Received: 30 March 2021
Accepted: 12 June 2021
Published: 17 June 2021

1. Introduction and Objective of the Study

Work must be protected, promoted, and granted to all citizens. Disabled workers are disadvantaged on the labor market, as they encounter difficulty or cannot carry out work processes due to their deficit [1], but they have the same right to be employed as any other citizen. The main barriers lie in the reluctance of employers to hire them and the small number of protected workplaces [2].

Over the years, regulations have been introduced to recognize the disadvantaged status and guarantee facilities to favor access to the labor market [3]. By favoring their employment, many people previously excluded from the labor market now have the opportunity to be included in a production process. To this end, Italian legislation has established "type B" (as in Law 381/1991) social cooperatives that deal with carrying out different activities, such as agricultural, industrial, and commercial, or services with the aim of promoting work placement for disadvantaged people; they are the ones this work refers to [4]. Social cooperatives have understood the necessity to adapt the production cycle to people instead of adapting people to the production cycle [5]. Through customized paths and targeted techniques, the disabled are trained and supported in developing their abilities, by encouraging the acquisition of the technical skills necessary to perform the required tasks [6]. Type B social cooperatives meet the needs of employers who must hire disabled workers, as stated by Law 68/99. The agreement can concern up to 30% of disabled workers of the enterprise, and employers undertake to entrust work orders to the social cooperative [7]. Overall, this means a potential need for the social cooperatives to grow in number, in volume, and in competitiveness in the near future, which is further corroborated by the rise of companies, such as FARE srl (http://www.fareinnovazione.com (accessed on 15 June 2021)), that explicitly aim at helping social cooperatives to grow.

In fact, when it comes to social cooperatives, all of them can be observed to have been developed through the years without a clear business objective and consistency, with the only aim to employ disabled workers. To describe this problem, the social cooperative L'Iride has been taken as an example. It started as a small mechanical assembly workshop that employed three disabled people. The activity was met with a great interest, and to fulfil the growing demand from companies, an increasing number of disabled workers were hired. Whenever there was a need to increase the production capacity, new workstations were installed without accounting for productivity, lead time, throughput, and other parameters important for a cost-effective management. This led to the development of many but small production cells. This segmentation, inefficient from a business point of view, made the cooperative unable to be competitive on the market.

Garcia-Sabater et al. noted that the survival of a company employing disabled workers is not easy in a market driven by costs and flexibility. Clients select the cooperative only if it can offer prices and flexibility as good as their competitors [8]. To favor competitiveness, it is essential to reorganize the cooperative to resemble a traditional company. The improvement of throughput, productivity, and efficiency can be reached through the layout study, with the aim of determining the optimal arrangement of each production element [9]. In social cooperatives, however, the optimization will have to be reached while also considering the peculiar social factors (not included at all in traditional layout optimization techniques/approaches), while, as a matter of fact, no previous study has focused on it. This causes the need to revise traditional techniques used in the layout study to fit disabled workers contexts. In the layout study adapted to social cooperatives, profit and social objectives must coexist, and both must be respected at the same time. "What is an objective for the ordinary enterprise becomes a constraint for the social enterprise, while vice versa, a constraint is transformed into an objective" [5]. The optimal spatial arrangement of production elements must be combined with the identification of the ability of the disabled and with the breakdown of the production process into elementary operations to cope with the ability of the disabled to perform only a single type of task. Knowing the characteristics of the operators, it is possible to match the ability of the worker to the most adequate task. These actions help to avoid the placement of the disabled in an unsuitable process [10], supporting the diverse skills and abilities of the disabled workforce [8]. Only through the combination of these improvement efforts is it possible to turn a social cooperative into a more and more competitive enterprise; in a few words, the status quo is a situation where the large majority of social cooperatives are actually not very competitive enterprises: they could not survive without the fiscal incentives they benefit from and without the need for disabled work and workers that large companies have due to the legislation. Thus, of course a social cooperative is an enterprise, yet not a very competitive one. Thus, the overall aim of our study was to transform social cooperatives into more competitive enterprises, without losing their identity.

More specifically, the objective of this study was to perform a layout study for the first time in a social cooperative to optimize the business result. An engineering technique, widely used in ordinary companies, with the aim of determining the optimal arrangement of each production element, has been adjusted to include the social factor, i.e., the needs of disabled workers.

Section 2 reviews the literature of papers concerning the layout study in ordinary companies. In Section 3, the influencing factors of social cooperatives have been identified and matched with the classic ones to develop the revised methodology, then a metric for the evaluation of the layouts has been provided. Section 4 describes the re-layout. The results and conclusion close the paper.

2. Literature Review

A facility layout is the physical disposition and interconnection of production activities within a company [11,12]. The term facility refers to elements of the plant, such as equipment, workstations, and departments. The process which defines the optimal arrangement of these facilities takes the name of "facility layout problem" [9,13]. Investing time, resources, and money in creating a good layout is cheaper than making a non-optimal layout that needs later adjustments [14].

A layout study is a multi-objective problem that takes into consideration many criteria during the optimization of the facility layout [15].

A good layout allows to:

- Minimize material handling;
- Ensure flexibility of arrangement;
- Provide high turnover of work-in-progress;
- Hold down investment in equipment;
- Make economical use of floor space;
- Promote effective utilization of labor;
- Provide safety, comfort, and convenience for labor [14].

2.1. Algorithms for the Layout Study

The plant layout used to be determined with a trial-and-error approach, by arranging each department manually at random [16]. A heuristic approach has to be applied to facilitate the research of a quasi-optimal layout [15]. This approach is an algorithm that can find a good solution for the problem but does not guarantee finding an optimal solution [17]. Often, the optimal layout cannot be found due to the complexity of the problem and the number of requirements with which to be complied, which, in many cases, are conflicting [15].

A literature review of articles or theses that deal with algorithms for the facility layout problem has been performed. The papers are reported in Table 1.

Table 1. Reviewed papers describing algorithms for the facility layout problem.

	Title	Authors	Discussion Elements
[18]	Efficient and flexible algorithm for plant layout generation	Weng L.	CORELAP, ALDEP, CRAFT, BLOCPLAN
[19]	An application of the CORELAP algorithm to improve the utilization of the classroom	Sembiring A. C., et al.	CORELAP
[20]	Plant Layout Optimization in the Steel Forging Industry by the CORELAP Algorithm	Binoy B. George B. K.	CORELAP
[21]	Evaluation of Existing Layout Improvement and Creation Algorithms for Use in the Offsite Construction Industry	Ritter C., et al.	CORELAP, ALDEP, CRAFT
[22]	Redesigning Furniture Production Floors Using Systematic Layout Planning and the ALDEP Method to Minimize Material Handling Costs	Budianto F., et al.	ALDEP
[23]	Development of a Suitable Plant Layout using Computerized Relative Allocation of Facility Techniques	Mallick P., et al.	CRAFT
[24]	Design and improvement layout of a production floor using an automated layout design program (ALDEP) and CRAFT algorithm	Suhardini D. Rahmawati S. D.	ALDEP, CRAFT
[25]	Redesigning a facility layout with quantitative and qualitative method in the printing industry	Hidayat T. P., et al.	CORELAP, CRAFT, BLOCPLAN

Table 1. *Cont.*

	Title	Authors	Discussion Elements
[26]	Production facility layout design using the BLOCPLAN algorithm	Puspita I. A., et al.	BLOCPLAN
[27]	A method of industrial plant layout and material flow analysis in AutoCAD	Sly D. P.	CORELAP, CRAFT, BLOCPLAN
[28]	Plant Layout Optimization using CRAFT and ALDEP Methodology	Deshpande V. A.	ALDEP, CRAFT

Many algorithms can be used, and they can be classified into three groups:

- Construction algorithms: they generate a layout by taking into consideration the relationship between the departments [29]. Examples are CORELAP and ALDEP [30];
- Improvement algorithms: they require an initial feasible layout [11]. Their aim is the reduction of internal transport costs by a pair-wise exchange position of departments [29]. An example is CRAFT [30];
- Hybrid algorithms: they can be used like both construction and improvement algorithms [26]. An example is BLOCPLAN [30].

The algorithms can be further classified in quantitative and qualitative methods [31], as reported in Table 2.

Table 2. Object, principle, and limits of quantitative and qualitative methods.

	Quantitative Methods	Qualitative Methods
Object	Minimizing material handling cost [27,31]	Maximizing closeness of departments [31]
Algorithms	CRAFT [25]	CORELAP, BLOCPLAN, ALDEP [25]
Principle	Departments with high material handling costs are placed close together, and those with low costs tend to be further apart [27]	The user subjectively determines the intensity of the relationship between two departments, analyzing some qualitative factors. The parameters considered are, for example, noise, heat, dust, flow of materials [31]
Limits	They take into consideration only parameters that can be quantified (cannot take into account noise, safety, pollutants, or vibration) [24]	Their evaluation is subjective and they do not describe the dependency between the departments appropriately [31]

The problems of manufacturing facilities are becoming more and more complex. The information to be considered is varied and from multiple sources; therefore, the method to be chosen has to fulfil more objectives, such as flexibility for future modifications, expandability together with optimization of utilization, efficiency, and total costs [15]. This complexity is even more amplified in a social cooperative where business and social objectives must be combined. The analysis of the papers listed in Table 1 has highlighted that each algorithm has some limits, as reported in Table 2. The complex problems may be solved by applying a method that combines qualitative and quantitative information, thus uniting the strength of both methods and, at the same time, minimizing their respective drawbacks [13]. An algorithm that considers both those factors is the Systematic Layout Planning [15]; therefore, it is the one that was chosen for this research.

2.2. Systematic Layout Planning

This is a procedure used to design a facility layout by considering the relationship between workplaces and placing the ones with a high frequency close together [32]. The Systematic Layout Planning is “an organized way to conduct layout planning. It consists of a framework of phases, a pattern of procedures, and a set of conventions for identifying, rating, and visualizing the elements and areas involved in planning a layout” [14]. The methodology, shown in Figure 1, is composed of 10 phases. For an explanation of this technique and details about the procedure, readers are suggested to refer to Systematic Layout Planning—4th edition [14].

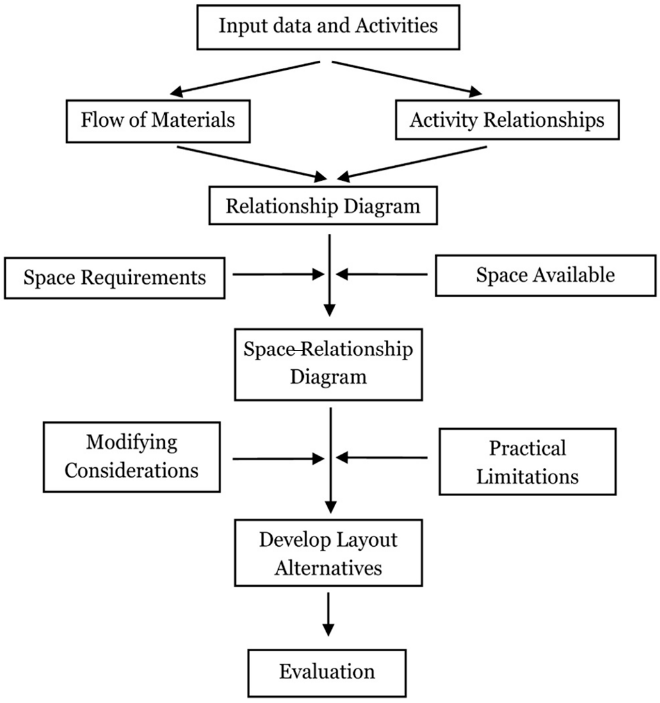

Figure 1. Systematic Layout Planning procedure, adapted from [32].

3. Data and Methodology

The interaction with the Start Up Innovativa a Vocazione Sociale FARE srl (http://www.fareinnovazione.com (accessed on 15 June 2021), an intermediary between for-profit manufacturing enterprises and social cooperatives, resulted in an enhanced opportunity to actively involve a social cooperative, so as to enable both a Focus Group and, later, an implementation of the proposed revised approach. Specifically, FARE srl was created with the aim of "transforming the hiring of people with disabilities from a legal obligation into an opportunity for companies, promoting the persons regardless of their disability", [10] and it focuses on the management and regulations, the persons, and, crucial for this research, on the industrialization relating to the growth of skills and the adjustment of methodologies and processes to the characteristics of the worker [10].

Even though already clear conceptually (as stated in the introduction), a preliminary talk with experts in the layout study and FARE srl made it even clearer that Systematic Layout Planning meets the requirements of the business goal, but it cannot be applied, as it is, to social cooperatives where the social factor is relevant; thus, a revised methodology is required to fit disabled workers contexts. The Systematic Layout Planning adapted to a social cooperative must consider the specific needs of the disabled and, at the same time, continue to pursue cost-effectiveness management. It will allow plant optimization so as to transform a social cooperative into a competitive enterprise in which production processes, workplaces, and procedures generate profit and meet the needs of the disabled.

3.1. Focus Group

The influencing factors of social cooperatives on the layout study must be determined. These parameters were matched with classic ones to work out how they affected the methodology and how the layout study may have been modified. To this end, a Focus Group was used, i.e., a small group of people gathered to evaluate concepts or identify issues.

The Focus Group adopted for this research was performed in one session of two and a half hours on the platform Microsoft Teams, due to the COVID-19 pandemic regulations that did not allow personal meetings. The moderator was the paper author. The participants were selected to represent the social cooperatives and the industrial environment. The managing director, operation manager, product manager, microswitch department manager, and electromechanical assembly department manager of L'Iride (five participants out of 30 workers) acted for the social cooperatives' environment. For the industrial field, two layout planners were selected: one worked on an industrial plant and dealt with the safety and health in workplaces, while the second one worked in an academic environment and had a more theoretical vision of the problem. The issues that emerged are described in the ensuing lines.

Local companies entrust work orders to social cooperatives, that are subcontractors, to comply with the legal obligation of Law 68/99. This requires the cooperative to manage many and diversified products, making job-shop the only feasible layout to be implemented. This layout, by grouping technologically homogeneous machines in the same place, favors operator specialization and flexibility, i.e., the ability to produce different parts by using the in-depth knowledge of technology [33]. In a social cooperative with an industrial vocation, the optimization of the plant and of the industrial parameters, such as lead time, throughput, work-in-progress, and the ability to change the production type in a very short time by reshaping the workplace to answer the variable demand, must be matched. This last need is very important to make the social cooperative competitive. Thus, the attention must go to flexibility and to standardization of the production processes attained by workplaces with similar modules and similar procedures, to enable the change from production of item A to production of item B in a short time by reconfiguring the work area.

The quantities required are not constant over the year, because subcontractors are frequently used for peak demands. This results in unfavorable working conditions for the disabled that tend to easily forget production practices when not used continuously. This means a misuse of the disabled workforce that must be retrained. The breaking of a job into elements with different levels of difficulty is essential, because a disabled worker can only perform one or few simple tasks that must be standardized and suitable to most production processes. In this way, the disabled worker remembers the production practices, becomes specialized in a specific operation, and his/her ability is enhanced.

To design a layout to meet the requirements of each worker is not feasible, because it would mean redesigning whenever the disabled worker changes. The workplace is adapted to both workers and products, avoiding a layout completely oriented to people and inefficient as to the production process, or vice versa.

By implementing all the necessary changes to transform a social cooperative into a competitive enterprise, the cooperative may require customers to comply with some conditions, such as quantities of raw materials delivered or fixed days for shipping, to simplify and improve the internal organization and spaces. The storage areas and the storage organization are critical points for social cooperatives, because as subcontractors, they manage small quantities of highly diversified products. Ideally, stock should be zero, but today, raw materials delivered are usually in a large quantity to satisfy the demand for months, thus occupying large storage areas. Disability does not allow the workers to pick up the required material in such a vast area; it is the department head that picks up raw materials. For this reason, it is always preferable to place stocks near workstations, avoiding a messy central warehouse far from production areas, which would lead to spending a lot of time in retrieving materials.

SLP must not all be renovated, as it would lose the aim to define the optimal arrangement of activities. Only some phases must be modified to be adapted to the new context. Having broken the process into elementary operations, we are dealing with single tasks. The need to place some activities close together may arise because they are part of the same production process or because they can be carried out by the same operator. Eye contact can be another need which requires activities to be placed close together. It should be guaranteed, mainly, where the handicap degree has a relevant impact on the production process, because the worker may interrupt the execution of its task without asking for help.

A common method used by companies to find the equivalent space, when the available is not sufficient, is working in shifts. With disabled workers, this is not feasible. The solution to increment production capacity lies once again in the use of flexible workstations that can be reconfigured easily and quickly when work orders change.

The Systematic Layout Planning for social cooperatives has been realized for the first time; therefore, there is no previous experience in this field. An additional phase can be helpful to verify whether the designed layouts are adequate to the disabled workforce. Then, an evaluation of the alternative layouts must be made, examining both quantitative and qualitative parameters to consider both social and industrial factors.

3.2. Revised Systematic Layout Planning

Systematic Layout Planning has been modified according to the suggestions that emerged from the Focus Group. The new procedure (Figure 2) was named "Systematic Layout Planning adapted to Social Cooperatives".

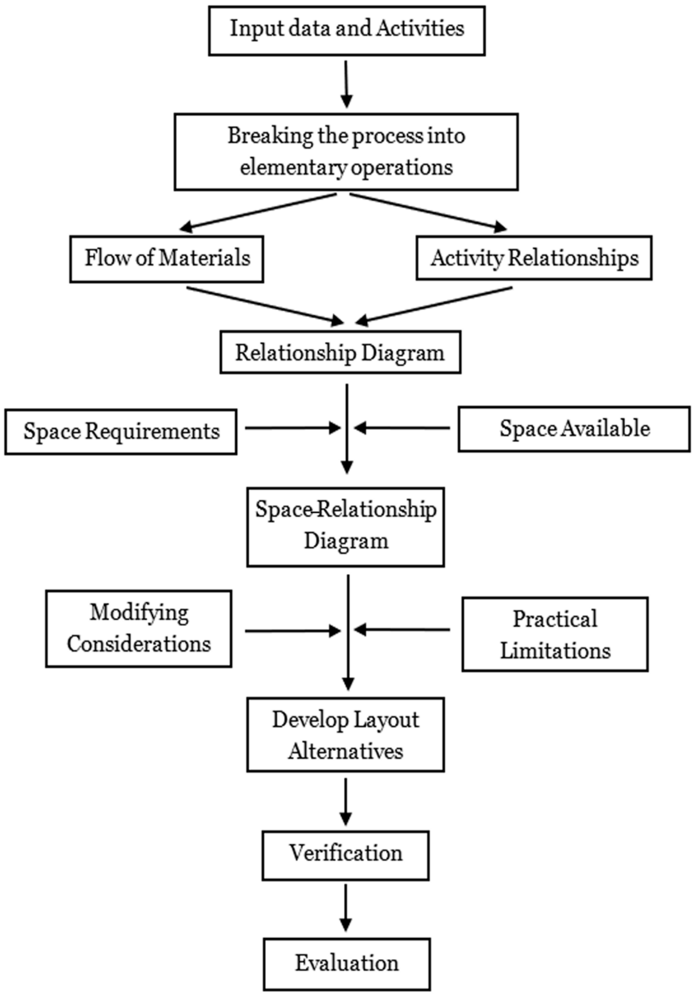

Figure 2. Systematic Layout Planning adapted to Social Cooperatives.

Only the parts differing from the SLP were taken account of. For the remaining parts, it is suggested to refer to Systematic Layout Planning—4th edition [12].

The annual production time is the most appropriate datum to be used as the dimensioning parameter for SLP adapted to Social Cooperatives; since they manage many different products, the number of items as a parameter could be misleading. Their production processes, volumes, shape, and other intrinsic characteristics differ and cannot be compared. Besides, production time outlines the goal of a social cooperative: to maximize the use of a disabled workforce; the higher the production time, the higher the use of a disabled workforce.

The layout type to be implemented is the job-shop. Cellular layout can be planned for a repetitive and constant demand of little diversified products over the years. Thus, the machining of morph-technological products improves the production planning processes and saturation rate.

3.2.1. Breaking the Process into Elementary Operations

The first phase of "Systematic Layout Planning adapted to Social Cooperatives" consists in five steps.

Phase 1: ABC analysis

Main products must be identified, which is done through ABC analysis, which is a technique for prioritizing the management of inventories. It divides inventories into three classes, A, B and C, using the total revenues as the segmentation element as for example in [34,35].

ABC analysis has been modified, by considering production time instead of revenues, as stated earlier:

- Class A: 20% of products that require 80% of total production time;
- Class B: 30% of products that require 15% of total production time;
- Class C: 50% of products that require less than 5% of total production time.

Class A products require the largest amount of total production time and are the most important job-generating opportunities for the disabled.

Phase 2: Determining elementary operations

One or more subsequent tasks executed by the same operator in the same workstation form an elementary operation.

The production processes of all the products must be broken into elementary operations, each characterized by some key elements. They are reported below but may change according to the products worked by the social cooperative:

- Annual production time;
- Mean working time;
- Product dimension or product volume;
- Degree of difficulty of the operation;
- Requirement of department head supervision;
- Minimum ability of the worker;
- Equipment and possible installation requirement;
- Other technical information, such as repetitive task, necessity for assembly kit, standard operation, etc.

Phase 3: Analysis of demand uniformity and workstation saturation

The demand of each elementary operation, considering the annual production time, must be evaluated to determine whether it is uniform over time. To assess whether the demand is uniform, the regularity index (IRE, the demand variation coefficient) is used. The regularity index (1) is the ratio between standard deviation and mean value of a sample from historical demand data.

$$\mathrm{IRE} = \sqrt{\frac{\sum_{i=1}^{T}(x_i - \bar{x})^2}{(T-1)\bar{x}^2}} \tag{1}$$

T is the number of periods through which the reference horizon has been discretized, x_i is the value of the demand for the i-th period, and $\bar{x}$ is the mean value of the sample.

The more uniform the demand, the closer the regularity index value is to zero [36]. It has been suggested to define a demand as not uniform if IRE > 0.65.

A workstation is said to be saturated when the production hours performed equal 1727 h/year or multiples, i.e., the theoretical annual production hours for the metal-mechanical industry [37].

Phase 4: Determining the elementary area type

There are three different types of elementary areas:

- Reconfigurable area: a workstation that does not involve installed equipment and can be reconfigured in a short time, according to demand;
- Not reconfigurable area: a workstation that involves installed equipment to perform the same operation for different products;
- Dedicated manufacturing cell: area where the same products needing the same production operations are realized, belonging to class A customers. Inside the cell, there can be both a reconfigurable and a not reconfigurable area.

The most appropriate type of elementary area for each elementary operation is determined through the diagrams in Appendix A (Figures A1–A3).

Phase 5: Determining work areas and their dimensioning

Elementary operations must be gathered in work areas where products with similar characteristics can be worked. They are grouped considering the elementary area type and key parameters, such as equipment type, product volume, supervision requirements, and operator position (standing or sitting).

A work area helps to deal with the problem of an irregular demand, because production peaks of one product can be compensated by a lower request for another one. Thus, the workstation can be saturated. Each work area is dimensioned and characterized by determining production capacity, products volume, products to be worked, operation types, equipment to be used, degree of difficulty of the task to be performed, and minimum ability required from the disabled. The work area must be properly defined through these characteristics to facilitate the production schedule. This also favors the attribution of the most fit workplace to each operator.

3.2.2. Flow of Materials and Activity Relationships

Before analyzing the flow of materials, warehouses are to be planned. A warehouse should not be central but dedicated to one or a few work areas, and a distinction between the raw materials and finished products areas is recommended to simplify the management and monitor stored quantities and waiting times.

Since social cooperatives deal with many products requiring different production flows and processes, the most adequate method to analyze the flow of materials is the From-To Chart.

The procedure of the Activity Relationships remains unaffected, while both supervision by a department head and resource sharing are recommended to be included among the reasons describing the closeness degree. Thus, work areas sharing equipment, or an operator can be placed close together.

3.2.3. Space Requirements

Space requirements can be calculated by following the methods described in the Muther procedure [14]. Some guidelines are provided here for reconfigurable workstations. A reconfigurable production system has an adjustable structure to enable workstation adaptability to a repeated change in production, as a response to the customer's demand [38]. The adjustment is accomplished by changing manufacturing methods, material flows, and logistic functions over the mid-term [39]. This can be achieved by implementing workstations that can be reconfigured for the products to be assembled.

The workbench must be ergonomically designed to minimize operator physical strain and enable efficient execution of the tasks. The optimal workbench dimension is determined by referring to operator movement classes:

- Class 1: finger movement with a stationary hand;
- Class 2: finger and hand movement with a stationary forearm;

- Class 3: finger, hand, and forearm movement;
- Class 4: finger, hand, and complete arm movement with a nearly stationary upper body;
- Class 5: whole body movement with no walking.

Movements from class 1 to class 4 are needed to perform a manual assembly task by an operator sitting at the workbench. When standing, all movement classes are allowed, but a no-stop performance of class 5 should be avoided, because it is tiring for the operator. The products to be assembled should be placed in the central area within class 3. Components should be placed in bins: the most frequently used ones are inside class 3, while the less frequently used are inside class 4 [40].

The components of the assembled products have different volumes and need to be stored in bins of different sizes; therefore, larger workbenches are required to provide additional space for bulky components. A workbench for bulky products is not optimized for small ones, and vice versa; in this way, reconfigurability and flexibility are not maximized. To avoid excessively large workbenches and favor the replenishment of raw materials, bins are placed on a rack system with wheels.

3.2.4. Space Available

When space available does not fulfil the needs, the equivalent space can only be found by facilitating the reconfigurability and the flexibility of workstations. The faster the changeover, the less production time is lost [41], avoiding idle time and earning time to be exploited in satisfying products demand, thus increasing production capacity.

3.2.5. Verification

The verification phase is needed to check whether the layouts may be implemented in the workplace under analysis to comply with the needs of the disabled.

Considerations, constraints, or requirements which could make it difficult or unfeasible to work in the new layout can be neglected. The real applicability of the layouts must be verified by experts from the production area of the cooperative. Should any problem arise, an evaluation must be made on whether to discard the layout or go back to any stage of the SLP and make the necessary modifications or adjustments.

3.2.6. Evaluation

The final evaluation is made through the three methods used for the traditional SLP. It is important to consider both quantitative and qualitative parameters together. The quantitative parameters evaluate the social cooperative as an ordinary company while qualitative factors help to consider the special needs of social cooperatives employing disabled workers. Parameters to be included are flexibility, reconfigurability, and standardization.

3.3. Space Saturation

3.3.1. Definition and Method

Since the most important parameter for a social cooperative is production hours, as in paragraph 3.2, this has emerged as necessary in the assessment of the value of a layout. A new metric, space saturation, has been defined as the ratio between production hours and square meters. The maximum value of space saturation is when the space required to perform a production task is minimized, obtaining, at the same time, the maximum possible number of production hours.

To assess space saturation, it is necessary to define:

- Production hours: hours spent at workstations by operators performing their tasks. Setup time, training time, and all other non-productive hours are not included;
- Space required to perform a production task: it is defined through the work module shown in Figure 3. Each module comprises space for:
  (a). Workstation: machine, equipment, or workbench;
  (b). Maintenance and set-up;

(c). Operator;
(d). Aisles: space for movement of personnel and material.

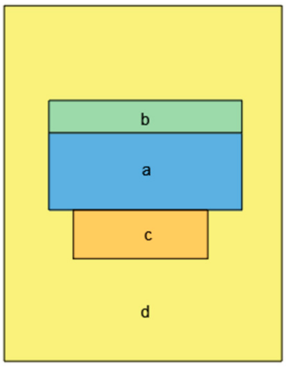

Figure 3. Work module.

The total area of each module (A_m) is defined by Equation (2):

$$Work\ module\ area = a + b + c + d \quad (2)$$

Space saturation can be assessed at three levels:

- Work module space saturation (S_m), considering the work module area and the production hours that can be performed. It is calculated by Equation (3):

$$\text{Work module space saturation} = \frac{\text{workstations numbers} * \text{production hours}}{A_m} \quad (3)$$

- Department space saturation (S_d), considering the whole department. If the work modules of the department are similar, S_d corresponds to the work module space saturation. Otherwise, it is calculated using Equation (4), where m is the number of work modules in the department.

$$\text{Department space saturation} = \frac{\sum_m S_m * A_m}{\sum_m A_m} \quad (4)$$

- Plant space saturation, considering all the n work modules of the plant. It is possible to consider only the production area (S_{pp}), as in Equation (5), or the overall plant (S_{op}) with warehouse and circulation aisles, as in Equation (6)

$$\text{Production plant space saturation} = \frac{\sum_n S_n * A_n}{\sum_n A_n} \quad (5)$$

$$\text{Overall plant space saturation} = \frac{\sum_n S_n * A_n}{\sum_n A_n + \text{non productive area}} \quad (6)$$

3.3.2. Optimum Space Saturation

Optimum space saturation can be evaluated as a ratio between theoretical annual production hours and the minimum work module area. The space needed for the work module is calculated by considering ergonomic guidelines, standards, or catalogues and is mostly influenced by products and equipment size. Two work modules have been defined: one for the assembly department and one for the mechanical machining department.

Standard Work Module for the Assembly Department

A work module in an assembly department has a workbench fit for a single operator. The worker can carry out manual assembly tasks with small bench machines.

The workbench dimension is determined according to the reachable area without inducing physical strain (class 4). By referring to south-eastern Europe's population [42], its dimensions are 158 × 48 cm.

The area of a work module is strongly influenced not only by the workbench, but also by aisles for personnel and material circulations. Their dimension is defined according to Legislative Decree 626/94 [43]. A minimum of 100 cm for personnel movement and of 120 cm for movement of material, when handled manually, are required. The standard work module is shown in Figure 4, a. Its area is 4.87 m^2; therefore, space saturation is 354.62 h/m^2.

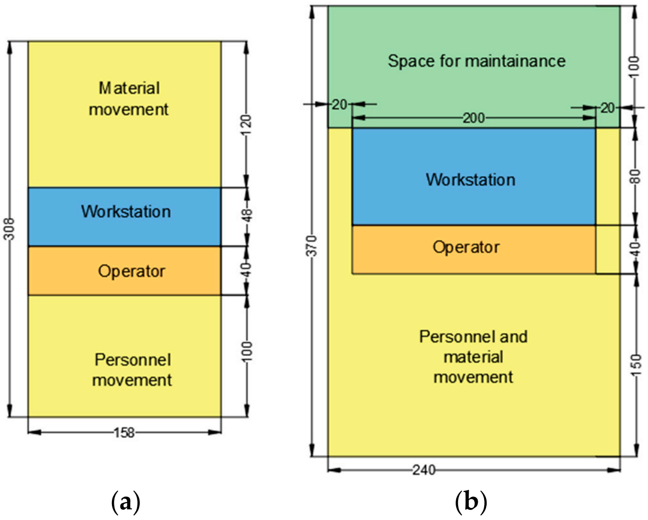

Figure 4. Standard work module: (**a**) Standard work module for assembly operations; (**b**) Standard work module for mechanical machining operations.

Standard Work Module for the Mechanical Machining Department

The standard work module for a mechanical machining department is determined by the medium dimensions of machining tools. On average, a machining tool is not greater than 2 m in length and 0.8 m in width. These dimensions are reference values for the workstation area. The aisle for personnel and material movement is in front of the machine tool and has a 150 cm width. The maintenance aisle is at the rear and has a 100 cm width. On both sides, a space of 20 cm is needed to avoid contact between machines.

The standard work module for mechanical machining operations (Figure 4b) has an area of 8.88 m^2, and the space saturation is 194.48 h/m^2.

4. Re-Layout of the Social Cooperative L'Iride

The social cooperative L'Iride has been undergoing a re-layout, with the aim to optimize the arrangement of activities to streamline production processes and work order management procedures. There is also the need to find free space to be allocated to new customers, considering that at the moment, there is no available space.

Currently, the production processes can be divided in three macro-categories: assembly, mechanical machining, and aids repairing. The last area is not affected by the re-layout, because it will be analyzed separately. The electromechanical assembly department is further divided into four areas: three are reserved for main customers (CST 1, CST 7, and CST 12), while the fourth one is used to produce items for other customers. The actual disposition of departments, offices, warehouses, and utility are highlighted on the plan in Figure 5.

Figure 5. L'Iride's initial plan–overall view.

Products required by each customer are morph-technologically homogeneous; therefore, the differentiation element is customers and not the several articles handled by the cooperative, resulting in a simpler analysis.

The future demand (Table 3) is predicted by looking at the trend of the existing data about production hours, starting from year 2019 and through the managers' in-depth knowledge about the demand trend of the previous years, for which there were no data.

Table 3. 2019's, 2020's, and expected production time.

	Production Time [h/year]		
Customer	**2019**	**2020**	**Expected**
CST 1	1467.37	1464.00	1640.00
CST 2	0.00	370.02	1700.00
CST 3	0.00	63.44	1600.00
CST 4	323.30	258.73	210.00
CST 5	1069.17	972.00	920.00
CST 6	441.53	257.24	340.00
CST 7	658.05	2526.47	2500.00
CST 8	39.23	28.76	-
CST 9	341.92	0.00	-
CST 10	0.00	0.00	-
CST 11	220.30	306.29	263.29
CST 12	1613.77	1104.93	660.00
CST 13	12,600.00	12,600.00	12,600.00
CST 14	1500.00	1500.00	3475.00

The main customers were identified with ABC analysis (Figure 6). Each process was then divided into elementary operations, determining the identification letter, operation type, annual production time, need for a workbench, equipment for the task and necessity for installation, difficulty degree of the operation, product dimension, and requirement about supervisions. Details are reported in Appendix B, Table A1.

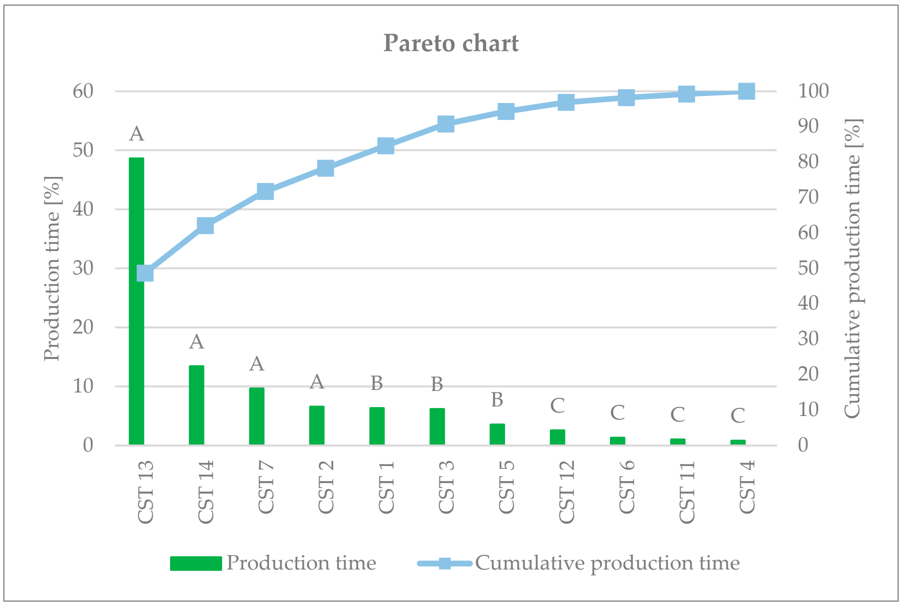

Figure 6. Pareto chart.

The regulatory index was calculated per each customer (1) for the years 2019 and 2020. The IRE for the expected situation was set to the mean value of the previous years; L'Iride managers' opinions were taken into consideration for customers whose demand was growing or decreasing when data were insufficient or when the demand was affected by more than one elementary operation. Subsequently, the saturation of the workstation was verified. Data of IRE and workstation saturation are reported in Table 4.

Table 4. IRE calculated for the years 2019 and 2020, and the expected situation; in the last column assessment of workstation saturation.

		IRE			
Customer	**Operation**	**2019**	**2020**	**Expected**	**Workstation Saturation**
CST 1	A B	0.61	0.55	0.58 1.10	1 workstation No
CST 2	C D	-	0.39	0.90 0.40	No 1 workstation
CST 3	E	-	-	0.65	1 workstation
CST 4	F	0.97	1.48	1.23	No
CST 5	G H	0.38	0.63	0.50 1.50	No No
CST 6	I	0.80	1.05	0.93	No
CST 7	J	0.72	0.75	0.73	1 workstation + 773 h
CST 11	K	1.03	1.64	1.34	No
CST 12	L	0.90	0.67	0.79	No
CST 13	M N	- -	- -	0.60 0.60	3 workstations + 419 h No
CST 14	O P Q R	1 1 1 1	1 1 1 1	0.65 0.65 0.65 0.65	1 workstation No No No

With these data, an elementary area type for each elementary operation was determined using the diagrams in Appendix A (Figures A1–A3). Elementary operations were grouped into work areas (Table 5), according to elementary area and equipment type, product volume, and supervision.

Table 5. Grouping elementary operations into work area.

	Work Area Name	Operation	Equipment	Product Volume	Production Hour Request	Required Workstations	Reserved Workstations	Available Production Hours
Reconfigurable area	Assembly workbench 1	F L	- Special-purpose tooling	Medium large	1066.50	0.62	1	1727
	Assembly workbench 2	A I J	Screwdriver, templet Screwdriver, templet Screwdriver	Medium	4685.90	2.71	3	5181
	Assembly workbench 3	G K	Screwdriver Crimping tools	Small	1311.46	0.76	1	1727
Dedicated cell	Dedicated cell 1	D	Screwdriver, templet	Small	1606.50	0.93	1	1727
	Dedicated cell 2	E	Screwdriver	Medium	1840.00	1.07	2	3454
	Dedicated cell 3	M1, M2	-	Small	5880.00	3.40	4	6908
Not-reconfigurable area	10 machines	N	10 machines	Small	7350.00	4.26	10	17,270
	Testing machine	H	Testing machine	Small	115.00	0.07	1	1727
	Pillar drill 1	C	Pillar drill 1	Small	178.50	0.10	1	1727
	Pillar drill 2	B	Pillar drill 2	Medium	86.10	0.05	1	1727
	Lathe	O	Lathe	Medium	1998.13	1.16	2	3454
	Milling machine	P	Milling machine	Medium	799.25	0.46	1	1727
	Sawing machine	Q	Sawing machine	Medium	799.25	0.46	3	5181
	Surface grinder	R	Surface grinder	Medium	399.63	0.23	1	1727

From this stage, the application of SLP proceeded without noteworthy differences from the traditional methodology. In addition to work areas, warehouses were planned and designed for work areas groups. The Flow of Materials phase determined functional areas with in-between flows. The From-To Chart was filled with the intensity of flows, considering differences in size, weight, and the risk factor of the items being moved. The Activity Relationships analysis considered other-than-flow requirements. The relationships between activities were divided into classes, identified by vowel-letters (A, E, I, O, U, and X), to simplify the reading of data. Flow and other-than-flow requirements were combined, and the result was the input data to design the Relationship Diagram. The space needed for each activity was determined by referring to the considerations explained in chapter 0. The area of not reconfigurable modules was the sum of space needed by equipment, plus additional space for maintenance, while the reconfigurable modules consisted of a workbench and a rack system. In both cases, space was reserved for the operator and aisles. Space reserved for the warehouse was determined, too. L'Iride, besides doing the re-layout, has been trying to reduce the amount of stocked material. For this reason, two layouts for each alternative were designed. The transitional layout was to store all the materials already present in the cooperative; these would be progressively reduced to reach the definitive layout, with small changes in the arrangement of the activities. Needed space did not exceed the existing area; thus, the Space Relationship Diagram was drawn with squares or rectangles of dimensions proportional to the area required by each activity. Handling methods were set in the Modifying Consideration phase, and subsequent practical limitations were highlighted. The constraints were the aisle-width and not-to-be changed location of some activities, such as the office, entrances, aids repair departments, and utilities.

Five alternative layouts were developed; two of them were rejected in the verification phase, because the implementation was too binding and either caused the stoppage of production for too long, or storage capacity was insufficient. It has been requested to design an additional layout by modifying one of the alternatives. The layouts that passed the verification phase were evaluated with quantitative and qualitative factors, together with advantages and disadvantages, and the best was selected.

5. Results

The transitional layout for the assembly department is shown in Figure 7 and the definitive selected layout in Figure 8. In the plan of the selected layout, the square and rectangle for each activity correspond to the functional area, i.e., workstation and operator space. Each is colored and has an identification number according to Figure 9.

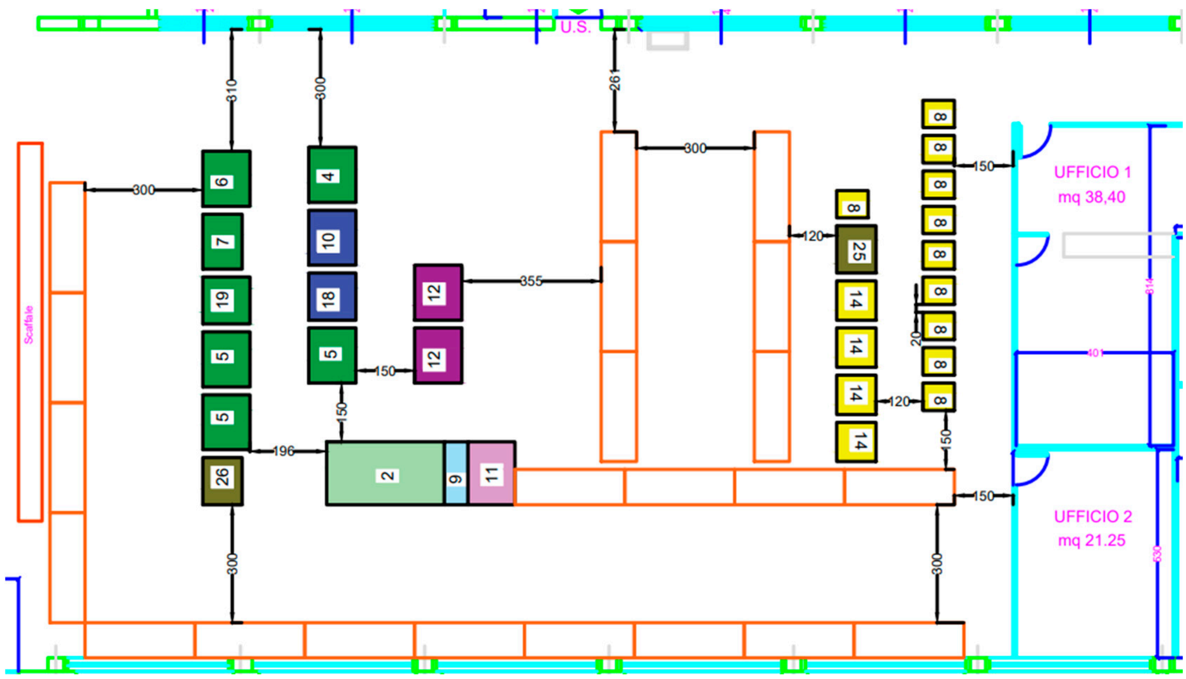

Figure 7. Transitional layout of assembly department (that is, a portion of the overall layout).

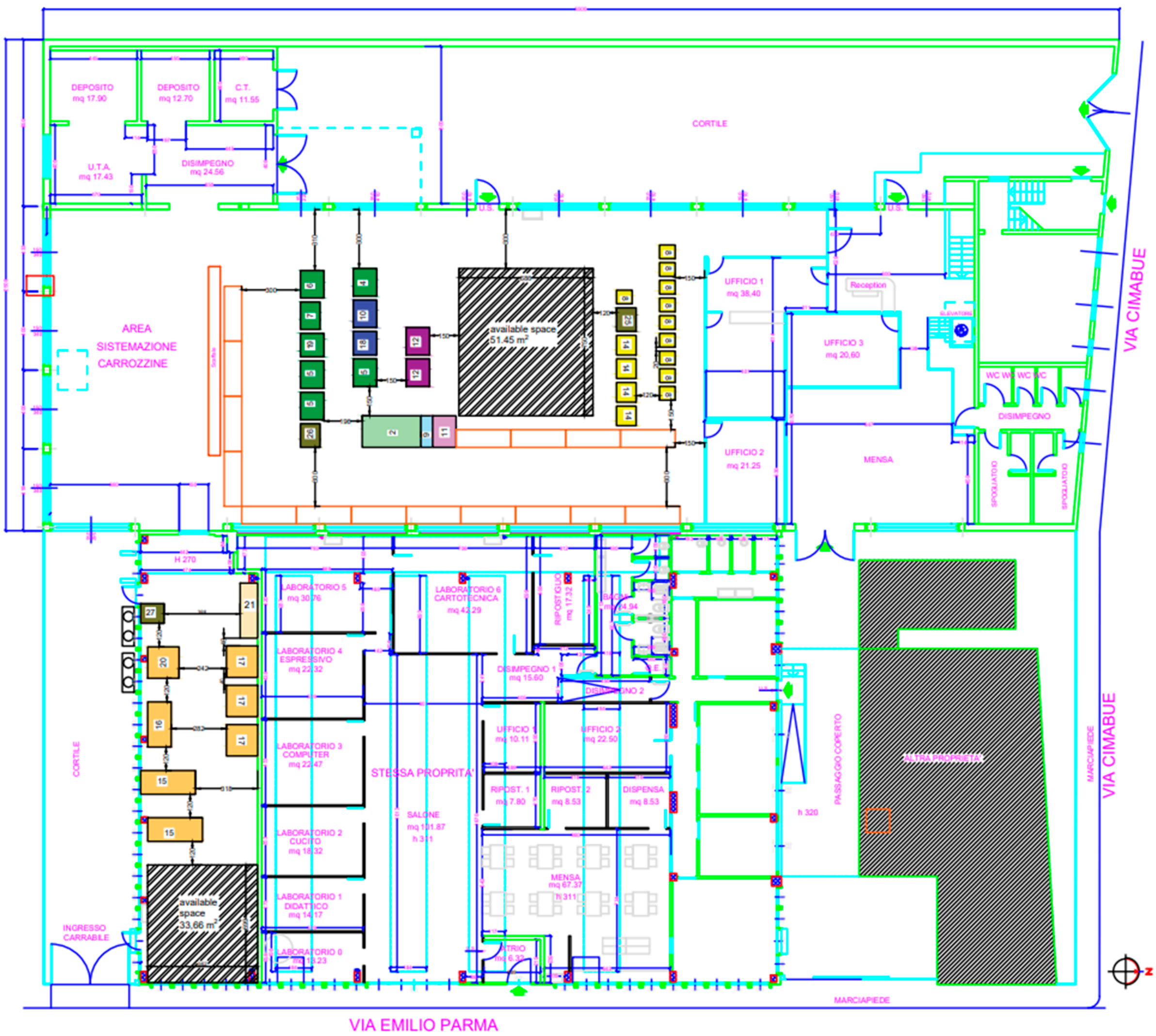

Figure 8. Definitive layout.

5.1. Space Saturation Assessment

At L'Iride, production hours are allocated to customers, not to workstations, making the assessment of work module space saturation impossible.

To assess space saturation, daily production was monitored to determine production hours, corresponding to the time spent by an operator to carry out assigned tasks.

The expected department and production plant space saturation of the definitive layout was assessed, and the data are reported in Table 6, together with the values of the years 2019 and 2020.

Table 6. Department and production plant space saturation.

	2019	2020	Expected
electromechanical assembly	47.20	56.19	170.66
microswitch assembly	110.69	110.69	366.89
assembly	70.68	76.35	241.51
mechanical machining	11.25	11.25	46.57
production plant	47.44	50.89	151.42

LEGEND		
Number	**Activity**	**Colour**
2	Assembly workbenches warehouse	
3	Assembly workbenches outbound warehouse	
4	Assembly workbench 1	
5	Assembly workbench 2	
6	Assembly workbench 1	
7	Testing machine	
8	10 machines	
9	Dedicated warehouse 1	
10	Dedicated cell 1	
11	Dedicated warehouse 2	
12	Dedicated cell 2	
13	Dedicated warehouse 3	
14	Dedicated cell 3	
15	Lathe	
16	Milling machine	
17	Sawing machine	
18	Pillar driver 1	
19	Pillar driver 2	
20	Surface grinder	
21	Mechanical machining warehouse	
25	Microswitch department head	
26	Electromechanical assembly department head	
27	Mechanical machining department head	

Figure 9. Legend of layout plans.

5.2. Conclusions

The application of Systematic Layout Planning, adapted to social cooperatives, has greatly improved the present situation at L'Iride.

The re-layout of the social cooperative was done mainly to allocate the new customers' activities and to find the space needed for the introduction of a new department. Both goals were achieved with the new implemented layout, by arranging workstations, which left 82.11 m^2 available area.

Newly arranged activities helped to streamline material flows, and, together with the new warehouse, the replenishment of workstations was simplified. Idle time due to absence of orders has been avoided through the removal of many small, dedicated areas.

To assess the improvement achieved with the new layout, the present space saturation was compared with the expected values to check the amount of the improvement. The data reported in Table 6 for space saturation were compared for the assembly department in Figure 10 and for the mechanical machining department in Figure 11. The values of the assembly operation departments showed a great improvement as compared to the years 2019 and 2020. The increment of space saturation of the assembly department was 241.7%, compared to the year 2019, and 216.3%, compared to the year 2020. The microswitch assembly exceeded the optimum value, because workbenches were smaller than standard, but this was a particular situation, and the improvement was of 231.4% for both years. However, the electromechanical assembly, which requires standard dimension workbenches, achieved a good improvement. The division of the assembly department into dedicated areas reduced space saturation. Removing the dedicated areas and working on products of different customers in the same area, made reaching workstation saturation easier. The lack of demand from a customer could be compensated by the demand of another, thus reducing idle time. With the changes, the improvement obtained in this department was of 261.6%, compared to the year 2019, and of 203.7%, compared to the year 2020.

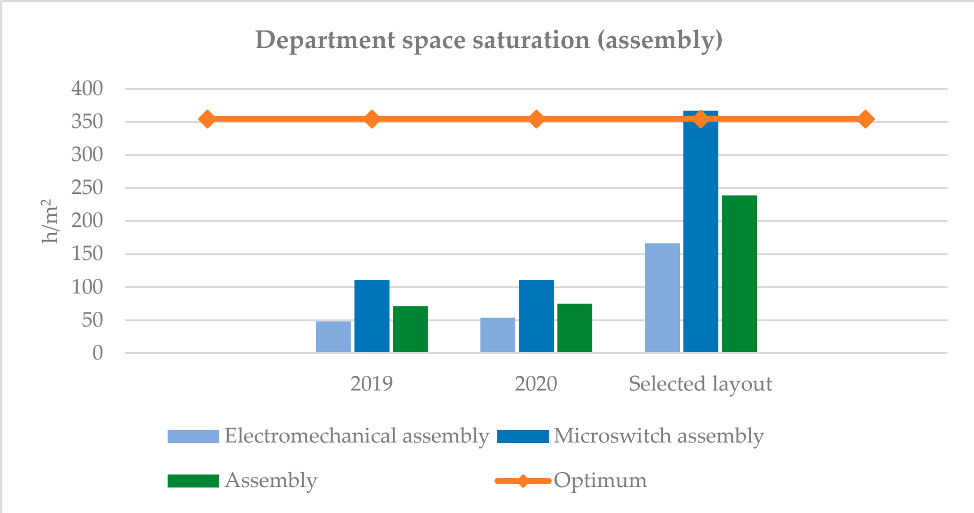

Figure 10. Department space saturation obtained for assembly.

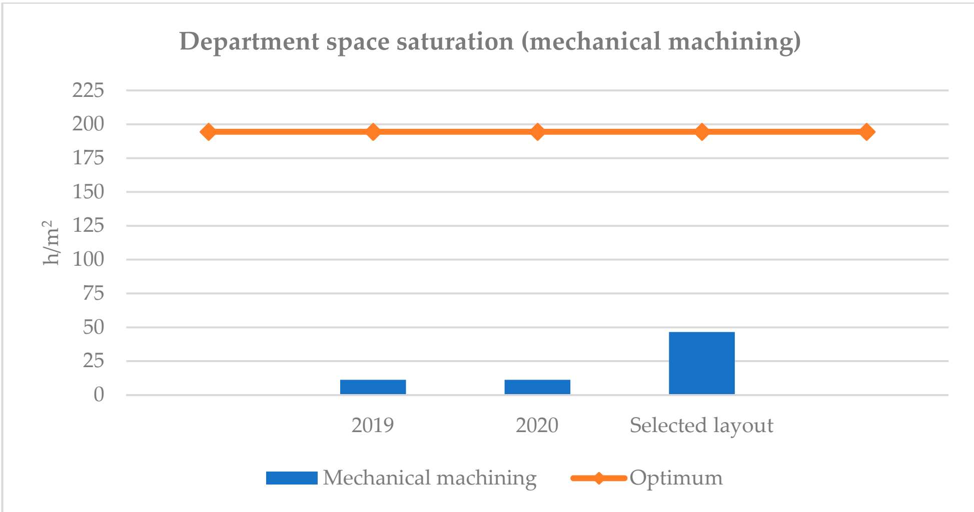

Figure 11. Department space saturation obtained for mechanical machining.

The mechanical machining department reached an improvement of 314% in space saturation. The gap between the optimum and the expected value was very large, because some resources were duplicated (sawing machines and lathe) and not fully exploited. Some equipment in the assembly department, such as the testing machine and pillar drill, were also undersaturated, as in Figure 12. A more specific demand for an operation or more customers requiring the use of the same equipment could partially overcome the problem, facilitating the saturation of the machines. Anyhow, it was difficult to accomplish because social cooperatives are subcontractors.

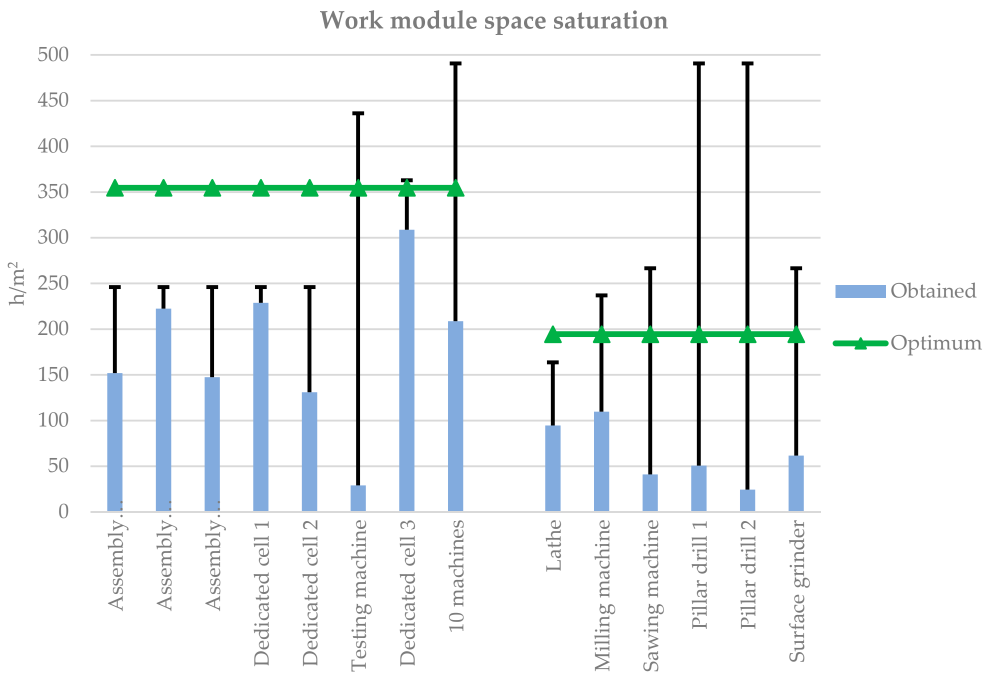

Figure 12. Work module space saturation obtained.

Looking at the overall production area, the improvement obtained was 219.2% and 197.5%, considering the years 2019 and 2020, respectively.

The increase in space saturation obtained in all the departments showed that L'Iride could be optimized, and the new methodology was effective.

Space saturation was the only method that could be used to assess the improvements, because at L'Iride, the standard industrial parameters used to monitor the production process have never been measured. Values in space saturation should be monitored over the next few years to validate the estimated improvement.

Since the methodology has been applied for the first time to L'Iride, there is no benchmark. Applying this evaluation system to other social cooperatives, and to enterprises, will allow for the assessment of the accuracy of the defined optimum space saturation and to value both the efficiency at L'Iride and the possibility of further improvements.

The Systematic Layout Planning, adapted to social cooperatives, will eventually be applied to other enterprises employing a disabled workforce. This will make it possible to evaluate whether the methodology is complete or requires further adjustments. The goal of the new SLP is to transform a social cooperative into a competitive enterprise. Spreading the methodology by applying it to other cooperatives could enhance this transformation process.

This work was only part of a larger project of FARE srl, aimed at favoring job opportunities for disabled workers and their inclusion into the labor market. What was investigated was only the internal improvement of the cooperative, which, however, is the first step to reach that goal.

Author Contributions: All authors were involved in choosing the research methodology, in data analysis, as well as in the results analysis and discussion. A.R. and G.J.L.M. were involved in writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors wish to thank all the people involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

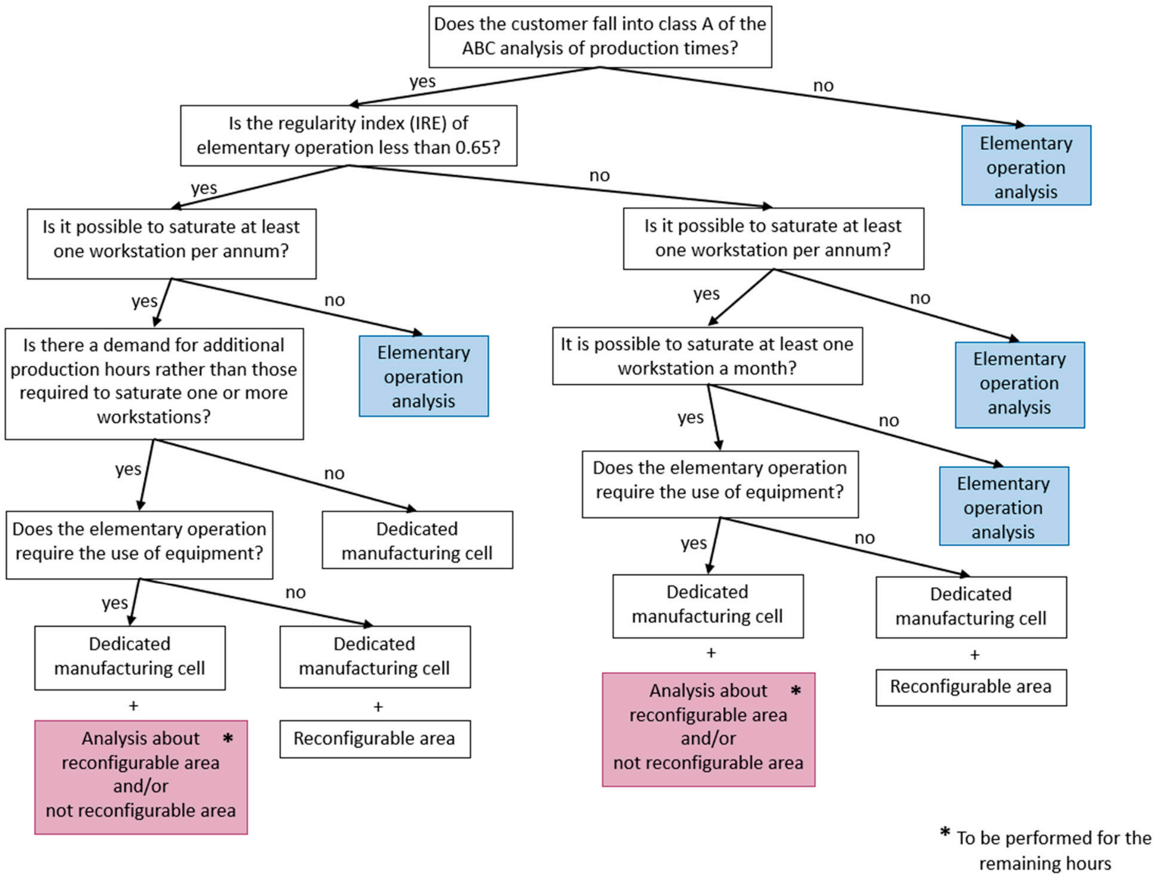

Figure A1. Graph to determine the elementary area type—part 1.

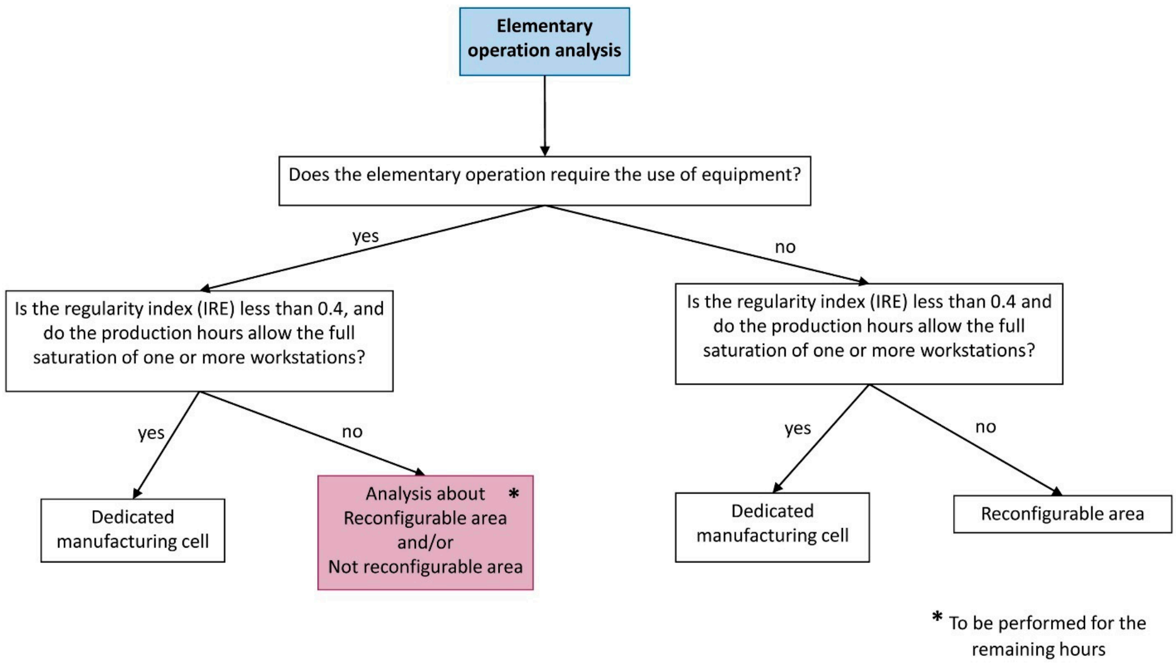

Figure A2. Graph to determine the elementary area type—part 2.

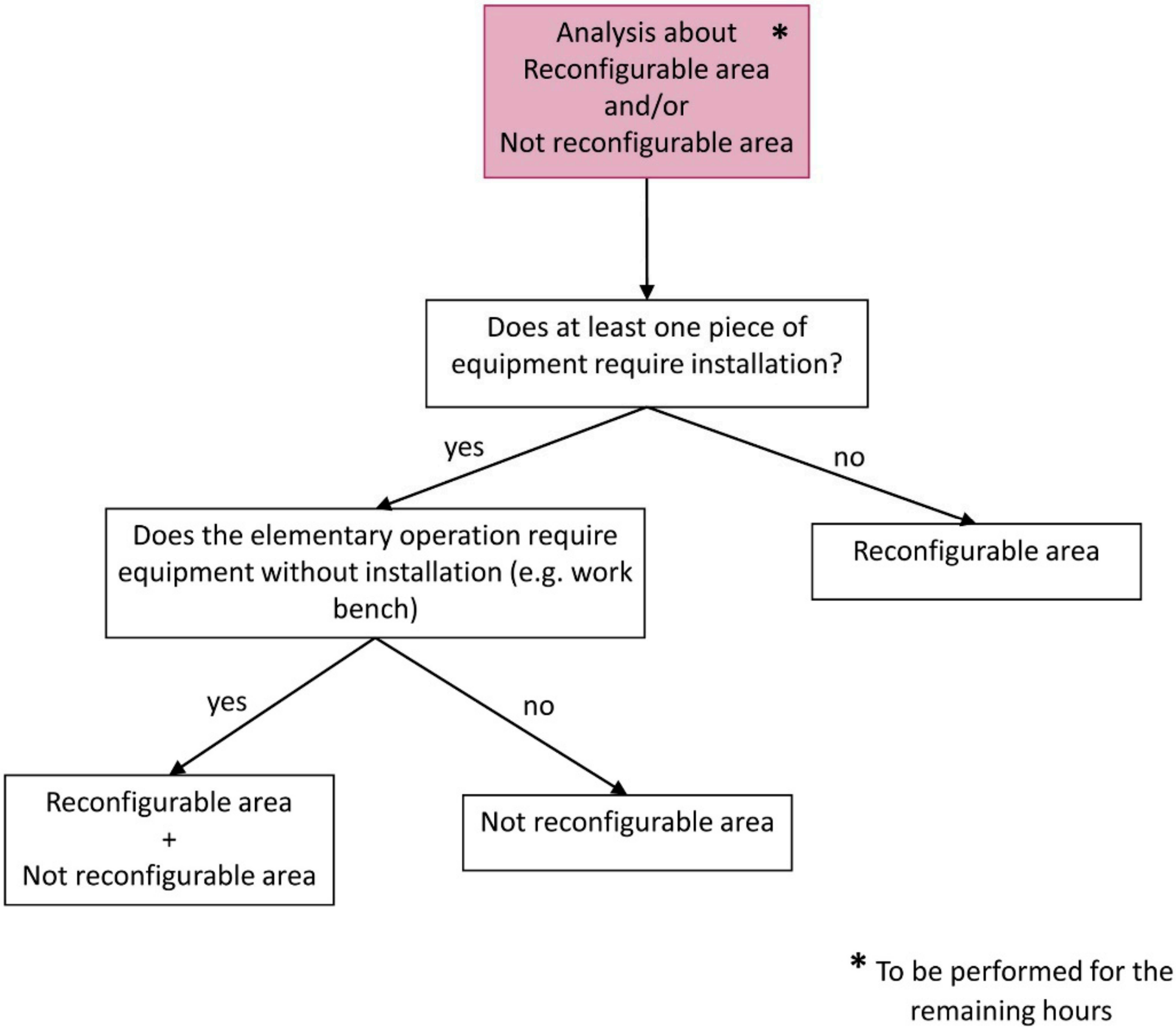

Figure A3. Graph to determine the elementary area type—part 3.

Appendix B

Table A1. Elementary operations.

Customer	Identification Letter	Operation Type	Annual Production Hours	Workbench	Equipment	Installation	Difficulty Degree	Product Dimensions	Supervisions *
CST 1	A	Assembly	15,558.00	Yes	Screwdriver Template	No No	Medium	Medium	1
	B	Drilling	82.00	No	Pillar drill 2	Yes	Medium	Medium	1
CST 2	C	Drilling	170.00	No	Pillar drill 1	Yes	Medium	Small	1
	D	Assembly	1530.00	Yes	Screwdriver	No	Medium	Small	1
					Template	No			
CST 3	E	Assembly	1600.00	Yes	Screwdriver	No	Medium	Medium	1
CST 4	F	Assembly	210.00	Yes	-	No	Medium	Medium	1
CST 5	G	Assembly	828.00	Yes	Screwdriver	No	Medium	Small	1
	H	Testing	92.00	No	Testing machine	Yes	Medium	Small	1
CST 6	I	Assembly	340.00	Yes	Screwdriver	No	Medium	Medium	1
					Template	No			
CST 7	J	Assembly	2500.00	Yes	Screwdriver	No	Medium	Medium	1
CST 11	K	Assembly	263.29	Yes	Crimping tools	No	Medium	Small	1
CST 12	L	Assembly	660.00	Yes	Special-purpose tooling	No	Medium	Medium /large	1
CST 13	M	Assembly	5600.00	Yes	-	No	Low	Small	2
	N	Various machining	7000.00 (700 per workstation)	No	10 machines	Yes	Low	Small	2
CST 14	O	Turning	1737.50	No	2 lathes	Yes	High	Medium	3
	P	Milling	695.00	No	Milling machine	Yes	High	Medium	3
	Q	Saw	695.00	No	3 sawing machines	Yes	High	Medium	3
	R	Lapping	347.50	No	Surface grinder	Yes	High	Medium	3

* 1 stand for electromechanical assembly, 2 for microswitch assembly and 3 for mechanical machining department head.

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