Optimization of the production flow for a machine and tool shop: A Case Study

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Abstract

The research was developed a machine and tool workshop, which arises from the need to carry out facility layout problem (FLP) for two new production lines. The main objective is to optimize the path of the work object through the production departments, achieving a reduction of the total cost of transport, by applying distribution methods in the plant. It began with the research of the theoretical foundation analyzing the existing methodologies about the optimization of plant distribution, applied in productive organizations. The workstations, as well as the necessary infrastructure, are identified in the production process with the dimensions of the workshop. A proposed plant distribution with a U-shaped material flow is developed due to the physical constraints of the workshop, complying with plant distribution principles and occupational safety and health standards for workers. Through the Systematic Layout Planning method and the Computer Relationship Design Planning method for each production line, considering that the main reason for relationship and closeness between departments is the productive flow. To contrast the results, the Computed Relative Allocation of Facilities method was applied to calculate the total cost of transport of the work object journey that was obtained from the distribution for each of the production lines.

Keywords
Facility layout problem, SLP, CORELAP, CRAFT, FLP

1. Introduction
The proper distribution of spaces and areas of work in a company has as its main objective to order the industrial elements so that the production processes are carried out in a fluid, efficient and that they are met in the scheduled time, reducing the occupational accident risks, optimizing production flow, improving employee mobility and increasing productivity, as (Vallhonrat & Corominas, 2010). The advantages of using appropriate plant distributions include reducing economic losses, avoiding large distances for the transfer of materials and tools, division of personnel in work areas, improving product quality by reducing process response times, as proposed (Cuatrecasas, 2012). The design should be simple to facilitate the distribution of the areas within the organization in order to provide better service and correct communication (Vallhonrat & Corominas, 2010). Prevents or minimizes occupational diseases and accidents, increasing productivity as processes are met on schedule, properly distributing materials, tools, and machines so that they are in the places they are needed and thus do not have to move them from long distances (Salazar, 2016). Integrating people, tools, activities, and processes reducing distances, using all spaces, providing safety and tranquility to workers is the purpose of distribution (Obregón, 2016). The contribution in Plant consists of the physical management of the factors and industrial elements that participate in the production process of the company, in the distribution of the area, in the determination of the relative figures and the location of the different departments. The main objective is that this provision of elements is efficient and carried out in a way that contributes satisfactorily to the achievement of the purposes established in the company, in addition the distribution in the plant allows the ordering of industrial elements such as materials, machines, equipment, devices, tools, workers, production spaces, storage and

all those that the company needs for its operation (Párreño, Férnandez, Pino, Puente, & De la Fuente, 2008). Adequate distribution "aims to reduce unnecessary travel, use available space in the best possible way, increase worker safety, improve quality of life at work and reduce risks that may affect good condition of materials, equipment and tools (Castán, Giménez, & Guitart, 2003)

The importance of a correct distribution in the plant is framed in the exact location of the resources in the different areas of the company, facilitating the flow of processes, making communication viable, improving the work environment, since each worker knows what to do and what elements he has for it. Maintenance becomes easier, safer and can be done in the shortest possible time. A limiting a that can be observed at the time of plant distribution is the reduced space, the quantity, weight and volume of the machines and equipment, the large number of workers, but above all the activities that are carried out in the production within the company, a situation that generates serious problems (André, 2019).

2. Materials and Methods

Studies of the art of authors who have presented and formulated solutions allow the resolution of the Facility layout problem, as is the case of (Mejía, Wilches, Galofre, & Montenegro, 2011), where it poses that the Computerized Relative Allocation of Facilities Technique (CRAFT) it's un heuristic method for the distribution of plants developed by (BUFFA, 1964), focuses on minimizing the expenditure of economic resources by mobilization between areas; personnel, materials, equipment, machinery and any resources needed. In addition, (Leiva, Mauricio, & Salas, 2013) express that the Computerized Relationship Layout Planning (CORELAP) method was created by (R.C. Lee, 1967) which uses mathematical construction models, which allows distributions to be made taking into account the closeness relationships of the areas so that they are contiguous. They are assigned a TCR or total rate of closeness, the higher values will be selected and located together. On the other hand, (Baca, y otros, 2014) says that the Systematic Layout Planning method (SLP) developed by (Muther, 1970) allows distribution in new or existing industrial facilities, can be used in organizations, companies, offices, workshops, factories, industrial plants or laboratories. It uses an orderly series of steps that are fulfilled in the four phases that make up it as it proposes. The authors applied all three methods (Montero Santos Yakcleem, 2019)achieving their contrast in a textile company, which shows the applicability of them.

To analyze the Facility layout problem (FLP), the proposed by (Jingfa Liu, 2020), which deals with the layout of facilities within a given plant floor is an NP-hard combinatorial optimization problem. This paper study's multi-objective unequal-area facility layout problems (UA-FLPs) with the flexible bay structure (FBS), whose objectives refer to the material handling cost, the closeness relationship, the distance requirement, and the aspect ratio of facilities. Comparing it to what has been analyzed by (Liu, 2020), where the unequal area facility layout problem (UA-FLP) is the problem of placing departments with different areas in a facility so that departments satisfy some given objectives and constraints. In this paper, two objectives including the material handling cost and the closeness rating are optimized. Based on the quasi-physical strategy, we introduce an extrusive elastic potential energy based on the overlapping distance between departments into the layout system. And (Zawidzki, 2020), that he analyses in his paper proposes a framework where architectural functional layout (FL) is optimized for the following objectives: functionality (defined by users), insolation (calculated according to geographical conditions), outside view attractiveness (assessed on-site) and external noise (measured on-site).

It starts first with the identification of the workstations, for the formulation of the productive flow of operations. After each of the work centers for the two production lines is defined, the SLP method is developed. When the relationship matrix is obtained, the calculate of the total closeness rating (TCR), which defines the order of importance of departments based on affinity is performed, through the CORELAP method, managing to analyze the proximity of the workstations analyzed by the previous method. The CRAFT method is defined to calculate the total routing cost of the work object, in addition to defining the type of material flow to be used.

3. Result and Discussion

The methodologies were applied in a textile company, dedicated to the manufacture, sale and commercialization of wool-based garments wholesale and retail. The following is evidence of the development of methods for plant distribution in the company under study, which was divided into four phases.

Phase 1 Process productive

The production process of Pressure Vessels begins in the cutting process, where the required measurements are marked on the steel sheets and then proceed to cut. Then moves to the rolling post, where the foils are enlisted. They move to the assembly process, where the rolled sheets and industrial accessories are welded. At the end, a quality inspection of the pressure vessel is carried out and it is decided whether a reprocessing of the product is necessary, or whether the product meets the quality requirements.

The Process of Heat Exchangers begins in the cutting process, where the required measurements are marked in the materials and then proceed to cut. Se transfer to the drilling and grinding process, where holes are made in the mirrors of the product and the tubes are bent or cut according to the product specification. The process of assembly, where the tubes and mirrors are solidly joined with industrial accessories. It is analyzed with a quality inspection of the heat exchanger and it is decided whether the product meets the quality requirements or if a reprocessing of the product is necessary.

Phase 2 Method Systematic Layout Planning

Table 1 is shown, the calculation of the surface of the production line of Pressure Vessels, the cutting department was subdivided into two, in order to group machinery and use the workshop space efficiently. Obtained an area for each of the three departments, resulting in the cutting department, with a total area of 68,5 m^2 is the most area required of the available space, for the production line of the Pressure Vessels.

Table 1. Calculation of Surfaces of the Pressure Vessel production line

Calculation of Pressure Vessel Surfaces					
Department of Labor	Space Requirements	Amount	Dimensions (m)	Total Dimensions (m)	Area (m^2)
Cut 1	Workbench	2	3,2 x 2,0	11,5 x 5,1	58,9
	CNC Cutting	1	8,3 x 4,3		
Court 2	Plasma Cutter	1	1,8 x 1,6	4,0 x 2,4	9,6
	Flame	1	1,4 x 1,1		
Rolled	Rolled	1	5,8 x 2,8	5,8 x 3,6	20,9
Armed	Welding	2	1,6 x 1,4	6,0 x 3,5	21,0

(André, 2019)

The table 2 indicates the calculation of the surface of the Heat Exchanger production line. The drilling and grinding department were subdivided into three, with the aim of grouping machinery and using the workshop space efficiently. Obtained an area for each of the three departments, resulting in the drilling and rectification department, with a total area of 122,6 m^2 is the one that requires the most area of available space, for the production line of the Heat Exchangers.

Table 2. Calculation of Surfaces of the Heat Exchanger Production Line

Calculation of Surface Heat Exchangers					
Department of Labor	Space Requirements	Amount	Dimensions (m)	Total Dimensions (m)	Area (m^2)
Cut	Electrode Oven	1	2,4 x 2,3	8,9 x 3,1	27,7
	Tape Saw	1	3,8 x 2,3		
	Around	1	2,7 x 1,6		
Drilling and Rectification 1	Milling machine	1	4,5 x 2,6	14,5 x 6,3	91,1
	Vertical Lathe	1	9,2 x 6,3		

Drilling and Rectification 2	Pedestal Drill	1	1,7 x 1,4	6,0 x 2,3	13,4
	Emery	1	1,2 x 1,2		
	Radial Drill	1	2,3 x 2,3		
Drilling and Rectification 3	Press	1	3,3 x 2,3	7,9 x 2,3	18,1
	Tube Bender	1	2,0 x 1,7		
	Threading machine	1	1,8 x 1,5		
Armed	Rapid Hawk	1	2,5 x 1,7	6,0 x 3,5	21,0
	Hydraulic Pump	1	1,6 x 1,5		

(André, 2019)

The table 3 shows the types and reasons for relationships and plotlines. Where the absolutely important relationship type is strictly related to the productive flow of each production line. Four plot lines are used for plotting this ratio. And the type of relationship that is particularly important is related to the use of the workforce between production departments of each line, to plot this relationship three plot lines are used.

Table 3. Types and reasons for relationships and plot lines

Code	Type of Relationship	Code	Reason for the Cause	Plot Line
A	Absolutely important	1	Productive flow	
E	Especially important	2	Use of the Workforce	

(André, 2019)

La figure 1 indicates the matrix of relationship between activities, of Pressure Vessels, where the three production departments are related to each other. Dando as a result, that the adjoining location of the cutting area with the rolling area, and the rolling area with the assembly area, is absolutely important due to the productive flow. To nearby location of the cutting area with the assembly area, is especially important due to the use of the inter-departmental workforce.

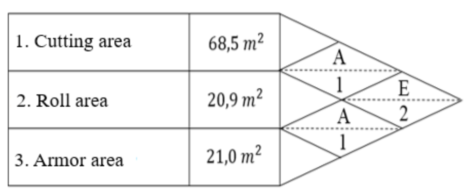

Figure 1. Pressure Vessel Relationship Matrix

(André, 2019)

The figure 2 shows the matrix of relationship between Heat Exchanger activities. The three departments of the production line are related to each other. To adjoining location of the cutting area with the drilling and grinding area, and the drilling and grinding area with the assembly area is absolutely important due to the productive flow. The close location of the cutting area with the assembly area is especially important due to the use of the inter-departmental workforce.

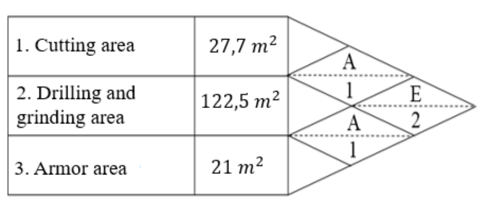

Figure 2. Heat Exchanger Activity Relationship Matrix

(André, 2019)

In order to represent in the form of graphs the information contained in the relational matrices of activities, the relational diagrams of activities of the departments involved in the production of the products Pressure Vessels and Heat Exchangers, respectively.

The figure 3 shows, the relational diagram between pressure vessel activities, where each of the three departments are located, connected by the corresponding plot line according to the relationship type. Itis either resulting in the adjoining location, department 1 or cut with department 2 or rotated, and department 2 or rolled with department 3 or reinforced is plotted with four plot lines and the nearby location of department 1 or cut with department 3 or armed, is plotted with three plot lines.

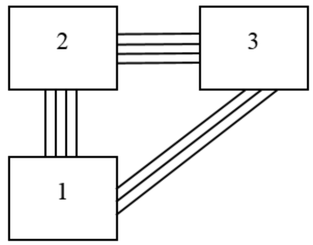

Figure 3. Relational diagram between Pressure Vessel activities

(André, 2019)

The figure 4 indicate the relational diagram between heat exchanger activities, where each of the three departments are located, connected by the plot line that corresponds according to the type of relationship determined in the relational matrix. Dis the result that the adjoining location, department 1 or cut with department 2 or drilling and rectification, and department 2 or drilling and rectification with department 3 or armed, is plotted with four plot lines; and the nearby location of department 1 or cut with department 3 or armed, is plotted with three plot lines.

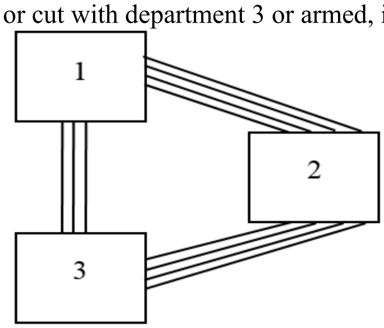

Figure 4. Relational diagram between Heat Exchanger activities

(André, 2019)

Based on the dimensions and areas obtained in the calculation of surfaces, for each work department and the relational diagrams of activities, the relational diagrams of spaces for the production line were prepared, of the products Containers of Pressure and Heat Exchangers, respectively.

The figure 5 indicate the relational diagram of pressure vessel spaces, in which each department is assigned the previously calculated area and the plot lines are maintained, assigned in the relational diagram between activities. Giving as a result that department 1 or cut is the one that requires the largest area of available space, for the production line, followed by department 3 or armed, and finally the department that requires the least area is the 2nd or rolled.

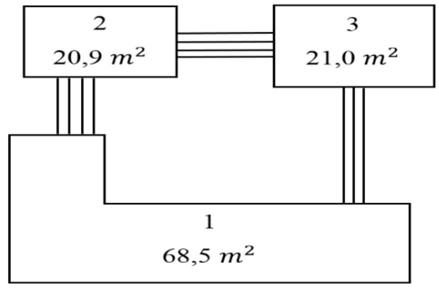

Figure 5. Relational diagram of pressure vessel spaces

(André, 2019)

The figure 6 shows, the relational diagram of spaces of Heat Exchangers, in which each department is assigned the previously calculated area and the plot lines, assigned in the relational diagram between activities are maintained. Giving as a result that department 2 or drilling and rectification, is the one that requires the largest area available for the production line, followed by department 1 or cut, and finally the department that requires the least area is the 3 rd. or armed.

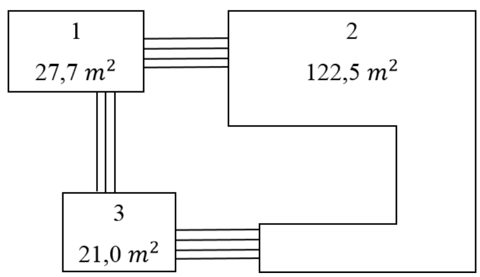

Figure 6. Relational diagram of Heat Exchanger spaces

(André, 2019)

Phase 3 Method Computerized Relationship Layout Planning

To validate the plant distribution proposal, developed by the SLP method, the method was developed CORELAP. This allowed the distribution to be carried out in the plant, considering the closeness of the areas, so that they are contiguous. To calculate the total rate of proximity of each department, entering the data of the matrices of relationships between activities, elaborated in the method SLP. The order of importance of each department, which is involved in the production of the Pressure Vessels and Heat Exchangers products, is generated according to the TCR calculated by the program, according to the data of the matrices.

The order of importance of the Pressure Vessel slabs departments, in which the casting department is placed in first position with a TCR of 12; secondly it was placed in the cutting department with a TCR of 11; and in third position in order of importance was placed to the assembly department with a TCR of 11. In addition, it is shown that the area required for the three departments of the production line of 1104 m^2 is less than the area available, 1703 m^2 arranged in the workshop for such a line. The order of importance of the Heat Exchangers departments, where, it is displayed that the area required for the three departments, of the production line of 1712 m^2 is less than the area available,3146 m^2 arranged in the workshop for such a line; in addition, it was obtained that the drilling and rectification department is placed in first position with a TCR of 12; in second place was placed in the cutting department with a TCR of 11; and in third place in order of importance was placed in the arming department with a TCR of 11. The layouts generated by the program for both production lines were made based on the calculated total commuter rate and validate the proposed plant distribution, the machine and tool shop developed by the SLP method.

Phase 4 Method Computer Relative Allocation of Facilities Technique

For the calculation of the total transport cost of the work object, of each of the production lines that were developed in the machine and tool workshop, the CRAFT method was applied, by means of excel plug-ins that fulfills the objective function, of the mathematical model. The objective function that mathematical model employs is described below:

$$CT_{TOT} = \sum_{i=1}^{n}\sum_{j=1}^{n} y_{ij}\, u_{ij} d_{ij}$$

n: Number of departments
y_{ij}: Unit count of loads moving from department i to j
u_{ij}: Cost of moving a unit load from department i to j
d_{ij}: Distance separating the i and j departments are given by the straight metric

In the table 4 shows data from the From-To matrix of Pressure Vessels, indicating that the path of the work object between departments is sequenced, cut 1 to cut 2, cut 2 to rolling and rolling to assembly. The flow for the production line is 23 units per month between departments, and the cost of moving a unit load between departments is $1,42, the unit cost is calculated by multiplying the 15-minute time spent moving a load, by the pay of the two operators who move the work object in that time.

Table 4. Matrix Data From –To Pressure Vessels

Department i (From)	Department j (To)	Production Flow	Cost of moving unit load
D1 - Court 1	D2 - Court 2	23	$ 1,42
D2 - Court 2	D3 - Rolling	23	$ 1,42
D3 - Rolling	D4 - Armed	23	$ 1,42
D4 - Armed			

(André, 2019)

In the table 5 shows data from the From-To matrix of Heat Exchangers, indicating that the route of the work object is sequenced between departments, cut to drilling and grinding 1, drilling and grinding 1 to drilling and drilling and rectification 2, from drilling and grinding 2 to drilling and grinding 3, and drilling and grinding 3 to assembly. And the production flow for the production line is 17 units per month between departments and the cost of moving a unit load between departments is $2,13; the unit cost is calculated by multiplying the 15-minute time spent moving a load, by the pay of the three operators who perform the displacement of the work object in that span of time.

Table 5. Matrix Data From –To Heat Exchangers

Department i (From)	Department j (To)	Production Flow	Cost of moving unit load
D1 - Court 1	D2 - Drilling and Rectification 1	17	$ 2,13
D2 - Drilling and Rectification 1	D3 - Drilling and Rectification 2	17	$ 2,13
D3 - Drilling and Rectification 2	D4 - Drilling & Rectification 3	17	$ 2,13
D4 - Drilling & Rectification 3	D5 - Armed	17	$ 2,13
D5 - Armed			

(André, 2019)

To complete the information required for costing, the plant distribution developed according to the SLP method and validated by the CORELAP method is entered the excel add-on matrix. When the solution was generated, the total cost of transport of the monthly work object was calculated for each of the production lines. In the table 6 shows the total cost of transporting the work object, calculated for both production lines; a monthly cost of $768,00 was obtained for the Pressure Vessel production line, and for the heat exchanger production line resulted in a monthly cost of $1 394,00.

Table 6. Total Cost of Transport of the Work Object

Production Line	Total Cost of Transportation of the Monthly Work Object
Pressure Vessels	$ 768,00
Heat Exchangers	$ 1 394,00

(André, 2019)

The cost obtained by the excel add-ins is then validated with the individual calculation of the total transport cost of the work object for each of the production lines fulfilling the objective function of the mathematical model of the method.

- Calculation of the total transport cost of the work object for the production line of the product pressure vessels.

$$CT_{TOT} = \sum_{i=1}^{n}\sum_{j=1}^{n}[(23\ x\ 1{,}42\ x\ 9{,}6) + (23\ x\ 1{,}42\ x\ 6{,}9) + (23\ x\ 1{,}42\ x\ 7{,}0)]$$

$$CT_{TOT} = \$\ 768{,}00/month$$

- Calculation of the total cost of transport of the work object for the production line of the Heat Exchangers product.

$$CT_{TOT} = \sum_{i=1}^{n}\sum_{j=1}^{n}[(17\ x\ 2{,}13\ x\ 12{,}5) + (17\ x\ 2{,}13\ x\ 14{,}0) + (17\ x\ 2{,}13\ x\ 5{,}5) + (17\ x\ 2{,}13\ x\ 6{,}5)]$$

$$CT_{TOT} = \$\ 1394{,}00/month$$

When using the methods SLP, CORELAP y CRAFT for the preparation of the proposal, the proposed plant distribution results in the location of production departments. Se locate based on the productive flow of the line achieving the optimal circulation and flow of materials, since it is carried out in a sequenced way causing the distance to travel between departments. To produce the Heat Exchangers product be the minimum of 38,50 meters and the minimum total cost of transport of the work object for the production line is $1394,00 per month.

The figure 7 shows the proposal for plant distribution of the machine and tools workshop. Where intends to implement the two production lines studied in research, for the manufacture of the products Pressure Vessels and Heat Exchangers. In calculating the necessary spaces, for each workstation, the dimensions of the machines were worked with; dimensions for the storage of products in process and dimensions for the requirements of each job, considering the current legal regulations, regarding the occupational safety and health of workers. The areas involved in the manufacture of each product were related to each other, having as the main reason for the relationship between activities, the productive flow of each line. The location of the machines on both production lines is U-shaped, due to the constraints of workshop spaces and thus optimally use the area by streamlining the flow of materials.

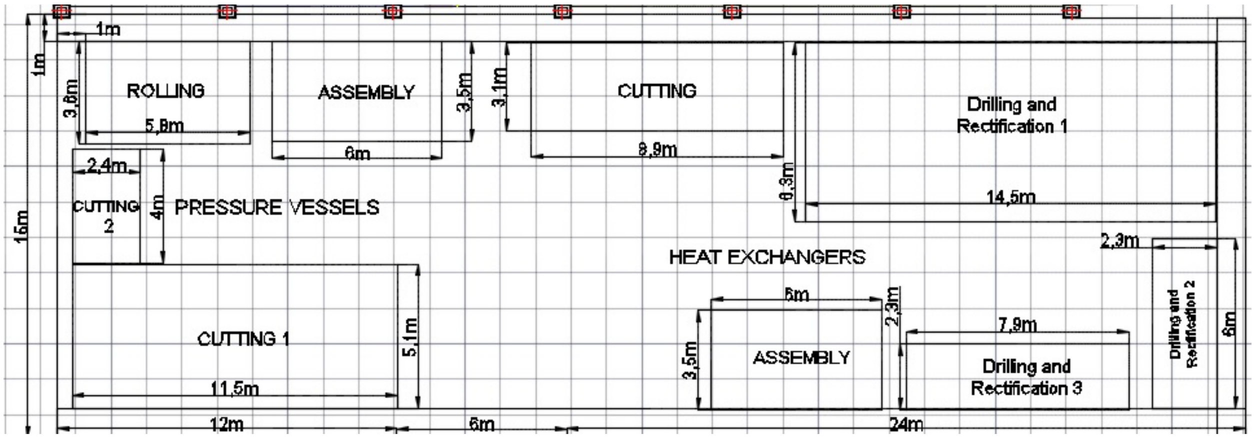

Figure 7. Proposal for distribution in the machine and tool workshop plant
Scale 1:500
(André, 2019)

Based on the proposal for plant distribution of the workshop and the production flow of both production lines, the route diagram was developed, as shown in figure 8. The diagram indicates the way forward, to produce the products Pressure Vessels and Heat Exchangers. The development of the diagram was checked the organization and distribution of the production departments, according to the production flow, allowing the reduction of the total cost of transport of the object of work.

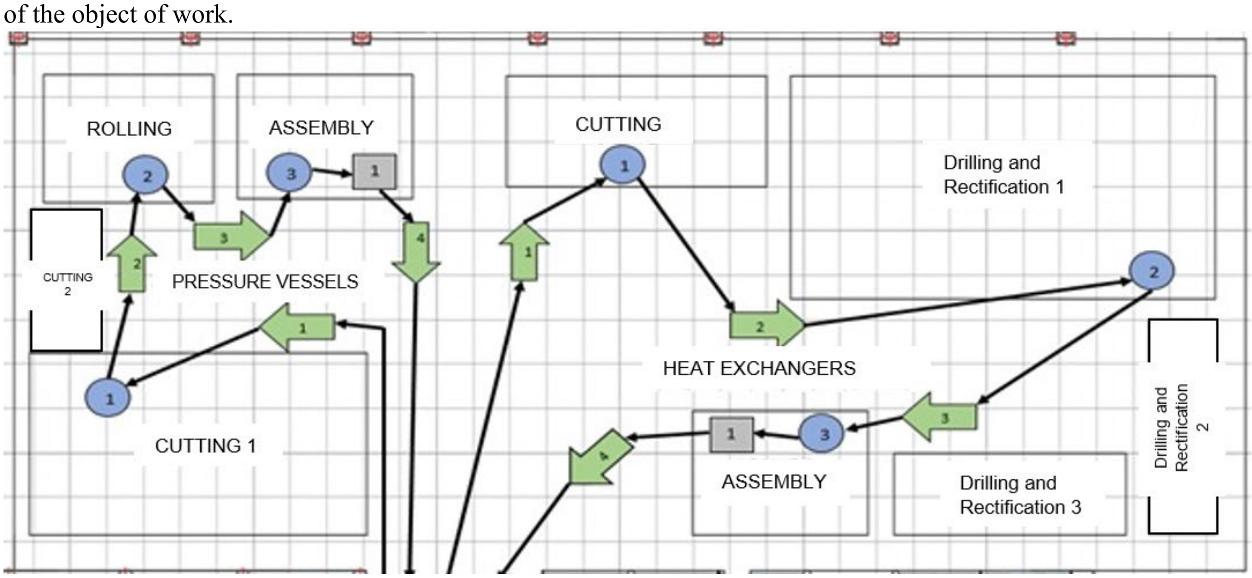

Figure 8. Route diagram of production lines

Scale 1:500
(André, 2019)

4. Conclusions

1. The study of the art was carried out to define the methods applicable for the solution of the problem of distribution in the plant of the workshop of machines and tools to optimize the available space; achieving the integration of the whole of the workforce, means of work and object of work.
2. For the proposed plant distribution of the production lines a U-shaped material flow was used due to the physical constraints of the space available in the workshops.
3. The plant distribution proposal developed by the application of the SLP method and validated by the CORELAP method, complies with the principles of plant distribution, allowing the optimization of the production flow, considering the commuter relationships between departments where the production flow is the main cause or cause of relationship.

4. Applying the CRAFT method contrasts the two methods previously applied and also calculates the total cost of transporting the work object route across the production lines, obtaining that for the production line Pressure Vessels comes at a cost of $768,00 per month and for the production line of Heat Exchangers presents a cost of $1394,00 per month per month.

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