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Material handling cost optimization for a pushbelt manufacturing company using computerized relationship layout planning Algorithm

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ABSTRACT
The strategic arrangement of a shop floor plays a crucial role in determining the operational effectiveness and financial performance of a manufacturing facility. The layout directly influences productivity, workflow, and even employee safety, making it a key factor in a plant's success. In this study, the objective is to refine the facility layout of a push belt manufacturing plant to decrease potential contract penalty fees that may arise from delays and to diminish the expenses associated with material handling. To address this challenge, the research adopts the computerized relationship layout planning (CORELAP) Algorithm to formulate an optimized layout. The implementation of this algorithm aims to reorganizing the shop floor to streamline the movement of workers and materials. The anticipated outcome of the newly designed layout is a significant reduction in the travel distance required for employees to complete their tasks. This optimization is expected to contribute to notable improvements in operation times and cost savings. Particularly, this enhancement results in the elimination of undesirable contract penalty fees and a notable reduction in material handling costs.

Keywords: *material handling, optimization, pushbelt manufacturing*

1. INTRODUCTION

In competitive markets, companies must deliver superior products or services while maintaining cost-effective production [1-2]. Consequently, they must strategically analyse and develop approaches to meet demands at reduced costs. The modern manufacturing facility must adapt quickly to fluctuating product mixes and demand, all the while minimizing expenses associated with material handling and machine relocation [3].Moreover, an efficient facility layout is fundamental for a plant to operate effectively, seamlessly, and safely [4]. In this case study of a push belt manufacturer, it is determined that an inefficient facility layout results in unnecessary travel distance. The consequences are increase in product storage costs and contract penalty fees. To solve the issue, several studies have been conducted. Farhad Azadivar & John(Jian) Wang used simulation and genetic algorithms that consider dynamic characteristics and operational constraints of the system as a whole [1]. A C Sembiring applied CORELAP Algorithm to enhance the utilization of space for classroom allocation [5]. Inaki Maulida Hakim and Vidyahningtyas Istiyanti also uses the CORELAP method to improve production facility layout for a secondary packaging area of a pharmaceutical company [2]. Li Weng proposed an efficient and flexible algorithm to generate plant layout [6]. Ikhsan Siregar and Khalida Syahputri applied BLOCPLAN Algorithm to improve the production facility design of a cup manufacture [7]. Kar Yan Tam designed a coding scheme using Genetic Algorithm to help solve large scale layout problems [8]. Tarigan also proposed a shop floor layout using process layout and product layout approach in an electronic appliance manufacturing company [9].

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In this paper, a push belt manufacturing plant has experienced an average delay of 20% in its deliveries over a continuous nine-month period, resulting in high storage costs and unwanted contract penalty fees It has been identified that the inefficient layout of the shop floor is the root cause of this issue. To address this problem, the CORELAP Algorithm is employed to propose an optimized layout for the manufacturing plant. Section 2 provides detailed information about the push belt manufacturing plant.

2. CASE STUDY

This research was conducted at a push belt manufacturing plant located in Long Thanh Industrial Zone, Dong Nai Province, Vietnam. The implementation was carried out from September 2023 until the beginning of December 2023. At first, the research identifies that three major causes leading to late deliveries are long travel distance in the shop floor, take/ give back tools or equipment, and workers waiting for materials or components. Then it is concluded that the reason behind those problems is the inefficient facility layout of the shop floor. At the next phase, the research collects data by field study. The field study was carried out on the entire shop floor, which is located inside the plant. Particularly, the materials flows are collected by examining each functional area's materials. The material flows are presented in Section 3.1. Workers' movements from one functional area to another were observed and recorded in 7 days. The facility layout was obtained from the plant's overall design file. After collecting the right data, the relationship closenesses between each functional area are grouped using a movements frequency chart which presents the movements between functional areas. Then, the CORELAP algorithm is applied to propose an optimized facility layout. The detail process is presented in Section 4.3. After that, an analysis of the results has been conducted. It presents the total travel distance of the proposed layout based on CORELAP, the reduction in total travel distance, and the results regarding to costs. The results are presented in Section 5.

3. COLLECTED DATA

3.1. Materials flows

The materials flows are categorized into three main lines: element line, assembly line, and loop line. Work-in-process is produced in the Element Line and Loop Line. The final product, the CVT pushbelt, is composed in the Assembly Line. The processes are presented in Figure 1:

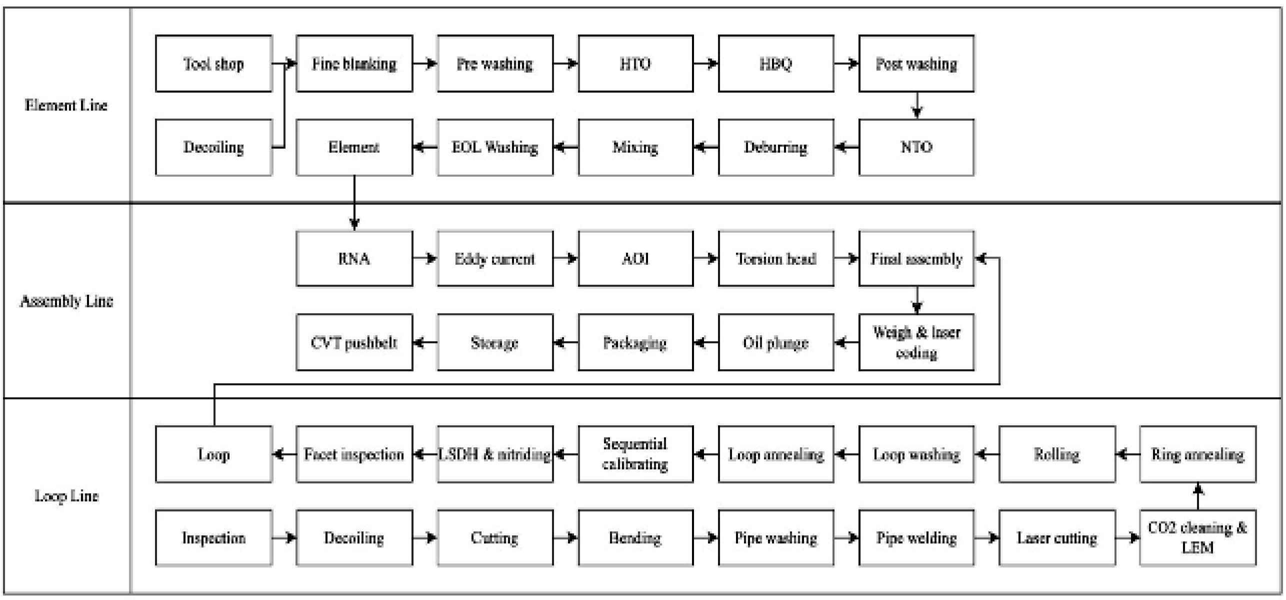

Figure 1. Materials flows

3.2. Current layout

After the initial layout file is obtained, it is essential to process the data by removing specific machines and equipment presented in the file. To help visualize the layout, a simple layout is designed. The design only shows the locations, areas, and names as Figure 2:

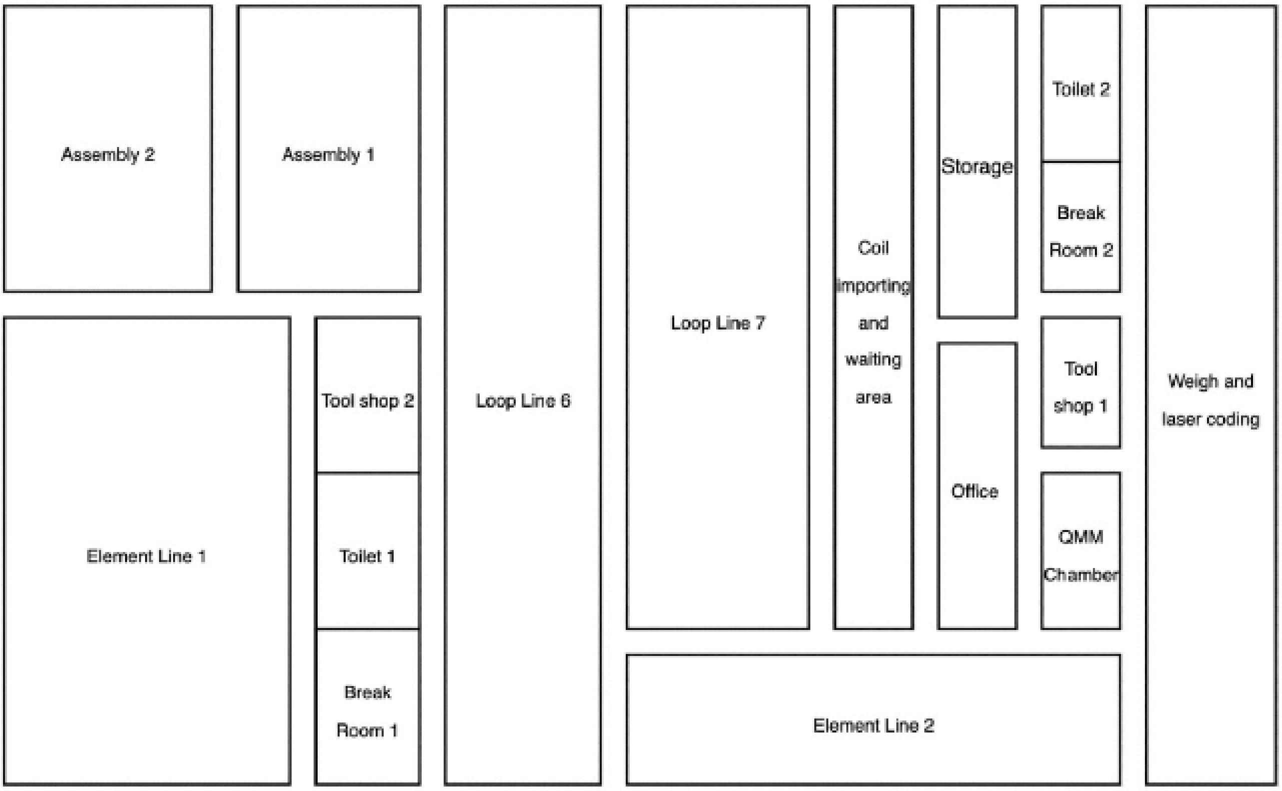

Figure 2. Simple design of current layout

3.3. Workers' movements records

In this study, each functional area is assigned a symbol so that it is easier to present in tables and illustrations. The symbols are presented in Table 1:

Table 1. Symbols used for functional areas

Functional area	Symbol
Assembly 1	A
Assembly 2	B
Element Line 1	C
Element line 2	D
QMM chamber	E
Toilet 1	F
Toilet 2	G
Break room 1	H
Break room 2	I
Loop line 6	J
Loop line 7	K
Coil importing and waiting area	L

Functional area	Symbol
Office	M
Storage	N
Tool shop 1	O
Tool shop 2	P
Weigh and laser coding area	Q

The workers' movements record in 7 days is presented in the movements frequency chart in Table 2.

Table 2. Workers' movement records in 7 days

From \ To	A	B	C	D	E	J	K	L	M	N	O	P	Q
A					22					80	13	15	156
B					24					85	18	21	133
C	128										30	33	
D	90	150									32	29	
E													
J	160	132							17		24	22	
K	153								15		26	18	
L			87	105					21				
M	24	22	15	17	14					6			
N													
O													
P													
Q													

4. Applying CORELAP Algorithm

The CORELAP Algorithm uses relationship rating to define the element placement order. This algorithm can produce a new layout while it doesn't require or depend on an initial layout [8]. The algorithm uses TCR (Total Closeness Rating) to select the placement of the facility elements, where TCR is the sum of the closeness rating of one department to others. The formula can be presented as below:

$$TCR = \sum_{j=1, i \neq j}^{m} W_{ij}$$

where:

m: number of departments

W_{ij}: rating score between departments i and j

The CORELAP Algorithm contains two main activities, which are defining the order of departments and placing them in the layout. These can be presented in the steps below:

- Allocate the department that has the largest TCR. If the same largest TCR is observed within some department, allocate the department having more A, then E, and so on.
- Once the department has the X relationship with the re-arranged department, it will be established in the final step. If there are a lot of X departments, re-arrange it by the decency of TCR.
- The next department will be allocated based on the close relationship with the first one (A, E, I). Using TCR if there is more than one possible outcome.
- Make the loop of the process until all departments are placed in the layout.

The detail of how the CORELAP Algorithm is applied is presented in Sections 4.1 and Section 4.2.

4.1. Relationship closeness grouping

In this stage, the relationship chart, with rankings A, E, I, O, U, can be constructed by classifying the movement records among the functional areas. Movement records will be categorized to rankings as in Table 3:

Table 3. Values of the rankings

Ranking	Value of movement records
A	110 - 160
E	80 - 109
I	40 - 79
O	10 - 39
U	0 - 9

Based on the movement records among the functional areas, the relationship chart, with rankings **A, E, I, O, U,** can be constructed in Table 4:

Table 4. Relationship closeness rankings

	A	**B**	**C**	**D**	**E**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**
A		U	A	E	O	A	A	U	O	E	O	O	A
B	U		U	A	O	A	U	U	O	E	O	O	A
C	A	U		U	U	U	U	E	O	U	O	O	U
D	E	A	U		U	U	U	E	O	U	O	O	U
E	O	O	U	U		U	U	U	O	U	U	U	U
J	A	A	U	U	U		U	U	O	U	O	O	U
K	A	U	U	U	U	U		U	O	U	O	O	U
L	U	U	E	E	U	U	U		O	U	U	U	U
M	O	O	O	O	O	O	O	O		O	U	U	O
N	E	E	U	U	U	U	U	U	O		U	U	U
O	O	O	O	O	U	O	O	U	U	U		U	U
P	O	O	O	O	U	O	O	U	U	U	U		U
Q	A	A	U	U	U	U	U	U	O	U	U	U	

4.2. Placing order

Table 5 summarizes the number of rankings, TCR scores, and the placing order based on TCR scores. It presents how many As, Es, Is, Os, Us each functional area has and the TCR score, where the TCR score can be calculated as:

TCR = (number of As × 4) + (number of Es × 3) + (number of Is × 2) + (number of Os × 1) + (number of Us × 0)

Table 5. Summary of rankings, TCR score, and placing order

Functional area	A	E	I	O	U	TCR	Placing order
A	4	2	0	4	2	26	1
B	3	1	0	4	4	19	2
C	1	1	0	3	7	10	4
D	1	2	0	3	6	13	3
E	0	0	0	3	9	3	7
J	2	0	0	3	7	4	13
K	1	0	0	3	8	7	8
L	0	2	0	1	9	7	9
M	0	0	0	10	2	10	5
N	0	2	0	1	9	7	10
O	0	0	0	6	6	6	11
P	0	0	0	6	6	6	12
Q	2	0	0	1	9	9	6

According to the CORELAP Algorithm, Area A, which is placed first, would be placed in the middle of the shop floor. The next one, Area B, is placed close and in the West corner of Area A. Because only Area C fits the width of the production area if it is placed above Area A and B, it is prioritized to place Area C in the North corner. Then Area D would be placed next to Area A in the East, since it has an A-relationship with Area A. The rest areas are placed similarly. Additionally, as requirements from manager, it is required that a bathroom and a breakroom must be placed next to each other; one pair is located at the end of the production area, and the other is located inside the production area.

5. RESULT

In CORELAP algorithm, it only produces one proposed layout. This layout is considered the optimized layout according to CORELAP. After placing the functional areas according to the CORELAP rules and order, the new layout will be obtained and presented in Figure 3.

Compared to the initial layout, the locations of all functional areas have been changed. However, areas Assembly 1 and Assembly 2 are still located close to each other due to their close relationship and they have the highest TCR scores. Areas Storage and Office are similar. Functional areas that have strong relationships (ranking A and E), such as Assembly 1, Assembly 2, Element Line 1, Element Line 2, Loop Line 7, have been located closer to each other compared to the initial layout.

As requirements of the warehouse manager, toilets and break rooms are still located close to each other. After introducing the new layout, it was noticed that workers' total travel distance decreased to 138,273 meters over a 7-day period. This represents a significant drop from the initial distance of 172,791 meters, resulting in a reduction of 34,518 meters, which is equivalent to 20%.

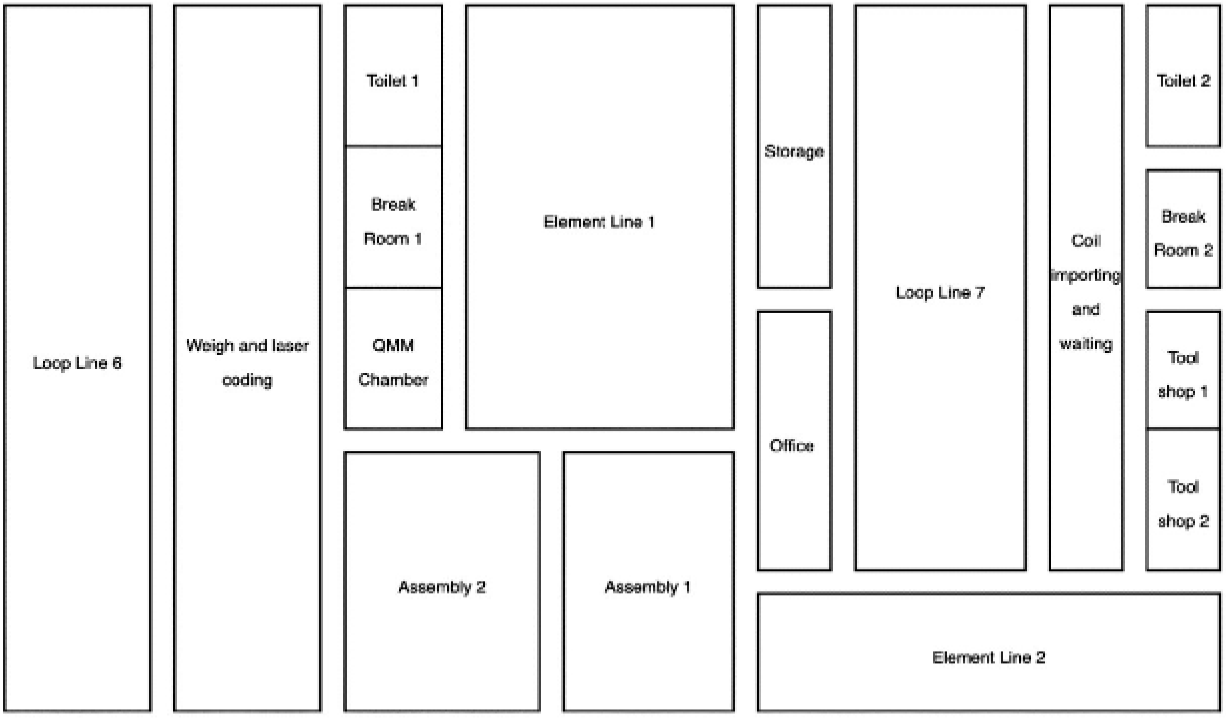

Figure 3. New layout based on CORELAP

6. CONCLUSION AND FURTURE RESEARCH

The research examines the challenges faced by a push belt manufacturing plant, particularly the potential contract penalty fees stemming from delays and subsequent additional material handling costs. After thorough analysis, the primary cause was identified as an inefficient facility layout on the shop floor. To tackle this issue, the study employed the CORELAP Algorithm. The Algorithm effectively proposed a new layout, which proved to be significantly advantageous. With the implementation of this new layout, it was observed that the total travel distance covered by workers over a span of 7 days reduced to 138,273 meters. This marks a noteworthy decrease from the initial travel distance of 172,791 meters, amounting to a reduction of 34,518 meters, equivalent to 20%.

The substantial 20% reduction in worker travel distance on the shop floor has demonstrated its potential to address the problem of late deliveries. Consequently, it leads to cost-saving benefits. Notably, it completely eliminates the contract penalty fee, which originally accounted for 3% of the total contract value. Additionally, it decreases storage costs by a notable 12%. These findings underscore the pivotal role of efficient facility layout in mitigating operational challenges and enhancing financial performance in manufacturing plants. Thus, the successful application of the CORELAP Algorithm in optimizing the layout stands as a testament to its efficacy in addressing complex industrial challenges.

Future studies could delve deeper into the human factors aspect of facility layout design. This entails examining ergonomic considerations, such as workstation design and layout, to optimize worker comfort, safety, and productivity. Incorporating ergonomic principles into layout optimization processes can lead to further improvements in worker satisfaction and overall operational performance. Furthermore, future research could explore the application of simulation modelling techniques to evaluate the impact of different layout configurations on various performance metrics, such as throughput, cycle time, and resource utilization. Simulation models can provide valuable insights into the complex interactions within manufacturing systems and help identify optimal layout configurations under different scenarios and constraints. Moreover, considering the increasing emphasis on sustainability and environmental responsibility, future research could investigate the integration of green design principles into facility layout optimization processes. This includes minimizing energy consumption, reducing waste generation, and optimizing material flow to enhance overall sustainability performance while maintaining operational efficiency.

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Ứng dụng giải thuật CORELAP nhằm tối ưu hóa chi phí di chuyển của nguyên vật liệu của một công ty sản xuất dây đai

Lê Đức Hạnh, Lê Đức Đạo và Trương Quốc Khôi

TÓM TẮT

Sự sắp xếp mặt bằng khu sản xuất đóng vai trò quan trọng trong việc xác định hiệu suất hoạt động và hoạt động tài chính của nhà máy. Cách bố trí trực tiếp ảnh hưởng đến năng suất, quy trình làm việc, và cả sự an toàn của nhân viên. Điều đó làm cho bố trí mặt bằng trở thành một yếu tố cốt lõi trong thành công của một nhà máy. Trong nghiên cứu này, mục tiêu là điều chỉnh cách bố trí mặt bằng của một nhà máy sản xuất dây đeo truyền đồng để giảm thiểu các khoản phí phạt tiềm năng trong hợp đồng phát sinh từ chậm trễ của đơn hàng và giảm thiểu các chi phí liên quan đến lưu kho nguyên vật liệu. Để giải quyết vấn đề này, nghiên cứu áp dụng Thuật toán computerized relationship layout planning (CORELAP) để xác định cách bố trí tối ưu. Việc thực hiện thuật toán này nhằm mục đích tái bố trí khu vực sản xuất để tối ưu hóa dòng di chuyển của công nhân và nguyên vật liệu. Kết quả của sự bố trí mới được dự kiến là giảm đáng kể khoảng cách di chuyển cần thiết cho nhân viên hoàn thành nhiệm vụ của họ. Sự tối ưu hóa này sẽ góp phần cải thiện đáng kể về thời gian hoạt động và tiết kiệm chi phí. Đặc biệt, sự cải thiện này dẫn đến việc loại bỏ các khoản phạt hợp đồng không mong muốn và giảm thiểu đáng kể chi phí xử lý vật liệu.

Từ khóa: *nguyên vật liệu, tối ưu hóa, sản xuất dây đai*

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