IE 312 - Facility Design & Planning

LAYOUT DESIGN FOR A HYPOTHETICAL FLEXIBLE MANUFACTURING SYSTEM

Part 1 Report

Bengü Yağmur Kaya (25%) – 2019402096

Ömer Osman Oğultürk (25%) – 2021402216

Yusuf Eren Bayhan (25%) – 2022402255

Zeynep Terzioğlu (25%) -2021401288

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1. Introduction

This project presents the design and analysis of a facility layout for a hypothetical Flexible Manufacturing System (FMS). The primary objective is to determine the optimal arrangement of machine centers to minimize the total material-handling cost, defined as the total distance traveled by Automated Guided Vehicles (AGVs) when loaded.

The FMS under consideration consists of six distinct Computer Numerical Control (CNC) machines: a Vertical Milling Machine (VMC), a Horizontal Milling Machine (HMC), a Universal Milling Centre (UMC), two Vertical Turning Centres (VTC1 and VTC2), and a Shaper (SHP). In addition to these processing units, a Central Buffer (CB) station is required to serve as temporary storage. The facility layout offers seven candidate locations (LOC 1 through LOC 7), each measuring 4 meters by 4 meters. Parts enter and leave the system via dedicated receiving and shipping stations

Material transfer between stations is executed by a fleet of AGVs moving along unidirectional lanes. These vehicles use the shortest path logic and carry a single load at a time. A critical constraint of the system is the limited queue capacity at machine input/output buffers. To prevent potential blockages and system deadlocks caused by full buffers, the Central Buffer temporarily holds parts until the destination machine becomes available. Figure 1 illustrates the candidate locations and AGV flow paths.

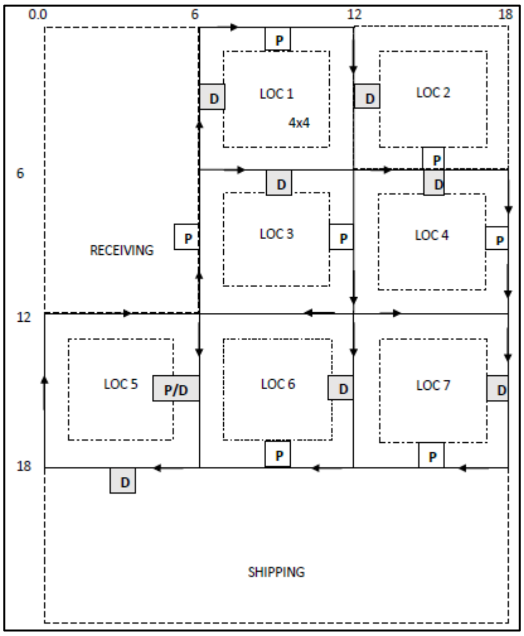

Figure 1: Candidate machine locations together with P and D stations and the AGV flow path

A constructive algorithm was first used to generate the initial layout, followed by an improvement algorithm that refined the arrangement by testing adjacent interchanges.

2. Analysis and Solution

2.1 Flow and Distance Matrices

Before applying the constructive and improvement algorithms, the flow and distance matrices were prepared. The transportation cost is calculated by using the material flow amounts and the distances between the locations.

2.1.1 Flow Matrix

The flow matrix was created by using the process plans in Table 1 and the machine data in Table 2. It shows the total flow between machine pairs. The flow matrix summarizes the total flow between machine pairs.

From-to Matrix	VTC1	VTC2	CB	HMC	UMC	VMC	SHP	Shipping
Receiving	13	7						
VTC1							13	5
VTC2				5		2	5	
CB								
HMC								9
UMC	5							
VMC				2				6
SHP		5		2	5	6		

Table 2.1.1 *From-to Matrix*

2.1.2 Distance Matrix

The distance matrix shows the shortest path distances between the Pick-up (P) and Delivery (D) points for each location. The Receiving (R) and Shipping (S) stations are also included in this matrix. This is necessary to calculate the total loaded distance of the AGVs correctly.

Distance Matrix	LOC1	LOC2	LOC3	LOC4	LOC5	LOC6	LOC7	Shipping
Receiving	6	18	6	12	24	18	24	30
LOC1	-	6	30	12	24	18	24	30
LOC2	30	-	30	0	24	18	12	30
LOC3	18	30	-	24	12	6	12	18
LOC4	48	60	48	-	42	60	6	24
LOC5	30	42	30	36	-	42	48	6
LOC6	30	42	30	36	24	-	48	6
LOC7	36	48	36	42	30	48	-	12

Table 2.1.2 *Distance Matrix*

2.2 Alternative Layout 1 - Constructive Algorithm

To generate the first layout alternative, a constructive algorithm was used to assign machines to the seven candidate locations sequentially. This method aims to obtain an initial yet systematic configuration that minimizes inter-station transportation while maintaining smooth part flow within the system.

2.2.1 Determination of Closeness Relationships

Flow values were grouped into heuristic intervals and mapped to qualitative closeness categories (A, E, I, O, U), each assigned a numerical coefficient reflecting the strength of interaction. The coefficient structure is provided in Table 2.2.1.1. Zero or negligible flow is assigned rating U, while the highest flow range corresponds to rating A with a coefficient of 10,000. This exponential weighting emphasizes the significance of high-flow relationships during the placement steps of the constructive algorithm.

Flow Interval	Closeness Rating	Rating Coefficient
0	U	0
0-3.25	O	10
3.25-6.50	I	100
6.50-9.75	E	1000
9.75-13	A	10000

Table 2.2.1.1 Heuristic closeness ratings according flows between machines

After calculating each machine's utilization levels, the values were normalized to enable consistent comparison across the system. The normalized utilizations were then grouped into five equally sized intervals to determine the corresponding closeness categories. Machines with high flow or high utilization were assigned stronger closeness relationships due to their operational criticality. The resulting utilization-based closeness ratings are presented in Table 2.2.1.2

Machine center	Time	Utilizations	Closeness Relationship
VTC1	3440	95,56%	A
VTC2	2780	77,22%	E
HMC	2980	82,78%	A
UMC	2400	66,67%	E
VMC	3120	86,67%	A
SHP	1950	54,17%	I

Table 2.2.1.2 Closeness Ratings Based on Machine Utilizations

Using the closeness intervals derived from the flow analysis and the utilization-based ratings, the relationships between the Central Buffer (CB) and all machine centers were determined. Since the input and output queues of the machines have limited capacity, machines that frequently interact with the rest of the system or operate at high utilization levels require closer access to the CB. Therefore, the CB machine relationships were assigned based on both the magnitudes of inbound and outbound material flows and the operational criticality of the corresponding machines. Machine pairs with high flow intensity or strong utilization based importance received higher closeness categories, whereas those with weaker interactions were assigned lower categories. The resulting CB activity relationships are summarized in the Table 2.2.1.3

Closeness Relations between Machines/Stations			
A	**E**	**I**	**O**
Receiving - CB	Receiving-VTC2	VTC1-Shipping	VTC2-VMC
CB -VTC1	CB-VTC2	UMC-VTC1	VMC-HMC
CB-HMC	HMC-Shipping	SHP-VTC2	SHP-HMC
Receiving - VTC1	CB-UMC	VTC2-HMC	
VTC1-SHP		SHP-UMC	
CB-VMC		VTC2-SHP	
		VMC-Shipping	
		SHP-VMC	
		CB-SHP	

Table 2.2.1.3 Activity Relationships

2.2.2 Calculation of Total Closeness Ratings (TCR)

Total Closeness Ratings (TCR) were computed by converting the qualitative closeness categories into numerical coefficients and summing the weighted interactions of each machine with all others and with the Central Buffer. Machines with higher flow intensity or greater utilization importance naturally received larger coefficients, resulting in higher TCR values. These values determined the placement priority of machines during the constructive algorithm. The calculated TCR values are presented in Table 2.2.2.1.

TOTAL CLOSENESS RATINGS (TCR)	
VTC1	30200
VTC2	2310
CB	32100
HMC	11120
UMC	1200
VMC	10220
SHP	10510

Table 2.2.2.1 TCR Values

2.2.3 Direct Constructive Algorithm Implementation

Once the TCR values were obtained, the constructive layout was generated using a heuristic placement procedure. In this approach, machines are sequentially positioned according to their TCR ranking, starting with the unit with the highest overall interaction strength. At each placement step, all available locations are evaluated using the **Weighted Placement Value (WPV)**, which reflects how well suited each location is for the next machine in the sequence.

The WPV for a location is computed by summing the weighted closeness relationships between the machine to be placed and all machines that have already been assigned, and dividing this sum by the distance between the corresponding locations:

$$WPV = \frac{\Sigma\, Closeness\ ratings\ with\ placed\ machines}{Distances}$$

Based on the TCR ranking obtained earlier, the placement sequence used in the constructive procedure is:

Placement Sequence= [SHP, UMC, CB, VTC2, HMC, VTC1, VMC]

The WPV calculations performed for each step of this sequence are provided in Table 2.2.3.1, and the resulting placement decisions are summarized in the following subsections.

SELECTED MACHINE	wpv1	wpv2	wpv3	wpv4	wpv5	wpv6	wpv7	PLACEMENT
CB	1666,67	555,56	1666,67	833,33	416,67	555,56	416,67	[LOC1, LOC2,CB, LOC4, LOC5, LOC6, LOC7]
VTC1	2225,56	892,22	-	1254,17	1266,67	2238,89	1258,33	[LOC1, LOC2,CB, LOC4, LOC5, VTC1, LOC7]
HMC	588,89	366,67	-	458,33	1000,00	-	916,67	[LOC1, LOC2,CB, LOC4, HMC, VTC1, LOC7]
SHP	339,31	241,85	-	282,18	-	-	217,00	[SHP,LOC2,CB,LOC4,HMC,VTC1, LOC7]
VMC	-	353,75	-	429,40	-	-	846,17	[SHP,LOC2,CB,LOC4,HMC, VTC1, VMC]
VTC2	-	113,89	-	139,46	-	-	-	[SHP, LOC2,CB, VTC2, HMC, VTC1, VMC]
UMC	-	55,56	-	-	-	-	-	[SHP, UMC,CB, VTC2,HMC, VTC1, VMC]

2.2.3.1 WPV values for all placements

2.2.4 Final Constructive Layout

After completing all WPV evaluations, the constructive algorithm produced an initial facility layout by assigning each machine to the location that maximized its weighted placement value at the moment of placement. Through this iterative process, the algorithm prioritized proximity between machine pairs with strong activity relationships and minimized the expected AGV travel distances across the system. The final arrangement obtained from the constructive phase is presented in Table 2.2.4.1.

Location	Assigned Machine
LOC1	SHP
LOC2	UMC
LOC3	CB
LOC4	VTC2
LOC5	HMC
LOC6	VTC1
LOC7	VMC

Table 2.2.4.1 Alternative Layout 1

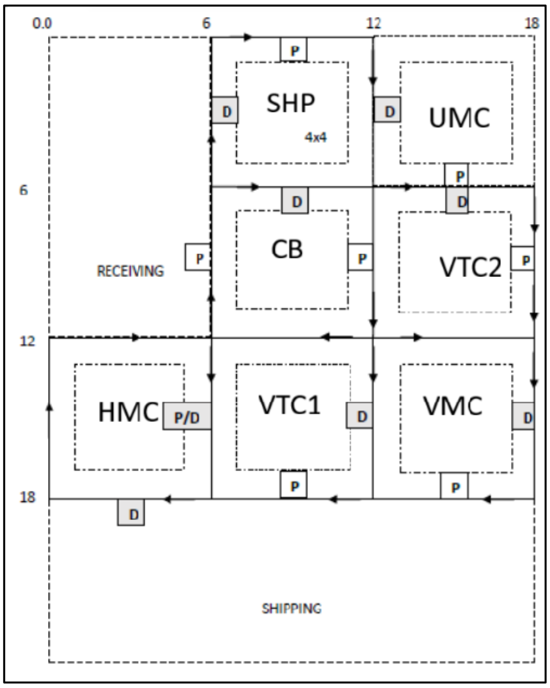

Figure 2.2.4.1 Alternative Layout 1

2.3 Alternative Layout 2 - Improvement Algorithm

To obtain an alternative layout, a flow distance-based improvement algorithm was applied. Similar to the constructive phase, this approach uses heuristic logic; however, instead of relying on closeness ratings or activity relationships, the objective here is to reduce total transportation cost by examining the interaction levels between machine centers and testing new placement alternatives.

The improvement algorithm begins with the initial layout obtained from the constructive procedure. The improvement algorithm used the initial layout as the baseline and evaluated adjacent interchanges by recomputing transportation costs via the flow and distance matrices.

The improvement procedure follows a structured sequence of steps:

1. Start with the constructive layout and compute its total transportation cost by multiplying every flow by the associated distance.
2. Identify all feasible pairwise swaps among departments that share a boundary or occupy compatible locations.
3. Perform each candidate interchange and recalculate the resulting transportation cost.
4. Compare all new costs with the current best layout. If a lower cost is achieved, adopt that alternative and repeat the procedure. If no further cost reduction is possible, the algorithm terminates, and the corresponding layout is accepted as the improved solution.

2.3.1 Initial Layout

The distance matrix for the Initial layout (Image 2.2.4.1) is derived by assigning the machines to their corresponding locations and utilizing the previously computed distance matrix. The resulting distance and from-to matrix is shown in Tables 2.3.1.1 and 2.3.1.2.

Distance Matrix	SHP	UMC	CB	VTC2	HMC	VTC1	VMC	Shipping
Receiving	6	18	6	12	24	18	24	30
SHP	0	6	30	12	24	18	24	30
UMC	54	0	30	0	24	18	12	30
CB	18	30	0	24	12	6	12	18
VTC2	48	60	48	0	42	60	6	24
HMC	30	42	30	36	0	42	48	6
VTC1	30	42	30	36	24	0	48	6
VMC	36	48	36	42	30	48	0	12

Table 2.3.1.1 Distance Matrix of Initial Layout

From-to Matrix	SHP	UMC	CB	VTC2	HMC	VTC1	VMC	Shipping
Receiving	0	0	0	7	0	13	0	0
SHP	0	5	0	5	2	0	6	5
UMC	0	0	0	0	0	5	0	0
CB	0	0	0	0	0	0	0	0
VTC2	5	0	0	0	5	0	2	0
HMC	0	0	0	0	0	0	0	9
VTC1	13	0	0	0	0	0	0	5
VMC	0	0	0	0	2	0	0	6

Table 2.3.1.2 From-to Matrix of Initial Layout

The transportation cost matrix is calculated by multiplying the distance matrix by the from-to matrix for each pair of stations. The resulting matrix is presented in Table 2.3.1.3

COST MATRIX	SHP	UMC	CB	VTC2	HMC	VTC1	VMC	Shipping
Receiving	0	0	0	84	0	234	0	0
SHP	0	30	0	60	48	0	144	150
UMC	0	0	0	0	0	90	0	0
CB	0	0	0	0	0	0	0	0
VTC2	240	0	0	0	210	0	12	0
HMC	0	0	0	0	0	0	0	54
VTC1	390	0	0	0	0	0	0	30
VMC	0	0	0	0	60	0	0	72

Table 2.3.1.3 Cost Matrix of Initial Layout

The sum of all costs in the matrix; the total transportation cost is 1908 for the initial layout.

2.3.2 Starting The Iterations

For each alternative, the from–to matrix is updated to reflect the new positions, and the transportation cost is recalculated using the same flow and distance logic. The possible adjustments are as follows:

1. SHP ↔ UMC
2. SHP ↔ CB
3. UMC ↔ VTC2
4. CB ↔ VTC2
5. CB ↔ HMC
6. CB ↔ VTC1
7. VTC2 ↔ VMC
8. HMC ↔ VTC1
9. VTC1 ↔ VMC

In the first iteration of the improvement algorithm, the positions of SHP and UMC were interchanged to evaluate whether relocating these two adjacent departments would reduce the total transportation cost. After applying the interchange, the updated flow and distance matrices were used to compute the new transportation cost.

Using this updated flow matrix and the corresponding distances between the new P/D points, a revised cost matrix was formed by multiplying each flow value by its associated distance. The total cost for this interchange was then obtained by summing all entries in the cost matrix.

The SHP ↔ UMC interchange resulted in a total transportation cost of 2232, which is higher than the initial layout cost of 1908. Therefore, this swap does not provide an improvement and is not selected for the next iteration.

From-to Matrix	UMC	SHP	CB	VTC2	HMC	VTC1	VMC	Shipping
Receiving	0	0	0	7	0	13	0	0
UMC	0	0	0	0	0	5	0	0
SHP	5	0	0	5	2	0	6	5
CB	0	0	0	0	0	0	0	0
VTC2	0	5	0	0	5	0	2	0
HMC	0	0	0	0	0	0	0	9
VTC1	0	13	0	0	0	0	0	5
VMC	0	0	0	0	2	0	0	6

Table 2.3.2.1 Results of Iteration 1

COST MATRIX	UMC	SHP	CB	VTC2	HMC	VTC1	VMC	Shipping
Receiving	0	0	0	84	0	234	0	0
UMC	0	0	0	0	0	90	0	0
SHP	270	0	0	0	48	0	72	150
CB	0	0	0	0	0	0	0	0
VTC2	0	300	0	0	210	0	12	0
HMC	0	0	0	0	0	0	0	54
VTC1	0	546	0	0	0	0	0	30
VMC	0	0	0	0	60	0	0	72

Table 2.3.2.2 Costs after applying interchange SHP–UMC

Interchanges	Costs
SHP ↔ UMC	2232
SHP ↔ CB	1932
UMC ↔ VTC2	2070
CB ↔ VTC2	1668
CB ↔ HMC	2070
CB ↔ VTC1	1716
VTC2 ↔ VMC	1956
HMC ↔ VTC1	2100
VTC1 ↔ VMC	2088

Table 2.3.2.3 Cost after interchanges.

Interchanges yielding lower cost were retained. At this point, the layout with the lowest transportation cost is accepted as the improved solution for Alternative Layout 2.

The most favorable interchange in the first iteration was **CB ↔ VTC2**, which reduced the total transportation cost from **1908** to **1668**. As this swap provided the greatest improvement and no other alternative achieved a lower cost, it was selected and implemented as the updated layout. This new configuration serves as the base layout for the next iteration of the improvement procedure.

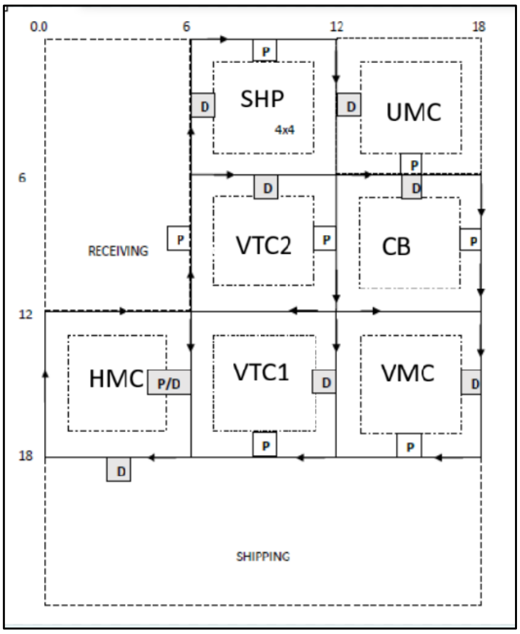

Figure 2.3.2.1 Alternative Layout after Iteration 1

From-to Matrix	SHP	UMC	VTC2	CB	HMC	VTC1	VMC	Shipping
Receiving	0	0	7	0	0	13	0	0
SHP	0	5	5	0	2	0	6	5
UMC	0	0	0	0	0	5	0	0
VTC2	5	0	0	0	5	0	2	0
CB	0	0	0	0	0	0	0	0
HMC	0	0	0	0	0	0	0	9
VTC1	13	0	0	0	0	0	0	5
VMC	0	0	0	0	2	0	0	6

Table 2.3.2.4 From-to Matrix of the new base Layout

COST MATRIX	SHP	UMC	VTC2	CB	HMC	VTC1	VMC	Shipping
Receiving	0	0	42	0	0	234	0	0
SHP	0	30	150	0	48	0	144	150
UMC	0	0	0	0	0	90	0	0
VTC2	90	0	0	0	60	0	24	0
CB	0	0	0	0	0	0	0	0
HMC	0	0	0	0	0	0	0	54
VTC1	390	0	0	0	0	0	0	30
VMC	0	0	0	0	60	0	0	72

Table 2.3.2.5 Cost Matrix of the new base Layout

After applying the CB ↔ VTC2 swap, the layout was updated as shown in the Figure 2.3.2.1 For the second iteration, all feasible interchanges were re-evaluated by examining the adjacency relationships in the new configuration. Only departments that share a common border are considered eligible for swapping, in accordance with the improvement algorithm rules.

Based on the updated layout, the following department pairs are adjacent and therefore constitute the possible interchanges for Iteration 2:

1) SHP ↔ UMC
2) SHP ↔ VTC2
3) UMC ↔ CB
4) VTC2 ↔ VTC1
5) CB ↔ VMC
6) HMC ↔ VTC1
7) VTC1 ↔ VMC

For each candidate pair, the departments were interchanged and the total transportation cost was recalculated using the same flow–distance methodology. The resulting costs for all swaps tested in Iteration 2 are summarized in Table 2.3.2.6.

Interchanges	Costs
SHP ↔ UMC	2052
SHP ↔ VTC2	1476
UMC ↔ CB	1908
VTC2 ↔ VTC1	1692
CB ↔ VMC	1716
HMC ↔ VTC1	1770
VTC1 ↔ VMC	1728

Table 2.3.2.6 Costs after interchanges

The most favorable result in this iteration was obtained by the SHP ↔ VTC2 interchange, which reduced the transportation cost to 1476, outperforming the previous best cost of 1668. Since this swap provides a clear improvement over the current layout, it was selected as the new configuration and used as the base layout for the subsequent iteration.

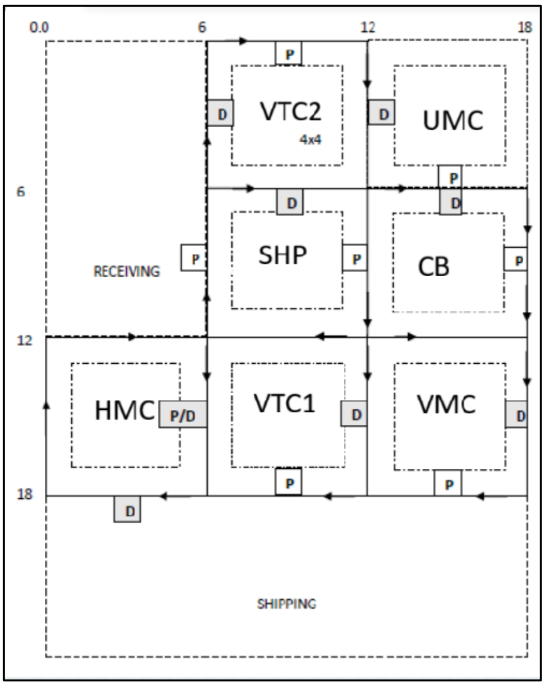

Figure 2.3.2.2 Alternative Layout after Iteration 2

Before initiating the third iteration, the adjacency relationships of the updated layout were examined to determine the feasible interchanges. Based on the new configuration, the possible interchanges for Iteration 3 are as follows:

- VTC2 ↔ UMC
- UMC ↔ CB
- SHP ↔ CB
- SHP ↔ VTC1
- CB ↔ VMC
- HMC ↔ VTC1
- VTC1 ↔ VMC

Each adjacent department pair was interchanged, and the total transportation cost was recalculated using the corresponding flow and distance data. The results of these evaluations are summarized in Table 2.3.2.7.

Interchanges	Costs
VTC2 ↔ UMC	1578
UMC ↔ CB	1656
SHP ↔ CB	1722
SHP ↔ VTC1	1594
CB ↔ VMC	1548
HMC ↔ VTC1	1578
VTC1 ↔ VMC	1536

Table 2.3.2.7 Costs after interchanges

As observed from the evaluation results, none of the interchanges tested in the third iteration produced a transportation cost lower than 1476, which had been achieved at the end of the second iteration. Since no further improvement was obtained, the algorithm was unable to identify a superior configuration beyond the layout generated in Iteration 2. The final layout determined by the improvement procedure is presented in Figure 2.3.2.2.

2.4 Comparison

Since both the constructive and improvement algorithms are heuristic in nature, neither guarantees a globally optimal layout. The constructive algorithm generates an initial configuration by placing machines according to their Total Closeness Ratings derived from flow relations and utilization levels. The improvement algorithm then operates on this layout by testing feasible adjacent interchanges and evaluating each alternative through direct transportation cost calculations. Through this process, the initial cost of 1908 obtained from the constructive method was reduced to 1476, after which no further improvements were observed. Overall, the two approaches complement one another: the constructive algorithm provides a structured starting point, while the improvement algorithm refines it to achieve a more efficient layout.

3. Summary & Conclusion

In this project, two alternative facility layouts were developed for a hypothetical Flexible Manufacturing System (FMS) using a constructive algorithm and an improvement algorithm. The constructive algorithm generated the initial layout by prioritizing activity relationships derived from material flow intensities and machine utilization rates. By positioning highly interdependent machines closer together, the constructive approach produced a coherent and feasible baseline arrangement with an initial transportation cost of **1908**.

The improvement algorithm was then applied to refine this layout through iterative pairwise interchanges among adjacent machine centers. Each feasible swap was evaluated based on its resulting transportation cost calculated from the updated distance and flow matrices. Through this process, the layout was progressively enhanced. The most significant improvement occurred during the second iteration, where the **SHP ↔ VTC2** interchange reduced the total cost to **1476**. In subsequent iterations, no feasible swap produced a better outcome, indicating convergence of the heuristic search.

Overall, the results demonstrate that while the constructive algorithm offers a structured and relationship-focused starting layout, the improvement algorithm provides meaningful enhancements by directly minimizing transportation distances. The combination of both heuristics enabled the development of an efficient final layout that balances logical machine proximity with reduced material-handling cost. This study emphasizes the practical value of integrating constructive and improvement heuristics in facility layout planning, particularly when dealing with complex flow structures and constrained spatial configurations.

4. 4. Appendices

5. IE312 | Project Part-1.xlsx

- **Tab-1: Distance & Flow Matrices**
  Contains the calculated initial distance matrix, flow matrix, and all supporting data used to compute transportation relationships.
- **Tab-2: Constructive Algorithm**
  Includes the Total Closeness Rating (TCR) calculations, utilization-based ratings, rating coefficients, and the resulting placement sequence with all Weighted Placement Value (WPV) computations.
- **Tab-3: Improvement Algorithm (Iteration-1)**
  Documents the first iteration of the improvement algorithm, including feasible interchanges, updated distance/flow matrices, and transportation cost results.
- **Tab-4: Improvement Algorithm (Iteration-2)**
  Details the second iteration of the improvement algorithm with revised adjacency relationships, evaluated swaps, and improvement outcomes.
- **Tab-5: Improvement Algorithm (Iteration-3)**
  Summarizes the third iteration, showing that no additional beneficial interchange was found and confirming convergence.
- **Tab-6: Summary of Iterations**
  Provides a consolidated comparison of transportation costs across all iterations and highlights the final layout selection.