IE 312 FACILITY DESIGN AND PLANNING

Layout Design for a Hypothetical Flexible Manufacturing System

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- Design of the alternative layout 1, constructive calculations → % 34

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- Introduction, design of the alternative layout 2, comparison, conclusion → % 33

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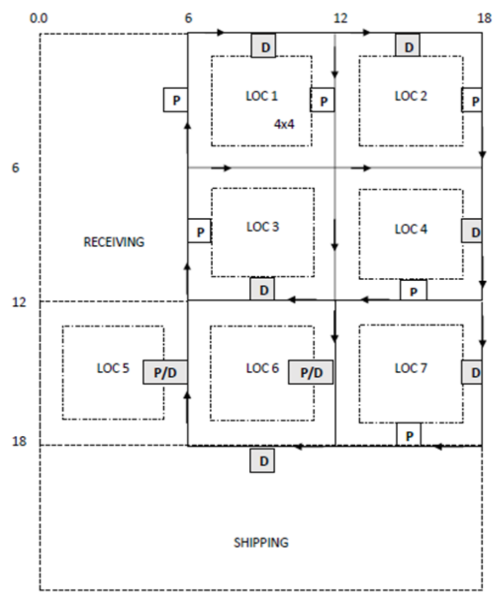
- Design of the alternative layout 2, improvement calculations → % 33

1. INTRODUCTION

Over the decades, the concept of facility planning has evolved and is continuing to evolve in a great manner. As one might guess it involves a variety of steps with great importance. One of such steps can be considered as a layout plan for a manufacturing system. Since even minor alterations could mean considerable changes in the cost of the design or the practicality of the manufacturing process, a highly comprehensive examination should be conducted. In order to analyze and understand the milestones of such a process, this report aims to focus on a hypothetical manufacturing system and its layout design. Specifically, the idea is to focus on the placement of the 6 CNC machines and a central buffer area according to the given hypothetical information on the machines. The machines to be placed can be named as follows:

- One vertical milling machine (VMC).
- One horizontal milling machine (HMC).
- One universal milling center (UMC).
- Two vertical turning centers (VTC1 and VTC2).
- One shaper (SHP)

Since the construction of a perfect layout design where there will be no case of queueing is nearly impossible, the central buffer area has a critical role because it provides a waiting room for the materials waiting for the occupied machines. The placement will not be made randomly, the basis layout for the placement could be given as follows:



The layout has its own fixed positions of receiving and shipping area. The “P” and “D” letters refer to the pickup and delivery points of the locations. Furthermore, since there will be a flow of material between these alternative locations, the distances between the pickup and delivery stations should be considered in detail. These flow transportations will be conducted by automated guided vehicles (AGV), which can only travel within the scope of given directions. In order to conduct such a flow analysis, the following data is given:

Table 1. Part types and the production rates

Part Type	Process Plan				Arrival rate (units per hour)
A	op1	op2	op3		4
B	op4	op2	op5	op6	4
C	op7	op8	op9	op10	6
D	op11	op12	op13		3
E	op14	op8	op15		3

Table 2. Machine allocations and processing times

Operation	Machine center	Processing time (sec.)
op1	VTC2	240
op2	SHP	120
op3	VMC	420
op4	VTC1	260
op5	VTC2	120
op6	HMC	300
op7	VTC1	220
op8	SHP	90
op9	UMC	480
op10	VTC1	120
op11	VTC2	440
op12	VMC	300
op13	HMC	360
op14	VTC1	150
op15	HMC	380

The latter table will be essentially important in the decision of the placement of the central buffer area since the processing times are huge indicators of whether there is a possibility of a queue at the delivery station of a machine. Since the needed information is provided, analysis is the next step to explore a solution for the hypothetical problem.

2. ANALYSIS

2.1. Alternative Layout 1

To construct an alternative layout, firstly necessary data should be gathered. In the given problem, qualitative data is limited to flow rates (Table 1.) and processing times of machines (Table 2.). Hence the flow analysis and relationship charts are constructed with respect to these data.

2.1.1 *Flow Analysis*

By using the arrival rates, a from-to matrix is constructed. Since no other information is given about the relationship between machines, relationships are assigned by using Table 3.

Table 3. From-to matrix

From-to Matrix	VTC1	VTC2	CB	HMC	UMC	VMC	SHP	Shipping
Receiving	13	7						
VTC1							13	6
VTC2				4		3	4	
CB								
HMC								10
UMC	6							
VMC				3				4
SHP		4		3	6	4		

Table 4. Relationships wrt. flow values

Flows(f)	Relationship
≥10	A
$10 > f \geq 6$	E
$6 > f \geq 4$	I
$4 > f \geq 3$	O
$3 > f$	U

2.1.2 *Activity Relationship Analysis*

Since there aren’t pre-specified flows between the central buffer area and other machines, this relationship diagram(Table 4.) is not enough for understanding central buffer relationships. Although it seems like there aren’t any flows in CB, as queues and deadlocks occur in the system, one will need to construct flows to the central buffer area. Since the problem's aim is to minimize flows occurring in CB, we need to place CB accordingly. By following the idea that the machines that are used the most are the ones that can be the main cause of queues, those machines are placed near the central buffer area.(Appendix B Table 1.)

Table 5. Relationships between machines and CB wrt. hourly process times

Hourly process times	Relationship
$t \geq 3000$	A
$3000 > t \geq 2500$	E
$2500 > t$	I

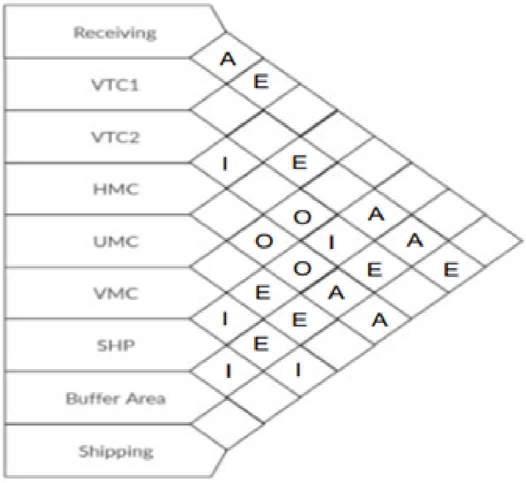


Figure 1. REL chart

2.1.3 *Constructive heuristic algorithm to develop a layout*

In the first phase of the algorithm, numerical values are assigned to closeness ratings and for each machine total closeness rating(TCR) is calculated.

Table 6. Total closeness rating

	A	E	I	O	TCR
VTC1	3	2	0	0	**32000**
VTC2	0	2	2	1	2210
HMC	2	0	1	2	20120
UMC	0	3	0	0	3000
VMC	0	1	2	2	1220
SHP	1	1	3	1	11310
CB	2	3	1	0	23100
Values	10000	1000	100	10	

In the second phase, the sequence of machines to be placed on the layout is determined. By the definition of the problem, the sequence (π) starts with the receiving area and ends with shipping; hence,$\pi_1 = R$ and $\pi_9 = S$. To decide on others, a list of machines (P) that have not yet been considered is constructed. First, the machine with the highest TCR value is put on the list as π_2. Since the highest TCR value belongs to VTC1 the updated P list is as follows.

$\pi = \{R,\ VTC1\}$

After this step, the machines that have relationships with the ones that are in the P list are examined by first looking at A relationships, then E, and respectively, and then the one with a higher TCR value is chosen. For example for π_3:

A relationships with P list → SHP and CB → $TCR_{CB} > TCR_{SHP}$ → π_3 is CB

$\pi = \{R,\ VTC1, CB\}$

After following the similar steps for all machines (Appendix A), The final π sequence is:

$\pi = \{R,\ VTC1, CB, HMC, SHP, UMC, VTC2, VMC, S\}$

The third and the final phase of the algorithm is to place the machines with the order given by π. For deciding location, a new method is constructed by taking weighted placement value as an example. Instead of using the idea of being fully or partially adjacent to the machine that is already placed, distance between machines are used. For each machine, every possible location value for the method we obtained is calculated by considering all the relationships that the machine has with the ones that are already placed in the layout and the inverse distances between them. Since the closest ones will result in higher values, the location that has the highest value will be chosen.

Since R is already located, the second machine in the sequence (VTC1) will be placed first. In this situation there is only one relationship which is between R and VTC1. Hence the location which is closest to the R will be chosen (LOC1).

Table 7. Distance matrix from receiving to other locations.

Distance Matrix	LOC1	LOC2	LOC3	LOC4	LOC5	LOC6	LOC7
Receiving	6	12	24	24	36	24	30

Next machine in the placement sequence is CB and again it has just one relationship. The relationship is between VTC1 and CB hence the location which has the smallest distance from LOC1 should be selected. As can bee seen from this step ties can occur in the algorithm and the method will break the ties arbitrarily and choose the LOC3.

Table 8. Distance matrix from LOC1 to other locations.

Distance Matrix	LOC1	LOC2	LOC3	LOC4	LOC5	LOC6	LOC7
LOC1		36	12	12	24	12	18

Next machine is HMC and it has only a relationship between CB, hence the distances from LOC3 will be used. Since LOC1 is already full, it will choose the next location that has the smallest degree. By breaking the ties arbitrarily, LOC2 is chosen for HMC.

Table 9. Distance matrix from LOC3 to other locations.

Distance Matrix	LOC1	LOC2	LOC3	LOC4	LOC5	LOC6	LOC7
LOC3	12	18		18	30	18	24

The next machine is SHP and it has relationships between VTC1 (A), CB(I), and HMC(O). Since there are more than one relationship, the relationship values will also be considered. After necessary calculations, LOC4 is chosen for SHP.

Table 10. Calculation table with possible locations for SHP

Remaining locations	VTC1 (A), CB(I), HMC(O)	Result
LOC4	$10000*\frac{1}{12}+100*\frac{1}{18}+10*\frac{1}{6}$	840.55
LOC5	$10000*\frac{1}{12}+100*\frac{1}{18}+10*\frac{1}{6}$	420.33
LOC6	$10000*\frac{1}{12}+100*\frac{1}{18}+10*\frac{1}{6}$	839.44
LOC7	$10000*\frac{1}{12}+100*\frac{1}{18}+10*\frac{1}{6}$	560.55

For the next machine UMC, similar steps are followed since it has more than one relationship.And LOC6 is chosen since it has the highest result.

Table 11. Calculation table with possible locations for UMC

Remaining locations	SHP (E), CB(E), VTC1(E)	Result
LOC5	$1000*(\frac{1}{24}+\frac{1}{30}+\frac{1}{18})$	130.56
LOC6	$1000*(\frac{1}{12}+\frac{1}{18}+\frac{1}{6})$	305.56
LOC7	$1000*(\frac{1}{12}+\frac{1}{24}+\frac{1}{36})$	152.78

For machine VTC2, LOC7 is chosen after necessary calculations and since the only remaining location is LOC5, it is assigned to the remaining machine VMC.

Table 12. Calculation table with possible locations for VTC2

Remaining locations	R(E), CB(E), HMC(I),SHP(I)	Result
LOC5	$1000*(\frac{1}{36}+\frac{1}{30})+ 100*(\frac{1}{30}+\frac{1}{18})$	70
LOC7	$1000*(\frac{1}{24}+\frac{1}{30})+ 100*(\frac{1}{12}+\frac{1}{36})$	86.11

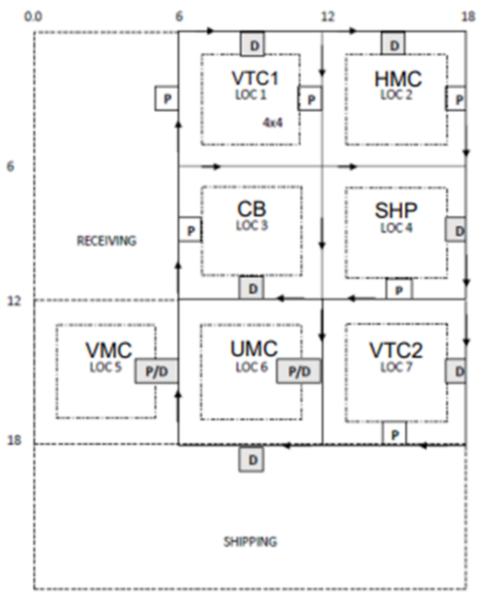


Figure 2. Final Layout for the Alternative 1.

Table 13. Cost matrix for Alternative Layout 1

		LOC1	LOC7	LOC3	LOC2	LOC6	LOC5	LOC4		
	Cost Matrix	VTCI	VTC2	CB	HMC	UMC	VMC	SHP	Shipping	Total Cost
	Receiving	78	210	0	0	0	0	0	0	288
LOC1	VTCI	0	0	0	0	0	0	156	108	264
LOC7	VTC2	0	0	0	144	0	36	144	0	324
LOC3	CB	0	0	0	0	0	0	0	0	0
LOC2	HMC	0	0	0	0	0	0	0	240	240
LOC6	UMC	180	0	0	0	0	0	0	0	180
LOC5	VMC	0	0	0	72	0	0	0	120	192
LOC4	SHP	0	144	0	90	36	72	0	0	342
									TOTAL=	1830

2.2. Alternative Layout 2

In order to acquire an alternative solution for the layout design, the constructed layout at the previous step can be used as an initial layout to implement an improvement algorithm. As an improvement heuristic, the CRAFT algorithm is considered. The CRAFT algorithm is based on interchanges between alternative location options and checks whether there is an improvement in the transportation cost matrix. An interchange between machines is only possible if the locations have the same size or they are adjacent. Since all of the possible areas for the machines have the same size, all of the interchanges between the locations are possible, in other words all 2-combinations of 7 machines are possible. This concludes that 21 interchanges should be made within the machine locations and afterwards, the interchange which results in a cost matrix with a better cost reduction should be chosen. Afterwards, the distance matrix should be updated with the interchange that gives the least cost.Then 21 interchanges should be repeated to see if there are any other interchanges that result with even better results. If no cost improvement occurs, one should stop the algorithm. In our case, since all of the areas are the same, there is no need for new centroid calculations to find the cost matrix. After adjusting the distance matrices, by multiplying with the flow matrix, cost matrices can be found. (Moving costs equal to 1 by assumption) Then, transportation cost equals to the sum of the matrix. So, the transportation cost of the initial layout has already been calculated in the previous process which is found as 1830. After calculating the possible 21 interchanges between the machines, it is observed that the interchange between the VTC2 and HMC machines results in a much more preferable transportation cost which is 1374 (Appendix C Table 1.). To see if there are any more improvements, after updating the distance matrix, 21 interchanges are repeated. The interchange between machines VMC and UMC results in a better cost ,which is 1230, (Appendix C Table 2.) than the first iteration hence another interchange is made and the distance matrix is again updated. After iteration three, total cost is reduced by interchanging CB and UMC and the total cost is 1122 after this iteration (Appendix C Table 3.). Since one can still find a better solution by making interchanges, iteration 4 is conducted. In this iteration, the algorithm cannot find a better cost than the previous iteration; hence algorithm stops.

So, the final improved layout and its distance and cost matrix can be given as follows:

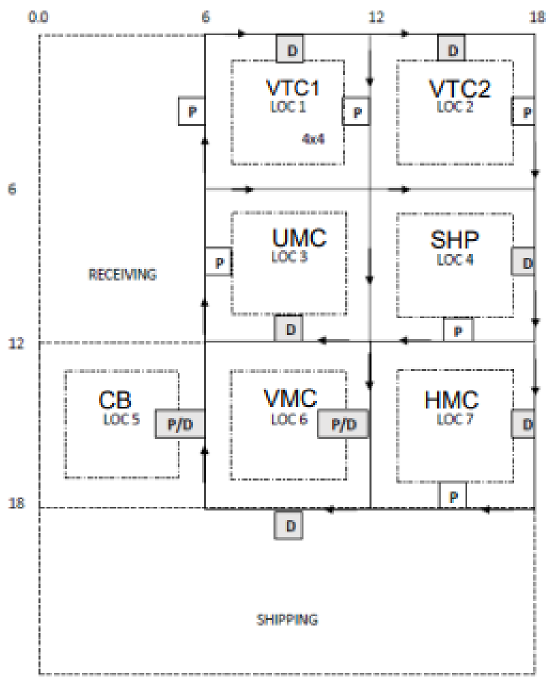


Figure 3. Final Layout for the Alternative 2.

Table 14. Cost matrix for Alternative Layout 2

	VTC 1(LOC1)	VTC 2(LOC2)	CB(LOC5)	HMC(LOC7)	UMC(LOC3)	VMC(LOC6)	SHP(LOC4)	Shipping	Total Cost
Receiving	78	84	0	0	0	0	0	0	162
VTC 1	0	0	0	0	0	0	156	108	264
VTC 2	0	0	0	48	0	54	24	0	126
CB	0	0	0	0	0	0	0	0	0
HMC	0	0	0	0	0	0	0	60	60
UMC	72	0	0	0	0	0	0	0	72
VMC	0	0	0	126	0	0	0	24	150
SHP	0	120	0	108	36	24	0	0	288
								TOTAL=	1122

2.3. Comparison

Since the second layout idea stems from using an improvement algorithm on the first layout, the second layout can be considered as a much more favorable layout. According to the assumptions made on the construction process of the first layout, a basis layout is created and this layout is used in the CRAFT algorithm. So, different assumptions may yield to an alteration in the basis layout and the solution as well. Furthermore, due to the heuristic nature of these algorithms, both of these alternative designs most probably do not provide an optimal solution, which is needed to keep in mind.

3. CONCLUSION

In this report, in order to provide a solution for the layout design of a hypothetical manufacturing system, 2 different alternative approaches are conducted. In the first step distance matrices and flow matrices are constructed. After making some assumptions, the relationship diagram is provided. By using a constructive heuristic algorithm, weighted placement values of the locations are calculated and placement has been made according to it. In the second step, in order to improve the solution in hand, the CRAFT algorithm is used. Locations having the same area means that all of the interchanges between the locations are possible and should be made to check whether one of which provides a better cost matrix. By doing so, it is provided that an interchange between VTC2 and HMC in the first iteration , an interchange between VMC and UMC in the second iteration after updating the distance matrix, and also between CB and UMC in the third iteration, offers a relatively higher reduction in cost. Again, as it was stated in the comparison, these 2 alternative solution methods do not guarantee an optimal solution. Yet, conducting such comprehensive approaches provides a great understanding of the planning process of a layout design.

4. APPENDICES

Appendix A.

The calculations for the placement sequence after π_3 .

$\pi = \{R,\ VTC1, CB\}$

A relationship with machines in the list:

SHP → 11310

HMC →20120 → higher TCR value hence chosen as π_4.

$\pi = \{R,\ VTC1, CB, HMC\}$

A relationship with machines in the list:

SHP → 11310 → Only remaining machine with A relationship hence chosen as π_5.

$\pi = \{R,\ VTC1, CB, HMC, SHP\}$

No more relationships, look for E relationships.

VTC2 → 2210

UMC→ 3000 → chosen as π_6 due to higher TCR value

VMC→1220

$\pi = \{R,\ VTC1, CB, HMC, SHP, UMC\}$

Remaining E relationships:

VTC2 → 2210 chosen as π_7 due to higher TCR value

VMC → 1220 chosen as π_8 since it is the last machine remaining.

Final placement sequence:

$\pi = \{R,\ VTC1, CB, HMC, SHP, UMC, VTC2, VMC, S\}$

Appendix B.

The hourly processing time is calculated.

Table 1. Hourly Processing Times

VTC2

Operations	Flow	Process Times
op1	4	240
op5	4	120
op11	3	440
	Total =	**2760**

SHP

Operations	Flow	Process Times
op2	8	120
op8	9	90
	Total =	**1770**

HMC

Operations	Flow	Process Times
op6	4	300
op13	3	360
op15	3	380
	Total =	**3420**

VMC

Operations	Flow	Process Times
op3	4	420
op12	3	300
	Total =	**2580**

VTC1

Operations	Flow	Process Times
op4	4	260
op7	6	220
op10	6	120
op14	3	150
	Total =	**3530**

UMC

Operations	Flow	Process Times
op9	6	480
	Total =	**2880**

Appendix C.

Table 1. Total costs after the interchanges of the Craft 1.

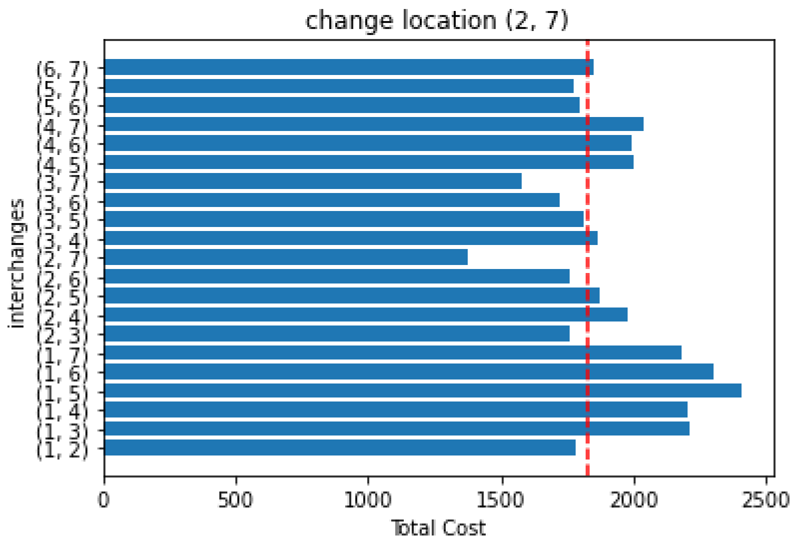


Table 2. Total costs after the interchanges of the Craft 2.

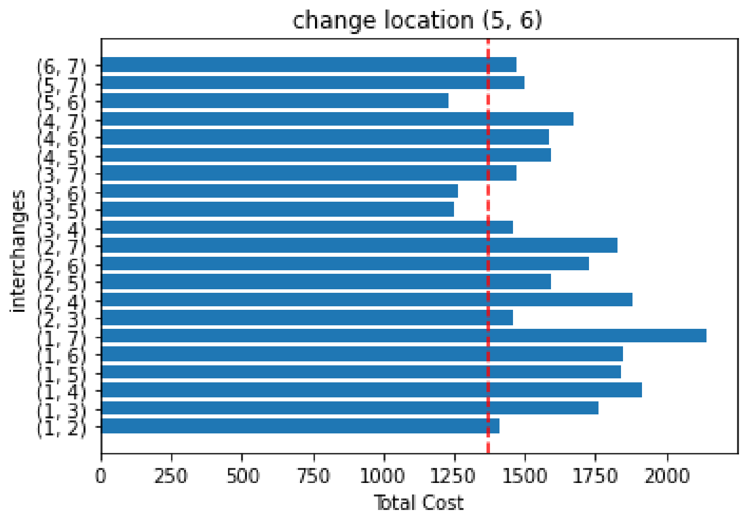


Table 3. Total costs after the interchanges of the Craft 3.

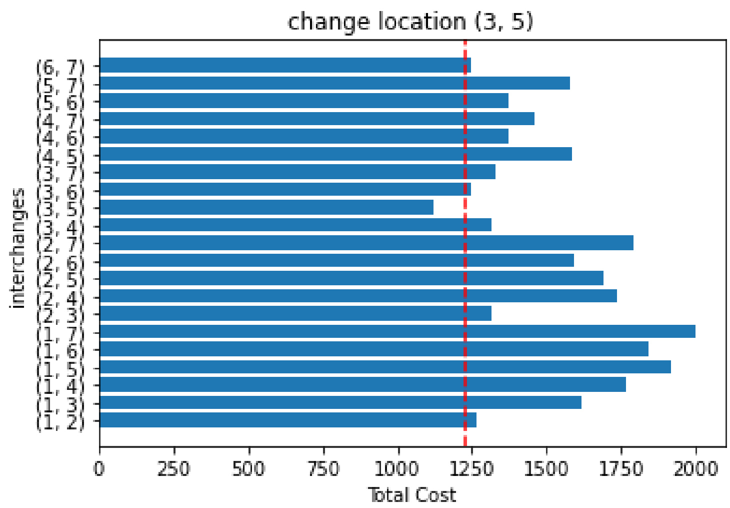


Table 4. Total costs after the interchanges of the Craft 4 where the algorithm stops.