Georgia Tech College of Engineering
H. Milton Stewart School of
Industrial and Systems Engineering

ISyE 6202 Supply Chain Facilities

Casework 3.1

YubWeng Factory Organization Testbed

Guillaume Eymery - Nathalia Gonzalez - Yong Suk Hong - Yaojie Huang - Anjulakshmi Karthikeyan - Louise Lacroix

H. Milton Stewart School of Industrial and Systems Engineering

Contents

List of Figures

List of Tables

TASK 1

Demand for each part depending on the scenario

We are given the demand forecast for each assembled unit in figure 1.

2025 Weekly Demand Forecast for Each Product						
Year	A1	A2	A3	A4	A5	Total
2025	962	1923	2500	1154	1538	*8077*

Figure 1: 2025 Demand Forecast for Each Product

We know as well the standard deviation of this forecast. If we want to reach 99.9% of the demand, we can find a confidence interval being [x-3.29σ, x+3.29σ].

We know that the coefficient of variation is equal to $\frac{\sigma}{mean}$. So we will determine the lower and upper bound using the interval [x(1-3.29$\times$ coeff of variation), x(1+3.29$\times$ coeff of variation]

We now have three demand forecasts for each assembled product. We want to determine the demand in terms of parts. So we will multiply this chart by the Number of Parts per Assembled Product Unit Demanded in 2025. Here is the weekly demand we obtain for each of these scenario.

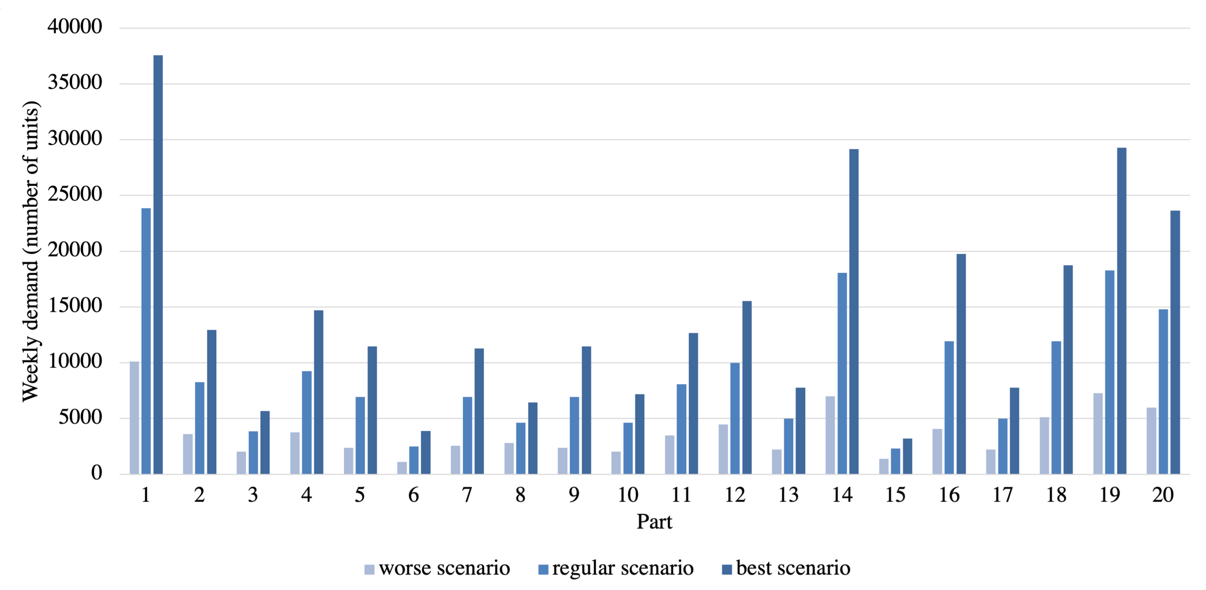


Figure 2: 2025 Demand forecast for each product and each scenario

TASK 2

Factory 1 - Function organization

Network organization

In a function based organization, we would create centers that can perform a single task. Here, this means that we would group the same equipment together in a single center. We would dedicate one center to one equipment. In order to find the network organization, we would look at all the flows in the warehouse and organize the centers so that to minimze travel distance. For instance, there is a lot of flow from J to I, which means we have to place them side by side. The organization is displayed in figure 53

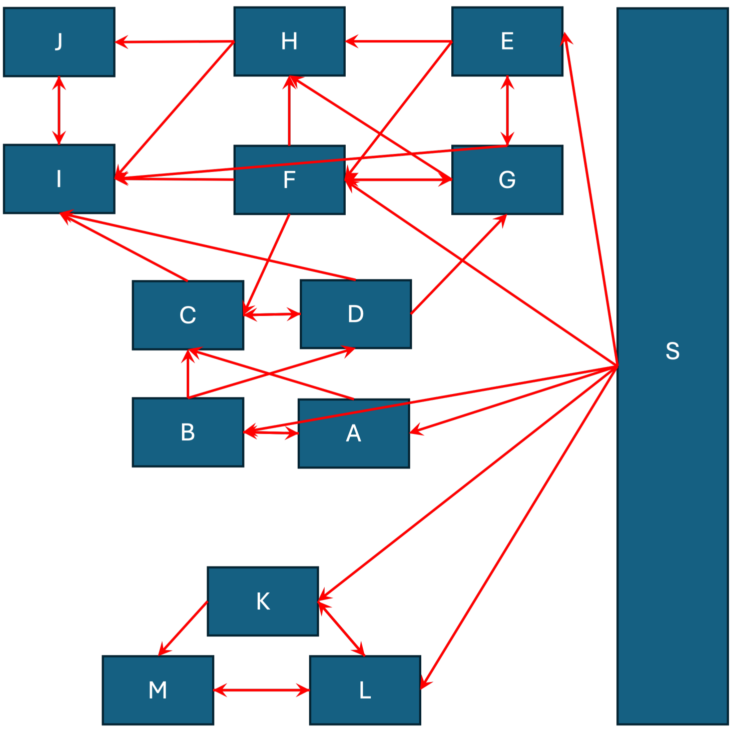


Figure 3: Network organization in a function based organization

Center-specific and overall resource requirements plan

Matrix of times required to complete each step for each part

In order to determine the number of machines we will need to complete all tasks, we will combine the process table from figure 4 with the process time one from figure 5.

Part	Process						
	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
P1	B	A	B	C	D	I	J
P2	A	C	D	H	J		
P3	B	D	C	I	J		
P4	A	B	D	G	H		
P5	B	C	D	I			
P6	A	B	C	D	H	I	J
P7	E	F	C	D	I	J	
P8	E	H	J	I			
P9	F	G	E	G	I	J	
P10	E	F	I	J			
P11	E	G	E	G	I		
P12	E	G	F	I	J		
P13	E	F	G	F	G	H	I
P14	E	F	G	H			
P15	E	G	F	H	J		
P16	F	H	I	J			
P17	K	L	M				
P18	K	L	K	M			
P19	L	M	L	M			
P20	L	K	M				

Figure 4: Process used at each step for every part

Part	Process Time (minutes/unit)						
	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
P1	2.5	1	2.5	0.5	2.5	1.25	2.5
P2	1.25	0.5	2.5	1	2	2	2
P3	1.75	3	3	0.5	2.5	2.5	2.5
P4	1	2	3	0.25	1.25	1.25	1.25
P5	0.75	0.75	3.5	1.75	3	1.25	2.75
P6	0.75	1.25	0.5	0.5	1		
P7	1.25	3	3.5	3.5	3	2	
P8	1.25	1.25	2.5	0.5	1		2
P9	1.75	0.75	1.25	0.5	1	3	3
P10	1.5	1	2	1.25	0.5		
P11	1.25	0.5	1.25	2.5	0.25		
P12	1.25	1.25	3	0.5	0.25	2	1.25
P13	1.25	1.25	1	2	2		1.25
P14	1.5	1.25	2	1.5	1.75	1	
P15	0.75	0.5	2.5	2.5	0.75		
P16	1.5	0.75	2.5	2.5	1	1.75	
P17	0.75	1.25	3.5	1	2.5		
P18	0.75	1	3.5	1	2		
P19	2.25	1	3.5	3.75	3.75		
P20	2	0.75	3	3	3		

Figure 5: Process time at each step for every part

We obtain the following matrix representing the time required to complete each step for each part and the type of equipment used being colored in a specific color.

Part	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
P1	1566	626	1566	313	1566	783	1566
P2	270	108	539	216	539		
P3	165	283	71	142	236		
P4	245	490	735	61	306		
P5	287	143	670	335			
P6	49	81	32	194	65	81	178
P7	188	282	141	658	235	376	
P8	134	215	54	107			
P9	335	143	239	96	239	574	
P10	180	210	150	240			
P11	264	106	264	53	158		
P12	259	130	259	324	583		
P13	162	162	65	130	32	259	162
P14	486	729	243	851			
P15	40	27	67	134	134		
P16	412	1647	412	824			
P17	97	389	453				
P18	234	390	156	1171			
P19	1098	1220	976	1830			
P20	788	296	1182				

Figure 6: Matrix of hours required to complete each step for each part

Optimal equipment used

When observing figure 6, we notice that at each step, we need to use different equipment and that one equipment can be used at several steps. As a result, we will need to determine the best combination of equipment in order to minimize costs. Indeed, we have the choice between the equipment displayed in figure 7.

Equipment	Installed price	Relocation cost	Useful life (years)	Number of operators
A	$ 150,000	$ 10,000	10	1 C1+1/4 C2
B	$ 200,000	$ 10,000	10	1 C1+1/4 C2
C	$ 250,000	$ 10,000	10	1 C1+1/4 C2
D	$ 300,000	$ 10,000	10	1 C1+1/4 C2
AB	$ 250,000	$ 10,000	10	1 C1+1/4 C2
AC	$ 280,000	$ 10,000	10	1 C1+1/4 C2
CD	$ 350,000	$ 10,000	10	1 C1+1/4 C2
ABC	$ 300,000	$ 10,000	10	1 C1+1/4 C2
ABCD	$ 400,000	$ 10,000	10	1 C1+1/4 C2
E	$ 400,000	$ 50,000	10	1 C1 + 1/2 C3
F	$ 400,000	$ 50,000	10	1 C1 + 1/2 C3
G	$ 400,000	$ 50,000	10	1 C1 + 1/2 C3
EF	$ 450,000	$ 50,000	10	1 C1 + 1/2 C3
EG	$ 450,000	$ 50,000	10	1 C1 + 1/2 C3
FG	$ 450,000	$ 50,000	10	1 C1 + 1/2 C3
EFG	$ 500,000	$ 50,000	10	1 C1 + 1/2 C3
H	$ 1,000,000	$ 100,000	15	2 C3
I	$ 500,000	$ 100,000	15	2 C3
J	$ 500,000	$ 100,000	15	2 C3
IJ	$ 750,000	$ 100,000	15	2 C3
K	$ 80,000	$ 2,000	8	1/2 C2
L	$ 100,000	$ 2,000	8	1/2 C2
M	$ 50,000	$ 2,000	8	1/2 C2
KL	$ 140,000	$ 2,000	8	1/2 C2
KM	$ 100,000	$ 2,000	8	1/2 C2
LM	$ 120,000	$ 2,000	8	1/2 C2
KLM	$ 150,000	$ 2,000	8	1/2 C2

Figure 7: Different equipment combinations and associated costs

We will iterate through several combinations and determine the optimal solution. We will proceed first as follows:

- Compute the time we will need equipment i $\in \{A, \cdots, M\}$ at step t $\in \{1, \cdots, 7\}$, considering 95% reliability and a two week inventory. We obtain the array in figure 8

A	593	659					
B	2125	601	1649				
C		265	257	330			
D		298	2046	897	1649		
E	1803		530				
F	786	1455	343	136			
G		427	324	221	34		
H		1960		1264	391	273	
I			591	955	666	910	170
J			56	1119	1571	1000	1836
K	349	311	164				
L	1985	820	1027				
M		1284	1721	3159			

Figure 8: Required time for each equipment at each step

- We know that the weekly capacity of one machine is 5 days a week $\times$ 2 shifts a day $\times$ 8 hours a day = 80. So we can compute the number of machines we need, dividing the required time by 80 and taking the ceiling. For instance, for A, we need $\lceil \frac{593+659}{80} \rceil = 16$ equipment.

A	B	C	D	E	F	G	H	I	J	K	L	M
16	55	11	62	30	35	13	49	42	70	11	48	78

Table 1: Number of equipment required

- We use these numbers and figure 7 to determine the number of workers, considering 90% efficiency

C_1	C_2	C_3
250	121	404

Table 2: Number of workers required

  The exact number of workers working in each center is displayed in the Excel file *Process_Step_Table*.

- Then we compute the costs of installation and operators to determine the total cost of one set of equipment. All computations are detailed in the Excel file *Process_Steps_Table*, sheet *Function ORG*

We notice that the cheapest option when considering operators costs and installation is reached when using single operation machines, that means preferring A and B equipment to AB equipment. We will therefore draw the corresponding layout and evaluate the final cost calculating the total distances traveled in the warehouse.

Layout of each center and of the overall factory

The next step is to propose a suitable layout. We have determined the number of machines in the previous part and the network before so we will respect this when designing the layout. We would consider that some equipment can share aisle so we will place them so as to maximize space utilization to minimize costs.

We will also have to include a storage area that would account for two weeks inventory. The computations have been done in the Excel file, sheet *racks*. We find that we need a 6912 square inches space for storage. We will add such a space (1,135,500 square inches) in the layout close to the last center visited before storage.

The layout is displayed in figure 9

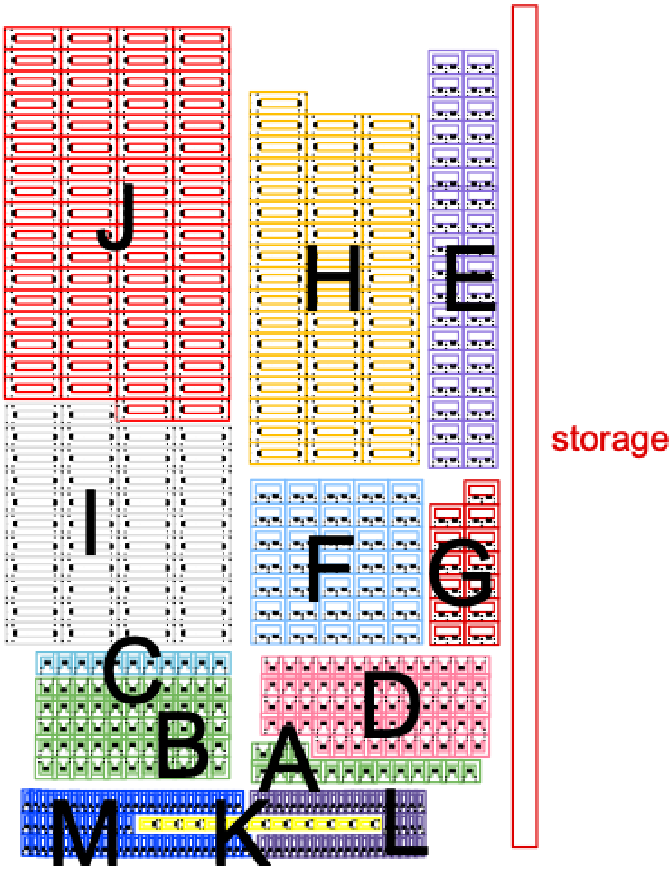


Figure 9: Layout of the function organization

Estimated intra-center work and flow patterns and utilization profile in each center

In a function organization, there will only be flow in and out inside each center since one center is dedicated to one equipment.

Estimated inter-center flows and travel distances and traffic

We have computed the various flows of product that will took place within the factory. In order to do so, we have followed the path of each part and have taken into account the number of parts we will produce. For instance, since we produce 37000 parts 1 a week, there will be a flow from B to A of 37000 due to part 1. We would do this for every part and every succession of equipment and regroup the total sum in a flow in/out matrix displayed in figure 10. The last column S is just a dummy column to remember that we will have workers going to storage, being close to assembly (assumed), at the end, after transporting a finished part, so they would start over and we do not have hundreds of workers waiting in the finishing centers such as H, I, J, M. We will use these numbers to compute the required number of handlers, considering that all parts go to assembly at the end, assuming that assembly is close to storage.

from (column) /to (line)	A	B	C	D	E	F	G	H	I	J	K	L	M	S	
A		56173	12945												69118
B	37589		52954	20367											110910
C				77175					5669						82844
D			5669				14698	16831	60344						97542
E						55401	55583	6438							117422
F			11276				56185	22988	22734						113183
G					24150	26534		51632	24150						126466
H									31427	22602				43860	54029
I										112402				30588	112402
J									6438					87091	6438
K												26503	42372		68875
L											42372		66330		108702
M												29279		79423	29279
S	31529	54737			93272	31248					26503	52920			290209
	69118	110910	82844	97542	117422	113183	126466	97889	150762	135004	68875	108702	108702	240962	1387419

Figure 10: Matrix of flow in a function based organization

You can read the matrix as follows: there is 37589 units of flow a week from B to A. We have grouped by the pair of equipment that have flows from one to another and sort them by the number of flows in figure 11.

PAIR	FLOW
IJ	112402
SE	93272
CD	77175
LM	66330
DI	60344
FG	56185
AB	56173
EG	55583
EF	55401
SB	54737
BC	52954
SL	52920
GH	51632
KM	42372
LK	42372
BA	37589
SA	31529
HI	31427
SF	31248
ML	29279
GF	26534
KL	26503
SK	26503
GE	24150
GI	24150
FH	22988
FI	22734
HJ	22602
BD	20367
DH	16831
DG	14698
AC	12945
FC	11276
EH	6438
JI	6438
CI	5669
DC	5669

Figure 11: Pair of equipment sorted by flow in a function based organization

Using all these flows, we have created a first type of network displaying all flows and minimizing travel distance. It is displayed in figure 13.

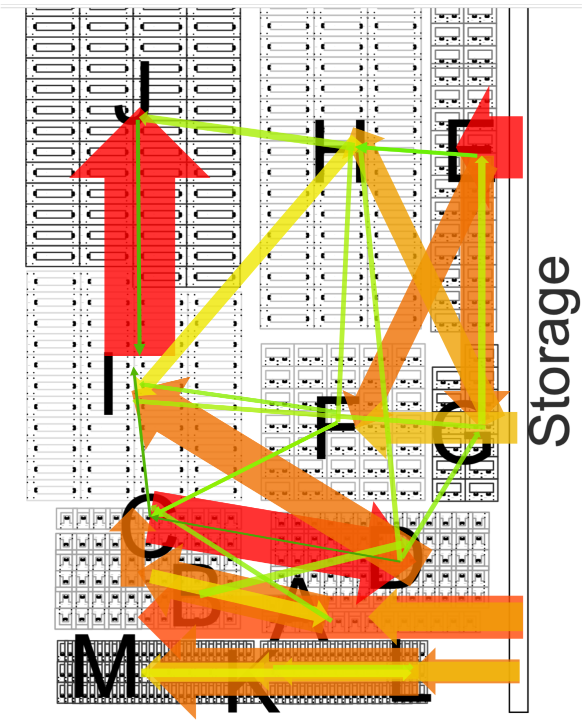


Figure 12: Combined flows in a function based organization

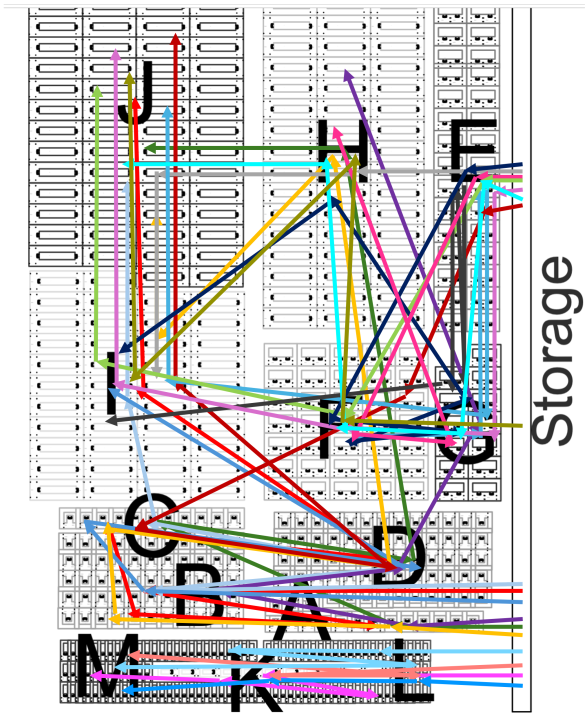


Figure 13: Flows for each part in a function based organization

Figure 12 shows the biggest flows with a big red arrow while light green arrows represent the smallest flows. We notice that this layout has put close to one another the centers that have the biggest flows such as IJ for instance. This is useful to minimize travel distance and limit congestion.

How will we compute travel distance in the warehouse?

Let us consider a maintenance operator in O that wants to move to point T. The fastest he can go is by taking the straight route between the two points. Therefore the distance would be:

$$D_{O,T} = \sqrt{(x_T - x_O)^2 + (y_T - y_O)^2}$$

In a warehouse environment however, this route is impossible to take. In our case, there can be machines that get in the way of this route. To reach T, the maintenance operator needs to take another path (path A in the following figure).
As an example, let's suppose that the operator followed the following path:

$$(O - A_1); (A_1 - A_2); (A_2 - A_3); (A_3 - A_4); (A_4 - A_5); (A_5 - T)$$

We can realistically suppose that the operator only turns in a 90 degree angle, and the action of turning does not add time to his trip.
We can now calculate the distance between two machines, by taking into consideration the multiple n obstacles in the warehouse:

$$\sum_{k=1}^{n} (|x_k - x_{k-1}| + |y_k - y_{k-1}|)$$

This distance is hard to compute in an environment where there is at least as many obstacles than there are machines (around 500). However, this distance is exactly the same as taking a second path (cf path B in the figure), with only one 90 degree turn.

$$\sum_{k=1}^{n} (|x_k - x_{k-1}| + |y_k - y_{k-1}|) = |x_n - x_0| + |y_n - y_0|$$

When divided by the max distance an operator can travel in one day, we can find the number of maintenance operators needed for the facility.

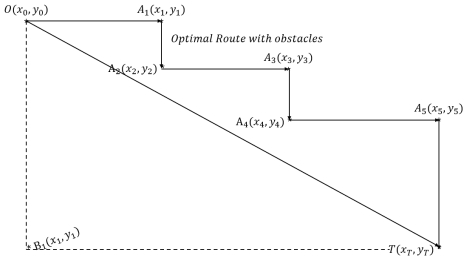


Figure 14: Manhattan distance visualization

In order to estimate the distance travelled across the warehouse we would consider the distance between two centroids. For instance, in figure 15, in order to determine the average distance between J and F, we should normally count the distance in blue. This is equal to the distance in red.

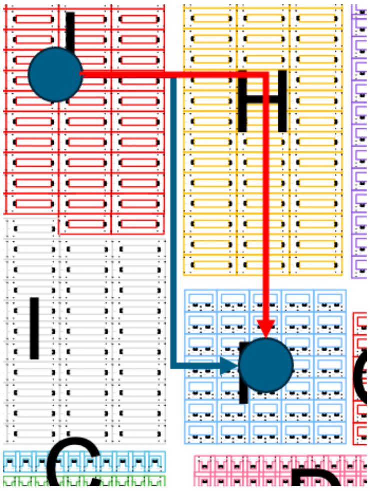


Figure 15: Calculation distances within two centroids

We will determine the coordinate of the centroids of each center on AutoCAD. In order to do so, we will group the equipment of each center as a *REGION* then we will use the function *MASSPROP* to access the coordinates. They are displayed in the figure 16

center	X - centroid	Y - centroid
A	-983.4	636.8
B	-2788.2	959.8
C	2775.5	1469
D	-883.1	1222
E	-238.8	4578.1
F	-1210.1	2243.5
G	-217	2194.6
H	-1237	4600.9
I	-2913.5	2558.7
J	-2889.2	4943.8
K	-1744.5	288.5
L	-1193.4	236.9
M	-2709.6	231
S	204.1	3178.2

Figure 16: Coordinates of the centroid of each center

We will use these coordinates to determine the total travel distance in the warehouse. We will consider that the material handling workers will have to come back to the storage space when a product is finished. The total travel distance is calculated in the Excel File *Process_Steps_Table*, sheet, *Function ORG*. We will consider that our handlers carry on item at a time first to compute the number of workers we will need. Indeed, since we hire them 8 hours a week and consider a walking speed of 3.4 miles/hour, they would walk one marathon a day under these circumstances. This is why then we will consider that they carry 10 items at a time (about 20 lbs), which means that they would be walking less than predicted before. To determine the time spent in traveling, we will divide this distance by the average speed (18,000 ft/hour). We obtain **23,000** hours a week. Therefore we will need $\lceil \frac{23{,}000}{80} \rceil$ = **575 handlers**.

Expected key factory performance indicators

We can compute the capacity utilization of each equipment. The results are displayed in figure 17.

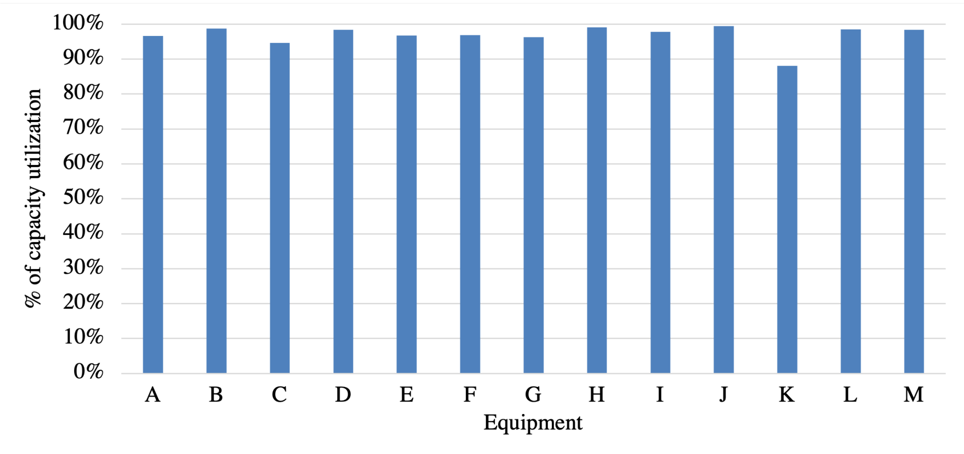


Figure 17: Overall capacity utilization of each machine in a function organization

We notice that no equipment is used under 88% of its capacity, and on average we use 97% of the capacity of our equipment. Indeed, in this layout, we can use our equipment to do a process for any part, this means that we will use any equipment A to perform process A on any part. This is why we have so little waste in capacity utilization.

If we look at the travel distance each handler walk through a week, we obtain an average of **13.6 miles a week per worker**.

Overall expected investment and direct operating costs

Here are the costs for this layout (in million of dollars). We consider in the building costs, \$250 per square feet as well as \$17 0,000 for racks for storage.

installation cost with depreciation	operator cost	handlers cost	material price	building costs	total cost
15	231	45	682	46	1,019

Table 3: 2025 Total Costs for the function organization

We notice that 70% of the total cost is due to material price. We don't really have a way of reducing this. The only way we can reduce costs is by leveraging other factors but we would only be able to reduce it of 30%.

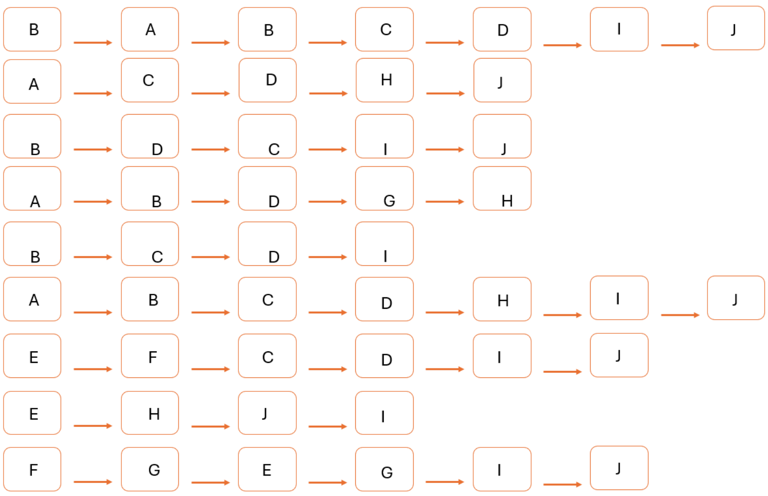
The handlers represent 15% of the workforce, this number may be reduce if we decide to make the workers walk more every day or using machines to be more efficient.

Factory 2 - Part Organization

Network organization

When we are using part organization for factory layout, we are simply creating centers that can manufacture each part. So in this case, we are creating 20 centers and each center can manufacture a corresponding part. Some benefits when utilizing part organization include cost saving and flexibility.

- Cost saving: arranging warehouse into part centers may require less labor to perform maintenance compared to other types of organizations. This is because this layout is more intuitive from labors' perspective. Whenever there is a malfunction part being produced, they can just go to the corresponding part center to find out the problem. Therefore, workers there would require less training cost.
- Flexibility: Demand cannot be predicted with accuracy. Sometimes clients may request a part that they do not usually require. In this case, we can still easily fulfill that clients' demand by simply queuing one more order into that specific part center.



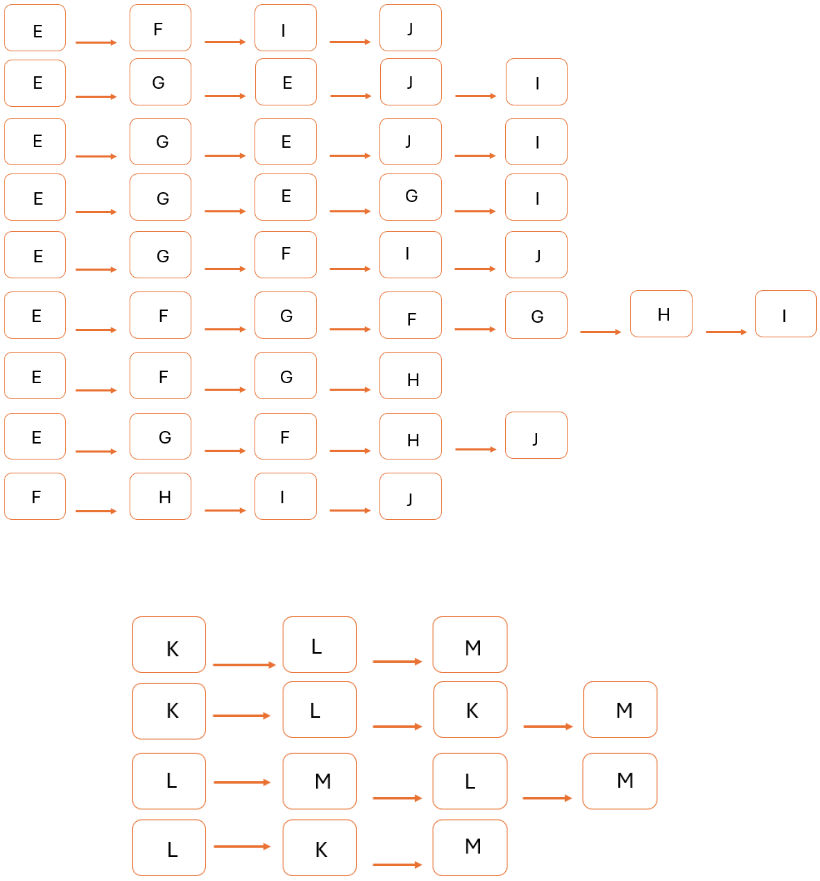


Figure 18: Networks Organization for the Part Layout

The flow of the part organization is more straight forward compared to other types of organizations: it is simply flowing from left to right. Since we are not combining any processes and we need to make sure that our end product in each center would be a part, we can simply utilize information given in figure 4, which is the process used at each step for every part. For instance, for part 1 center, we should include processes in the following sequence: B $\rightarrow$ A $\rightarrow$ B $\rightarrow$ C $\rightarrow$ D $\rightarrow$ I $\rightarrow$ J. All the materials will flow through the center and go straight to storage.

Center-specific and overall resource requirements plan

To find the number of machines of each type of process required for each part center, we start by looking at figure 6, which is the number of hours required to complete each step for each part in a week. Since we have to finish each part at the end of each center, our total number of machines needed for that center are the total number of each process machines needed to fulfill all the process demand in that center.

Center	Process	Demand
P1	A	627
P1	B	3133
P1	C	314
P1	D	1567
P1	E	0
P1	F	0
P1	G	0
P1	H	0
P1	I	784
P1	J	1567
P1	K	0
P1	L	0
P1	M	0

Figure 19: Resource Requirement in Part1 Center in Part Organization

This chart shows how much materials are needed in each process station within part1 center in order for part1 center to successfully produce part1. Now, we shall find resource requirements for the remaining 19 part centers using similar methodology. After we find all resource requirement for all part centers, we can divide that column of numbers by 80 then by 0.95. We divide it by 80 because works on average spend 80 hours a week working and we further more we divide it by 0.95 because we need to take the 95 percent equipment reliability into account. And then we aggregate our results to get the following data for the amount of equipment of each process station needed for each part center:

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
A	9	4	0	4	0	1	0	0	0	0
B	42	0	3	7	4	2	0	0	0	0
C	5	2	1	0	2	1	2	0	0	0
D	21	8	4	10	9	3	9	0	0	0
E	0	0	0	0	0	0	3	2	4	3
F	0	0	0	0	0	0	4	0	5	3
G	0	0	0	1	0	0	0	0	4	0
H	0	3	0	5	0	1	0	3	0	0
I	11	0	2	0	5	2	4	2	4	2
J	21	8	4	0	0	3	5	1	8	4
K	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	0	0	0	0	0	0

Figure 20: Equipment Requirement for Each Process Station in Part Center 1-10

	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20
A	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0
D	0	0	0	0	0	0	0	0	0	0
E	7	4	3	7	1	0	0	0	0	0
F	0	4	4	10	1	6	0	0	0	0
G	3	2	2	4	1	0	0	0	0	0
H	0	0	4	12	2	22	0	0	0	0
I	3	5	3	0	0	6	0	0	0	0
J	0	8	0	0	2	11	0	0	0	0
K	0	0	0	0	0	0	2	6	0	4
L	0	0	0	0	0	0	6	6	28	11
M	0	0	0	0	0	0	6	16	41	16

Figure 21: Equipment Requirement for Each Process Station in Part Center 11-20

We then compute our number of operator needed using metric shown in figure 7 while taking 90 percent workers efficiency into account:

C_1	C_2	C_3
295	139	467

Table 4: Number of Workers Required in Part Organization

Layout of each center and of the overall factory

Since our end goal is to produce 20 different parts in 20 different centers, we decide to make our layout in a way so that it can flow through the warehouse and get to the storage as fast as possible. With this design principle in mind, we simply choose to arrange the 20 different centers vertically in one column. Since there will be no interactions between centers, materials will simply come in from the left, enter their corresponding center, transform into parts, and go into storage on the right. This way, we believe, will reach maximum efficiency.

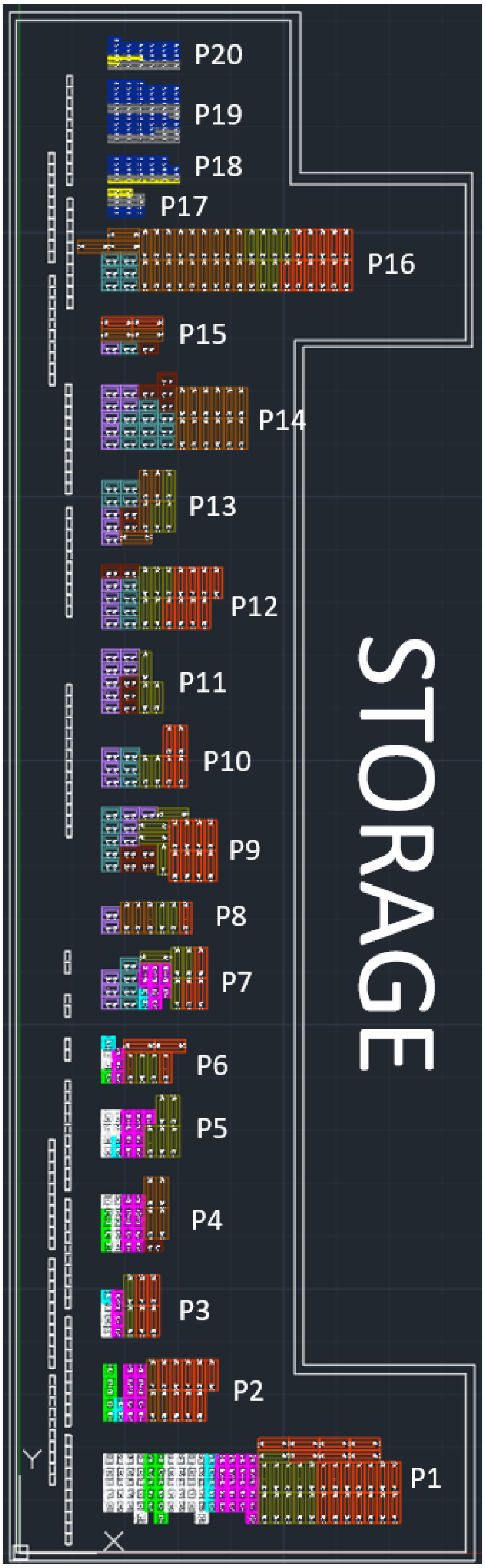


Figure 22: Layout for Part Organization

Estimated intra-center work and flow patterns and utilization profile in each center

There will be no intra-center flows in our layout since we put process stations next to each other in every part center. All process stations within a part center will be accessible to each other without additional need of handlers. Materials will simply be sent into the center and travel across different process stations through conveyors.

Estimated inter-center flows and travel distances and traffic

One nice thing about considering part organization as our layout is that we do not have to consider inter-center flows nor workers' travel distance nor potential traffic. This is because our centers do not interact with each other at all. Materials go into part1 center, become part1, leave part1 and go straight into storage. Part1 would not go into Part2 or any other part centers. Therefore, in a sense, part organization is extremely efficient because it completely gets rid of costs of handlers when it comes to movements between centers. The only time we should consider using a handler is when we need to move finished parts to the storage. To calculate distance handlers need to cover to put away finished parts to storage, we developed coordinates for each part centers' outbound location and coordinates for its corresponding storage location:

Centers	X	Y
P1	355	135
P2	234	224
P3	166	292
P4	175	408
P5	189	505
P6	195	600
P7	222	680
P8	204	734
P9	233	831
P10	198	943
P11	170	994
P12	240	1130
P13	184	1245
P14	270	1342
P15	170	1436
P16	355	1495
P17	147	1581
P18	189	1621
P19	189	1670
P20	189	1756

Figure 23: Coordinates for part center outbounds

Centers	X	Y
P1	355	211
P2	325	224
P3	325	292
P4	325	408
P5	325	505
P6	325	600
P7	325	680
P8	325	734
P9	325	831
P10	325	943
P11	325	994
P12	325	1130
P13	325	1245
P14	325	1342
P15	325	1436
P16	355	1435
P17	325	1435
P18	325	1435
P19	325	1435
P20	325	1435

Figure 24: Coordinates for corresponding storage

Centers	Distance(ft)
P1	76
P2	91
P3	159
P4	150
P5	136
P6	130
P7	103
P8	121
P9	92
P10	127
P11	155
P12	85
P13	141
P14	55
P15	155
P16	60
P17	324
P18	322
P19	371
P20	457
Total	3310

Figure 25: Distance for each part center to its storage

This is the travel distance between each center's outbound to its corresponding location. Previously, we computed the resource requirement(figure 19) and equipment requirement(figure 20 and 21), therefore we can find out how many parts we can produce per week. And then we can use this number and the travel distance chart to find total distance handlers need to cover per week.

Center	Weekly Produce	Weekly Distance(ft)
P1	37,589	2,856,764
P2	12,945	1,177,995
P3	5,669	901,371
P4	14,698	2,204,700
P5	11,479	1,561,144
P6	3,886	505,180
P7	11,276	1,161,428
P8	6,438	778,998
P9	11,479	1,056,068
P10	7,191	913,257
P11	12,671	1,964,005
P12	15,543	1,321,155
P13	7,772	1,095,852
P14	29,162	1,603,910
P15	3,219	498,945
P16	19,769	1,186,140
P17	7,772	2,518,128
P18	18,731	6,031,382
P19	29,279	10,862,509
P20	23,641	10,803,937
	Total Distance	51,002,868

Figure 26: Weekly Distance Required for Handlers

Since we are assuming a handler will carry 10 items at a time, this means that the total weekly distance required for handlers will be $\frac{51{,}002{,}868}{10} = 5{,}100{,}286.8$ ft. And the yearly distance required will be $5,100,286.8 \times 52 = 265{,}214{,}914$ ft. In addition, we assume that a handler walks at a speed of 18,000 ft per hour 60 percent of the time. Therefore, the amount of hours that a handler would need in a year to do this task is $\frac{265{,}214{,}914}{18{,}000 \times 0.6} = 24{,}557$ hours. Therefore, the corresponding cost would just be $24,557 \times 40 = 982{,}280$ dollars.

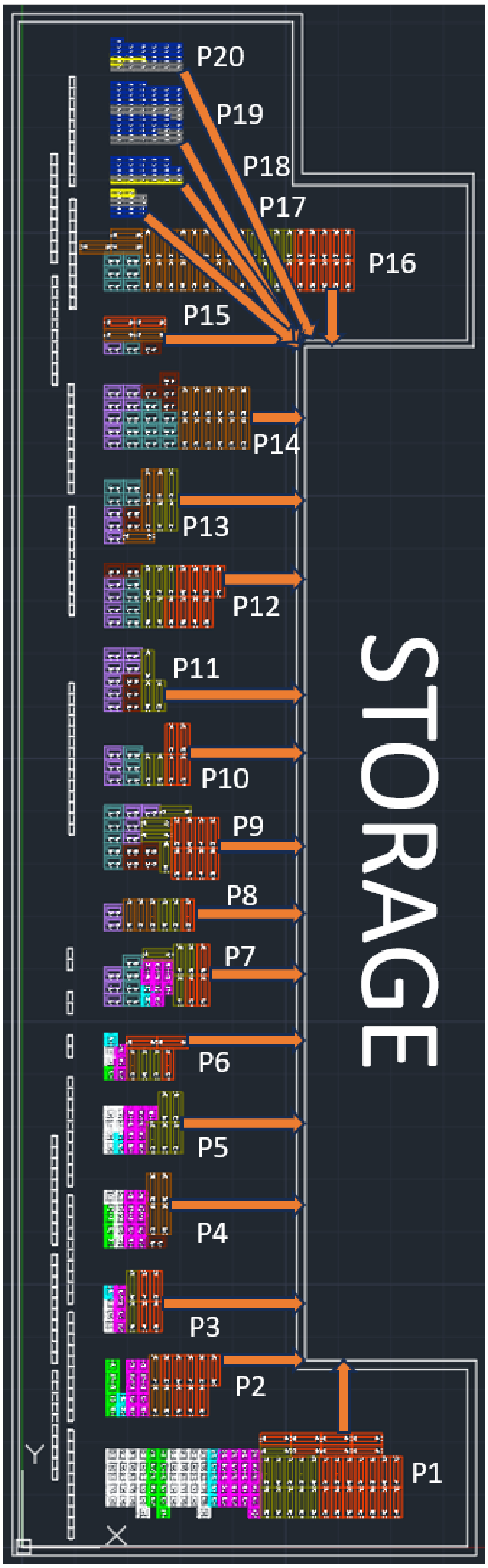


Figure 27: Handler Travel Flow from Part Centers to Storage

Expected key factory performance indicators

- Throughput: we may calculate the throughput of this system in terms of hours by dividing daily production by 24 hours

Center	Daily Production	Throughput(unit/hr)
P1	5370	224
P2	1850	78
P3	810	34
P4	2100	88
P5	1640	69
P6	556	24
P7	1611	68
P8	920	39
P9	1640	69
P10	1028	43
P11	1811	76
P12	2221	93
P13	1111	47
P14	4166	174
P15	460	20
P16	2825	118
P17	1111	47
P18	2676	112
P19	4183	175
P20	3378	141

Figure 28: Throughput in Part Organization

- Maintenance: our equipment reliability is expected at 95 percent, while this seems to be a high number, it does not grantee that we will perform our throughput. On top of that, the part organization is extremely sensitive to equipment breakdown since we have all process station connected with each other with conveyors, which means that if one of the process station in the middle breaks down, it may be hard for maintenance people to go in. To hedge the risk, we may consider implementing machines that can access the middle stations.

Overall expected investment and direct operating costs(in millions)

installation cost with depreciation	operator cost	handler cost	material price	building cost	total cost
196	331	1	722	172	1,422

Despite the success to reduce handlers cost to almost none, we are looking at cost spikes at almost every other cost categories, especially when it comes installation, operator and building costs. We are building more process stations within each centers compared to other layouts in order to more conveniently produce and deliver parts. This has also caused our building space to increase, since we need enough space to fit each of our parts center into our layout.

Factory 3 - Product Organization

Network organization

In a product organization, we create dedicated centers for each client product, with each center responsible for producing all parts required for that specific product. This setup is beneficial when products are standardized with minimal differentiation and high production volumes, as it reduces setup times and increases efficiency by focusing solely on one product line. There's no need for switching centers or reconfiguring equipment.

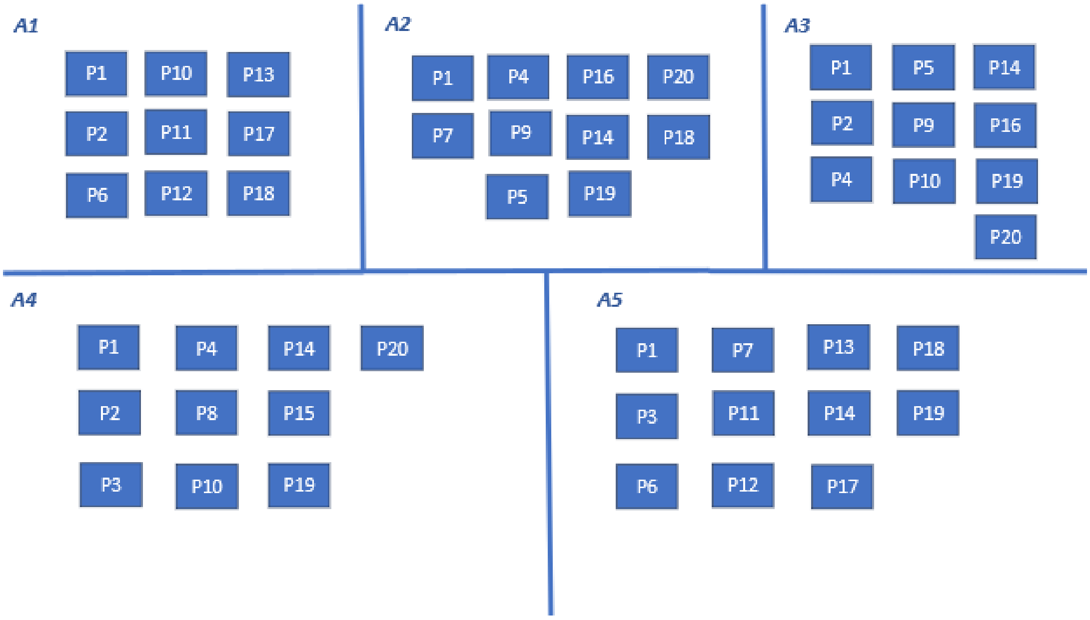


Figure 29: Network Organization in a product based organization

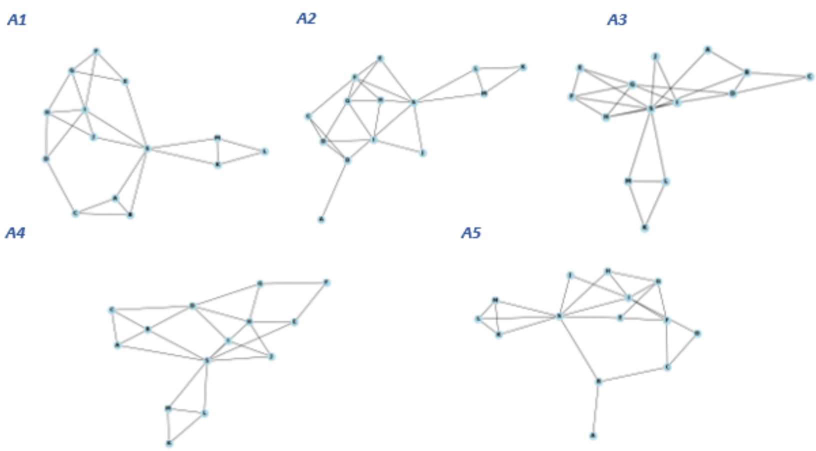


Figure 30: Network flow for each center in a product based organization

In a product organization, each center is dedicated to producing all parts required to make a product, with no material flow between centers. As a result, each center is configured with the equipment required to manufacture the parts for its specific product.

Center-specific and overall resource requirements plan

For the product organization, we need to first calculate the resources each center requires. Starting with the figure representing the number of parts per assembled product unit, we calculated requirements by multiplying normalized weight of each part for products. This information shows the quantity of parts needed for each product.

Part	Number of Parts per Assembled Product Unit Demanded in 2025					
	A1	A2	A3	A4	A5	Total
P1	4	2	4	4	1	15
P2	1		2	2		5
P3				2	1	3
P4		1	2	2		5
P5		1	2			3
P6	1				1	2
P7		2			2	4
P8				4		4
P9		1	2			3
P10	1		1	1		3
P11	2				4	6
P12	4				4	8
P13	2				2	4
P14		4	2	2	2	10
P15				2		2
P16		1	4			5
P17	2				2	4
P18	4	1			4	9
P19		3	3	3	1	10
P20		2	3	3		8

Figure 31: Number of Parts Per Assembled Product Unit

For example, we calculate center A1's requirements by multiplying (4/15 * P1 + 1/5 * P2 + 1/2 * P6 + 1/3 * P10...) from the figure 6. Based on this, and following previous processes, we can determine the equipment time requirements, accounting 95 percentage reliability and a 2 week inventory

	A1	A2	A3	A4	A5
A	259	140	393	393	70
B	923	645	1289	1203	321
C	129	170	235	184	139
D	657	957	1447	1176	659
E	471	388	334	349	795
F	365	661	810	299	594
G	178	201	246	107	285
H	218	771	1787	767	352
I	629	523	1023	486	640
J	1040	794	1849	1117	792
K	235	125	117	117	235
L	388	910	967	967	607
M	787	1413	1431	1431	1109

Figure 32: Total required time for each equipment by center

After calculating the total required time for each piece of equipment by center, we determine the number of workers and the total amount of equipment needed, using the metric shown in Figure 7 and accounting for 90 percent worker efficiency

	A1	A2	A3	A4	A5
C1	94	98	146	115	90
C2	39	53	64	61	40
C3	125	142	292	154	130

Table 5: Total Number of Workers Required per Week

Equipment	**A1**	**A2**	**A3**	**A4**	**A5**
A	4	2	5	5	1
B	12	9	17	16	5
C	2	3	3	3	2
D	9	12	19	15	9
E	6	5	5	5	10
F	5	9	11	4	8
G	3	3	4	2	4
H	3	10	23	10	5
I	8	7	13	7	8
J	13	10	24	14	10
K	3	2	2	2	3
L	5	12	13	13	8
M	10	18	18	18	14

Table 6: Total Number of Equipment Required per Week

Layout of each center and of the overall factory

Similar to part organization, our layout does not need to consider inter-center flows or worker travel distance. Since all processes are dedicated to a single center, each flow is focused on one product. This setup can be efficient, but it may require more equipment, as each piece is dedicated solely to its respective center.

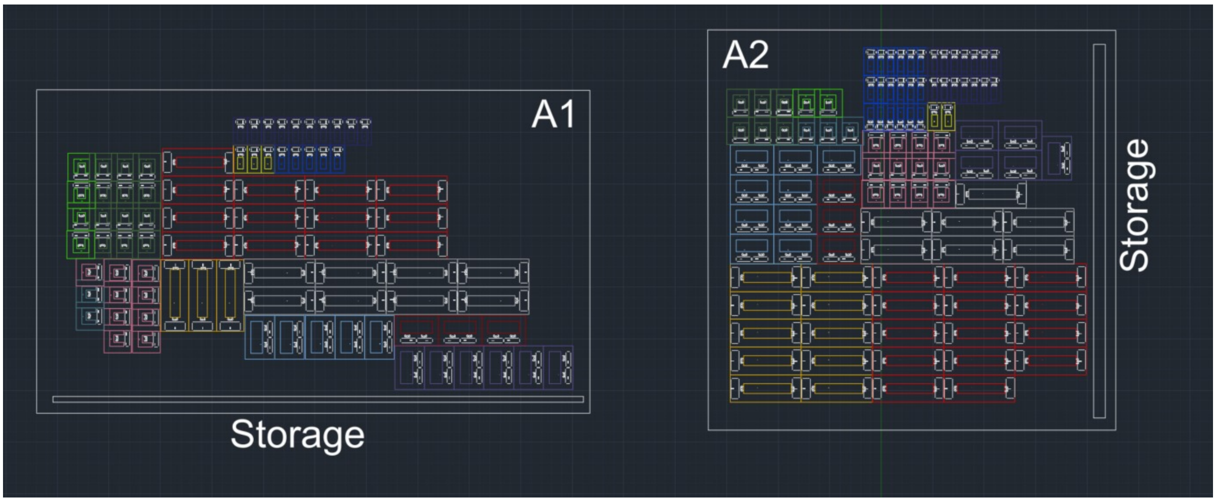


Figure 33: Layout of Production Organization

Estimated intra-center work and flow patterns and utilization profile in each center

A1 Flow	A2 Flow	A3 Flow	A4 FLow	A5 Flow
22136 IJ	18431 IJ	35890 IJ	17887 SE	31577 SE
18279 SE	17568 LM	31044 JS	17650 MS	24668 EG
16220 EG	17303 SE	23469 SF	17650 SL	19749 IJ
14556 CD	17303 EF	22855 CD	17568 LM	15357 EF
12758 JS	16777 MS	17677 BC	16201 IJ	15300 JS
12211 KL	15492 FG	17677 DI	15904 AB	15139 MS
12211 SK	14695 SL	17677 SB	15202 CD	13605 FG
12211 MS	14605 HS	17650 MS	14835 HJ	12211 KL
11967 AB	14605 GH	17650 SL	14574 JS	12211 SK
11967 BC	14477 DI	17568 LM	13804 SB	11658 GF
11658 GF	14477 CD	15904 AB	11713 GH	10087 CD
10169 FI	13419 JS	15816 FH	11713 HS	9742 LM
10024 DI	8839 BC	15816 HI	11058 SA	9719 GH
10024 BA	8839 SB	13486 FG	10024 BA	8448 GE
10024 SB	8784 ML	11713 HS	10024 BC	8448 GI
8325 KM	7993 KM	11713 GH	10024 DI	8448 IS
8325 LK	7993 LK	11058 SA	9660 BD	8325 KM
7772 FG	7952 AB	10024 BA	8866 KM	8325 LK
6283 EF	7781 SF	8866 KM	8866 LK	8144 DI
5829 HI	5638 FC	8866 LK	8784 ML	7772 FI
4532 DH	5012 BA	8784 ML	8230 EF	5833 HS
4532 SA	3954 FH	8230 EF	6438 EH	5829 HI
4224 GE	3954 HI	8230 SE	6438 IS	5638 FC
4224 GI	3827 GI	7653 GE	6438 JI	4449 AB
4224 IS	3827 EG	7653 EG	5880 DG	4449 BC
3886 LM	3827 GE	7653 GI	5833 FG	4396 SB
3886 GH	3827 GI	7653 IS	5178 DH	2928 ML
2589 AC	2940 BD	5880 BD	5178 AC	2928 SL
2589 HJ	2940 DG	5880 DG	3780 DC	2506 BA

Figure 34: Layout of Production Organization

Estimated inter-center flows and travel distances and traffic

Product Organization layout should have no inter-center flows. This is because the mission of product organization is to create 5 different product centers within the warehouse so that each center can produce a different type of product, in this case, product A1 to A5. In order to do this, each product center are provided with sufficient number of different process stations so that periodic demand of each product can be fulfilled. We can think of each product center as a mini function organization: materials go into the center, travel through process centers to become parts, and then finished parts will combine with other finished parts to form products and finally being sent to storage.

Expected key factory performance indicators

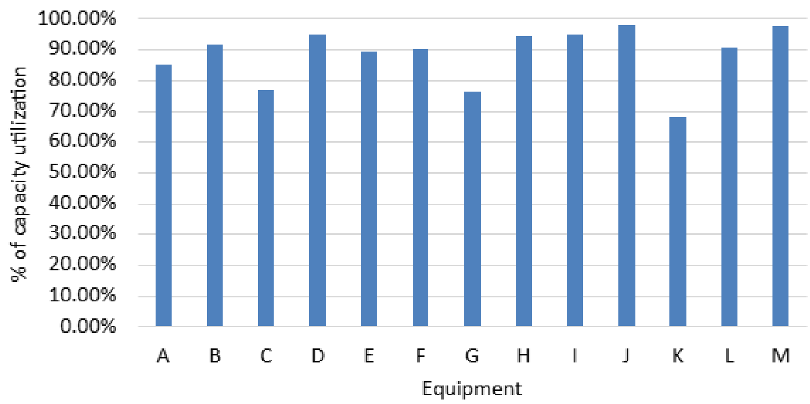


Figure 35: Layout of Production Organization

From the utilization performance of each equipment, we can observe that equipment utilization is lower compared to the function organization shown in Figure 17. This aligns with the layout, as the lack of movement among centers may contribute to efficiency within each center. However, this layout could lead to lower equipment utilization, potentially requiring additional equipment to meet demand.

Overall expected investment and direct operating costs

2025 TOTAL COSTS						
	installation cost (with depreciation)	**operator cost**	**handlers cost**	**material price**	**building costs**	**total cost**
A1	2,235,000	37,602,600	7,996,800	92,932,126	9,602,250	150,368,776
A2	2,840,833	43,306,200	9,564,800	125,263,502	9,557,000	190,532,335
A3	4,921,667	78,086,400	12,779,200	192,657,906	14,321,000	302,766,173
A4	3,021,667	48,167,000	10,192,000	163,043,580	11,069,750	235,493,997
A5	2,465,833	38,416,000	9,408,000	108,425,926	8,316,750	167,032,509
Racks					170,340	1,046,364,130

Factory 4 - Fractal organization

Network organization

In our fractal organization, we propose creating four centers, each designed to handle $\frac{1}{4}$ of the total demand for all 20 parts. This strategy allows us to efficiently group the necessary equipment to meet the specific demands associated with each quarter of the total output.

To develop an effective network organization, we will analyze all flows within the warehouse. Our goal is to arrange these centers in a way that minimizes travel distances for personnel and materials. For example, we have identified significant flow between locations J and S. To optimize operations, we will position these machines close to the storage location.

The overall organization is illustrated in Figure 73, which visually represents the layout and the relationships between the different centers.

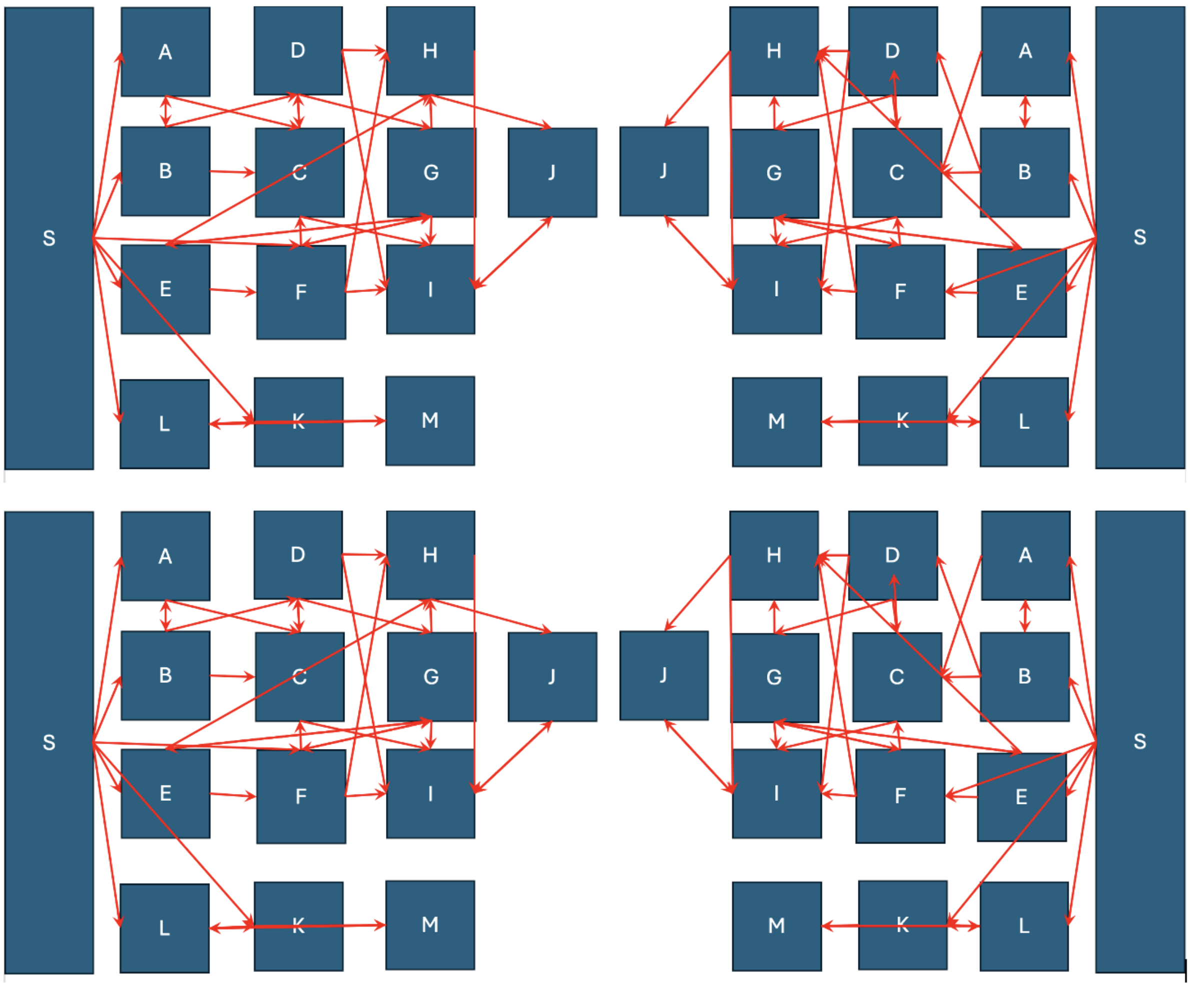


Figure 36: Network organization in a fractal based organization

Center-specific and overall resource requirements plan

Matrix of times required to complete each step for each part

To determine the number of machines necessary to complete all tasks, we will merge the process table from Figure 4 with the process time information from Figure 5 to produce Figure 6. Following this, we will calculate the time needed for each step based on a quarter of the demand, as proposed for our four centers.

To determine the demand for each center, we took the actual demand in the best-case scenario, divided it by 4, and then rounded up to the nearest whole number.

Part	Weekly Production (Best Scenario)	Weekly Production Fractal (4)	NEW Weekly Production (Best Scenario)
P1	37589	9398	37592
P2	12945	3237	12948
P3	5669	1418	5672
P4	14698	3675	14700
P5	11479	2870	11480
P6	3886	972	3888
P7	11276	2819	11276
P8	6438	1610	6440
P9	11479	2870	11480
P10	7191	1798	7192
P11	12671	3168	12672
P12	15543	3886	15544
P13	7772	1943	7772
P14	29162	7291	29164
P15	3219	805	3220
P16	19769	4943	19772
P17	7772	1943	7772
P18	18731	4683	18732
P19	29279	7320	29280
P20	23641	5911	23644
Total	290209	72527	290240

Table 7: Weekly Production for the fractal layout

The resulting matrix illustrates the time required to complete each step for every part in each center, along with the type of equipment used, which is color-coded for easy reference.

Part	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
P1	392	157	392	78	392	196	392
P2	67	27	135	54	135		
P3	41	71	18	35	59		
P4	61	123	184	15	77		
P5	72	36	167	84			
P6	12	20	8	49	16	20	45
P7	47	70	35	164	59	94	
P8	34	54	13	27	0		
P9	84	36	60	24	60	144	
P10	45	52	37	60	0		
P11	66	26	66	13	40		
P12	65	32	65	81	146		
P13	40	40	16	32	8	65	40
P14	122	182	61	213			
P15	10	7	17	34	34		
P16	103	412	103	206			
P17	24	97	113				
P18	59	98	39	293			
P19	275	305	244	458			
P20	197	74	296				

Figure 37: Hourly production time per center in a fractal organization

Optimal equipment used

Upon reviewing Figure 37, we observe that each step requires different types of equipment, with some equipment being applicable to multiple steps. Therefore, it's essential to determine the optimal combination of equipment to minimize costs. We have several options available, as shown in Figure 7 Different equipment combinations and associated costs.

As per previous comparison with several combination the decision is to proceed as follows:

1. Compute the time we will need equipment $i \in A,,M$ at step $t \in 1,,7$ for each center, considering 95% reliability and a two week inventory. We obtain the array in figure 38

A	148	165					
B	531	150	412				
C		66	64	82			
D		75	512	224	412		
E	451		132				
F	197	364	86	34			
G		107	81	55	9		
H		490		316	98	68	
I			148	239	166	227	43
J			14	280	393	250	459
K	87	78	41				
L	496	205	257				
M		321	430	790			

Figure 38: Required time for each equipment at each step in each center in a fractal organization

2. We know that the weekly capacity of one machine is 5 days a week$\times$2 shifts a day$\times$ 8 hours a day $= 80$. So we can compute the number of machines we need, in each center dividing the required time by 80 and taking the ceiling. For instance, for A, we need $\lceil \frac{148+165}{80} \rceil = 4$ equipment per center. And times 4 centers $= 16$ machines

Center	Equipment per Center	Total # Equipment
A	4	16
B	14	56
C	3	12
D	16	64
E	8	32
F	9	36
G	4	16
H	13	52
I	11	44
J	18	72
K	3	12
L	12	48
M	20	80
Total	**135**	**540**

Table 8: Equipment per Center and Total Equipment in a fractal organization

We use these numbers and figure 7 to determine the number of workers, considering 90% efficiency. The specific number of C1, C2, C3 workers in each center are

C1	C2	C3
524	251	844

Table 9: Number of C1, C2, C3 workers in a fractal organization

computed in the sheet Fractal ORG.

3. Then we compute the costs of installation and operators to determine the total cost of one set of equipment. All computations are detailed in the Excel file *Process_Steps_Table*, sheet *Fractal ORG*.

Layout of each center and of the overall factory

The next step is to propose an appropriate layout. Based on our previous analysis, we have established the number of machines and the network design, and we will incorporate these factors into our layout. We will also consider that some equipment can share aisles, allowing us to arrange them to maximize space utilization and minimize costs.

Additionally, we need to include a storage area that accommodates two weeks' worth of inventory. Calculations from the racks sheet, indicate that we require 887,000 square inches for storage. We will position this space in the layout near the last center visited before storage.

The layout for the fractal organization is displayed in figure 39

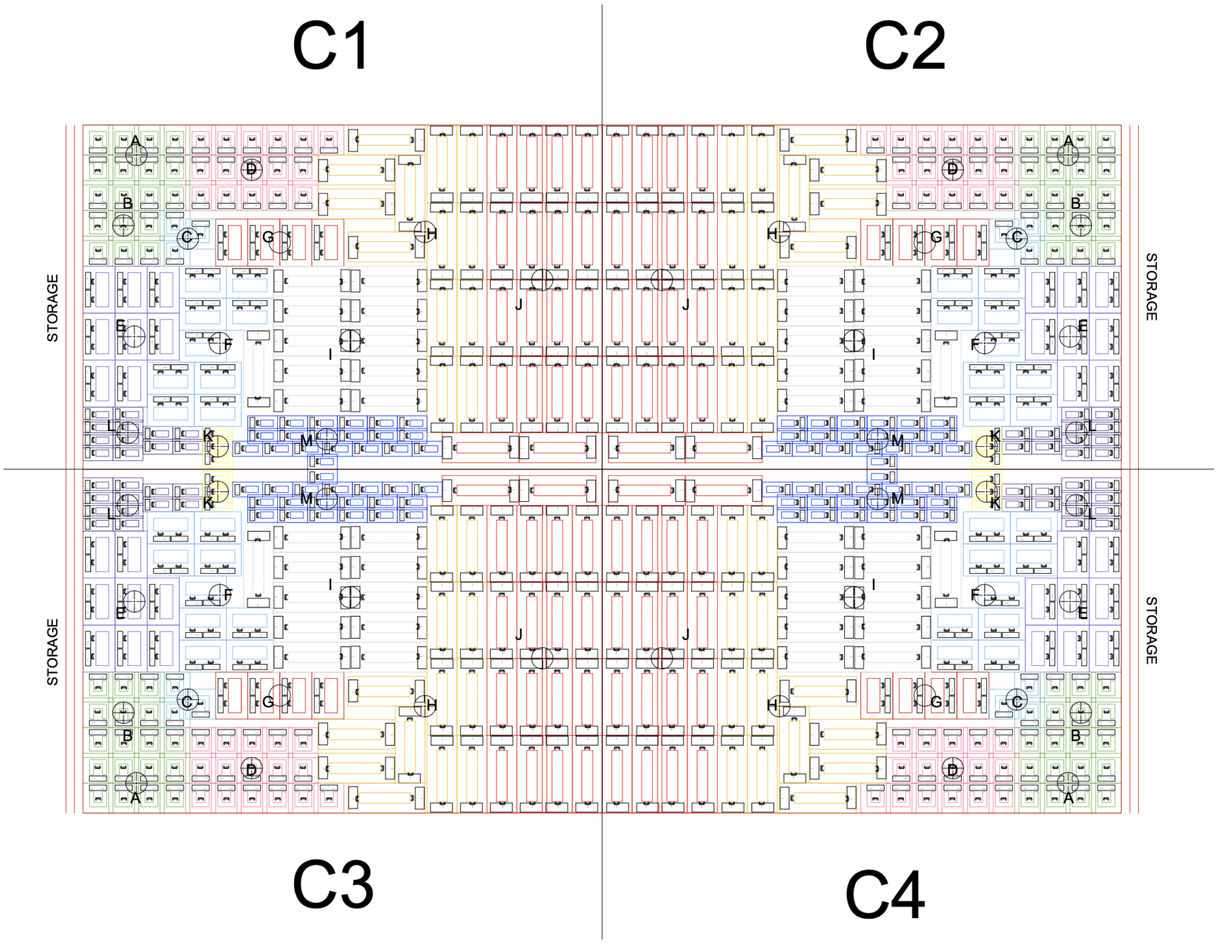


Figure 39: Layout of the fractal organization

Estimated intra-center work and flow patterns and utilization profile in each center

For this fractal organization, we have chosen to maintain a single flow within each center, as each section of the layout is capable of handling one-fourth of the total demand.

Estimated inter-center flows and travel distances and traffic

We have examined the various product flows in the factory by tracking the movement of each part and factoring in the production volume. For instance, with a weekly output of 37,000 units of part 1, we expect a corresponding flow of 37,000 units from B to A. This analysis will be conducted for each part and all sequences of equipment, resulting in a flow in/out matrix shown in figure 40. The final column, marked S, acts as a placeholder to signify that workers will return to storage to restart the process, preventing an overflow of workers at finishing stations such as H, I, J, and M. This information will help us calculate the required number of handlers, based on the assumption that all parts will ultimately be directed to assembly.

from (column) /to (line)	A	B	C	D	E	F	G	H	I	J	K	L	M	S	
A		56180	12948												69128
B	37592		52960	20372											110924
C				77184					5672						82856
D			5672				14700	16836	60348						97556
E						55404	55588	6440							117432
F			11276				56188	22992	22736						113192
G					24152	26536		51636	24152						126476
H									31432	22608				43864	54040
I										112416				38364	112416
J									6440					128584	6440
K												26504	42376		68880
L											42376		66332		108708
M												29280		79428	29280
S	7884	13686			23320	7813					6626	13231			72560
	45476	69866	82856	97556	47472	89753	126476	97904	150780	135024	49002	69015	108708	290240	1460128

Figure 40: Matrix of flow in a fractal based organization

You can read the matrix as follows: there is 37592 units of flow a week from B to A. We have grouped by the pair of equipment that have flows from one to another and sort them by the number of flows in figure 41.

PAIR	IJ	CD	LM	DI	FG	AB	EG	EF	BC	GH	KM	LK	BA	HI	ML	GF	KL	GE	GI	SE	FH	FI	HJ	BD	DH	DG	SB	SL	AC	FC	SA	SF	SK	EH	JI	CI	DC
FLOW	112416	77184	66332	60348	56188	56180	55588	55404	52960	51636	42376	42376	37592	31432	29280	26536	26504	24152	24152	23320	22992	22736	22608	20372	16836	14700	13686	13231	12948	11276	7884	7813	6626	6440	6440	5672	5672

Figure 41: Pair of equipment sorted by flow in a fractal based organization

Guillaume Eymery - Nathalia Gonzalez - Yong Suk Hong - Yaojie Huang - Anjulakshmi Karthikeyan - Louise Lacroix

By utilizing all these flows, we have developed an initial network that illustrates all flows while minimizing travel distance. This can be seen in Figure 42 and more specific in one center in figure 43. In relation to the flow sat each machine , we can observe Figure 43.

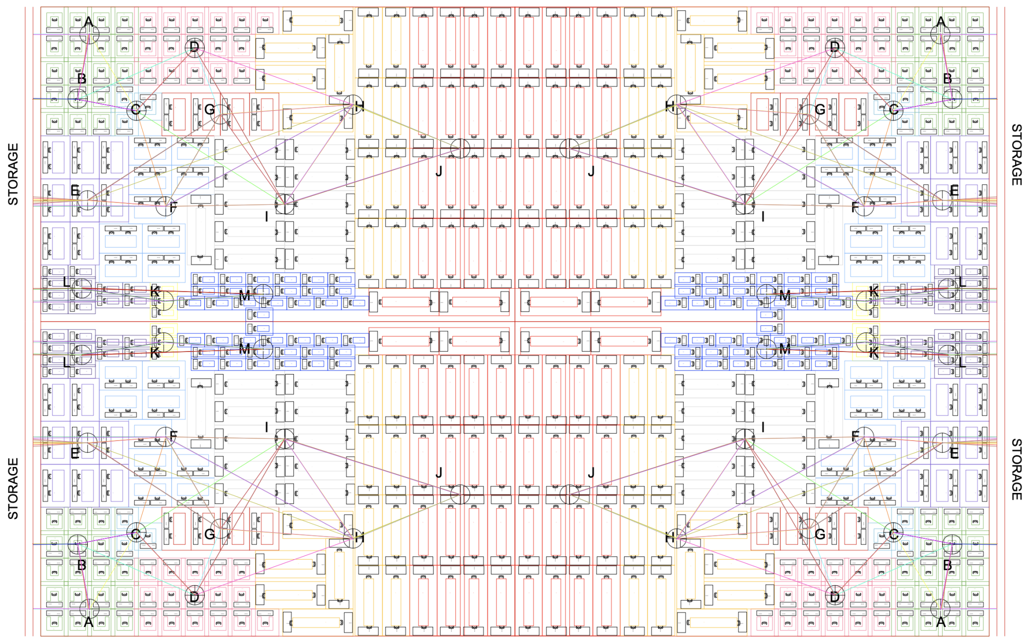


Figure 42: flow for each part in a fractal function organization

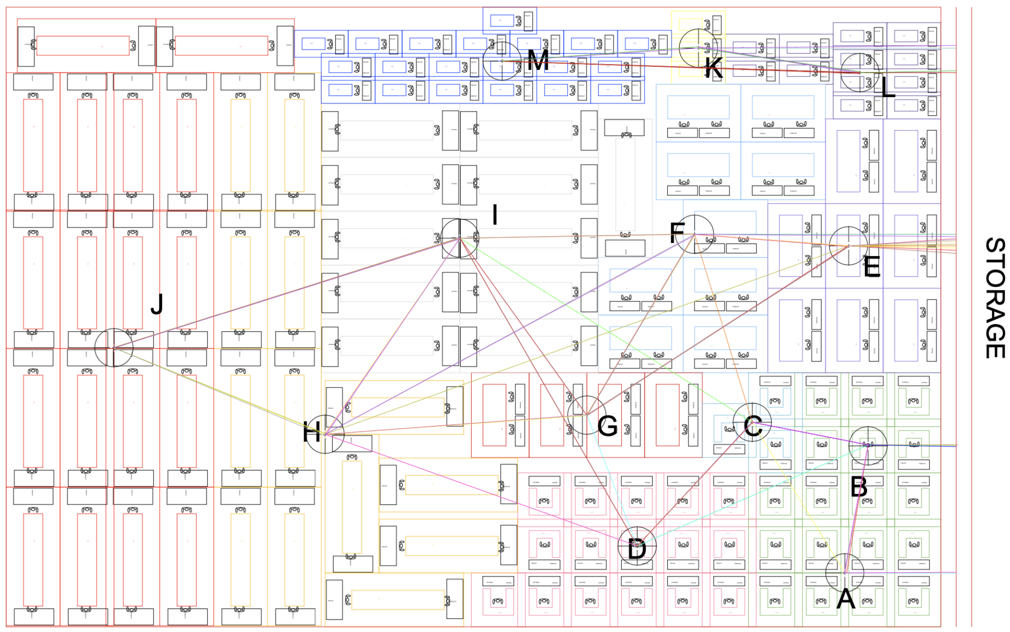


Figure 43: Flow for each part in a fractal organization for one center

For the calculation of the distance we are going to do same process as function organization consider a maintenance operator in O that wants to move to point T.

In order to estimate the distance traveled across the warehouse we would consider the distance between two centroids. For instance, in figure 44, in order to determine the average distance between J and F, we should normally count the distance in blue. This is equal to the distance in red.

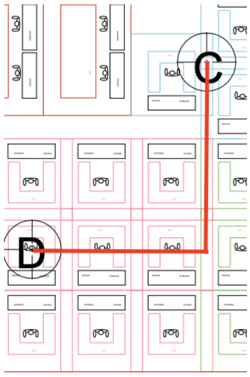


Figure 44: Calculation distances within two centroids in the fractal organization

We will determine the coordinate of the centroids of each group of machines in one center on AutoCAD. To do so, we will group the equipment of each center as a region in one center and then we will use the function MASSPROP to access the coordinates. With this coordinates we can replicate the distance between the machines groups four times to find it in every center. They are displayed in the figure 45.

center 1	X - centroid	Y - centroid
A	24.97	14
B	18.9	47
C	49	53.15
D	78.9	21
E	24	99
F	64	102
G	92	55
H	160	50
I	125	101
J	214.9	72.48
K	63	150.36
L	21	144
M	114	147
S	-4	72.48

Figure 45: Coordinates of the centroid of each group of machines for one center in the fractal organization

We will use these coordinates to calculate the total travel distance within the warehouse in one center and replicated for all the 4 centers. It's important to note that material handling workers must return to the storage area after completing their tasks. The total travel distance is detailed in the Excel file in the *Process_Steps_Table* sheet, under *Fractal ORG*.

Initially, we will assume that handlers transport one item at a time to estimate the number of workers needed. Since they work 8 hours a week and walk at a speed of 3.4 miles per hour, they would cover the equivalent of one marathon each day. To provide a more practical estimate, we will assume they carry 10 items at once (about 20 lbs), which will decrease the overall distance traveled.

To determine the time spent traveling, we will divide the total distance by the average speed of 18,000 feet per hour. This calculation yields a total of 33,400 hours per week in all centers. As a result, we will require **835** handlers for all 4 centers.

Expected key factory performance indicators

We can compute the capacity utilization of each equipment. The results are displayed in figure 46.

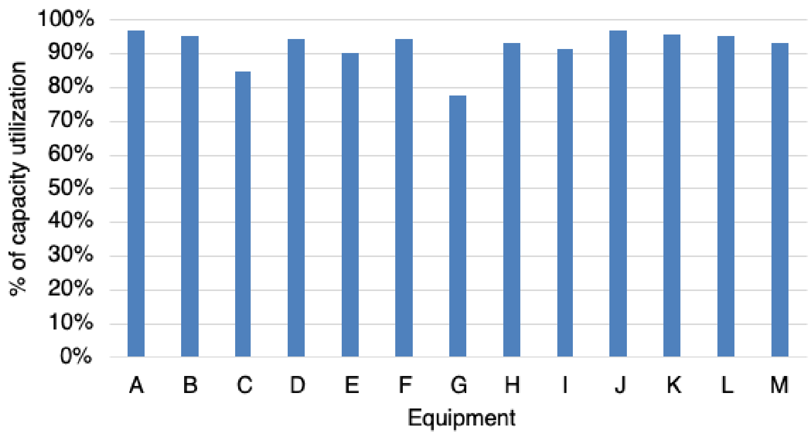


Figure 46: overall capacity utilization of each machine in a fractal organization

Overall expected investment and direct operating costs

Here are the costs for this layout (in million of dollars)

installation cost with depreciation	operator cost	handlers cost	material price	building costs	total cost
15	243	66	681	39	1,044

Table 10: 2025 Total Costs for the fractal organization

Factory 5 - Freestyle Layout - Step Oriented Layout

First of all, let us explain why we chose a Step Oriented Layout for our Freestyle Layout:

- Flexibility in Production: A step-oriented layout provides high flexibility for producing multiple parts with different processes. Since the layout is organized by steps, different parts can follow unique paths through the machines, making it easy to switch between parts with varying production requirements. This adaptability is crucial when each part requires a different number of steps (from 4 to 7 in our case).

- Efficiency for Varied Production: Given that the factory produces 20 different parts, a step-oriented layout ensures that the machines are organized in the order that aligns with the workflow. Each part can move smoothly through the production line without unnecessary backtracking or delays, which increases the efficiency of handling different part types.

- Reduction in Bottlenecks: By arranging machines in a sequence that matches the required steps, it is easier to balance the workload across the machines. If one machine becomes a bottleneck, the layout makes it easier to redistribute steps to other machines, reducing idle time and improving throughput.

- Reduced Material Handling Costs: Since parts follow a specific sequence of steps, a step-oriented layout reduces the need for transporting parts back and forth between machines. This decreases material handling costs, minimizes movement of parts, and lowers the risk of damage during transit.

Network organization

To map the network organisation, we will consider each step separately. Then, we integrate the machines required for each step. Finally, we join the machines together from one center to the other. We get the following network:

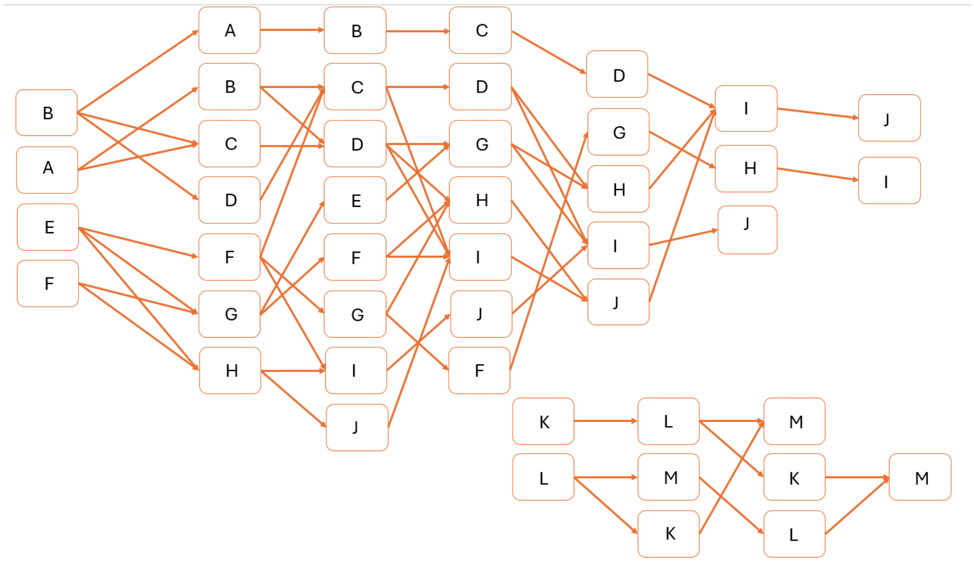


Figure 47: Network Organisation for the Freestyle Layout

The network appears to be complicated, especially for Step 2, 3 and 4. But we must keep in mind that the flow diminishes as the steps increases. We can also see that K, L and M machines form a closed network. We will try to regroup them together when planning the layout.

Center-specific and overall resource requirements plan

Now that the network is established, we may calculate the number of each machine per step. To do so we evaluate the capacity of each machine per week as well as the overall demand per week. By computing the ratio of the two and rounding up to the next integer, we get the following table:

	Step 1	**Step 2**	**Step 3**	**Step 4**	**Step 5**	**Step 6**	**Step 7**
A	9	10	0	0	0	0	0
B	30	9	23	0	0	0	0
C	0	4	4	5	0	0	0
D	0	5	29	13	23	0	0
E	25	0	8	0	0	0	0
F	11	21	5	0	0	0	0
G	0	6	5	4	1	0	0
H	0	28	0	18	6	4	0
I	0	0	9	14	10	13	3
J	0	0	1	16	22	14	26
K	5	5	3	0	0	0	0
L	28	12	15	0	0	0	0
M	0	18	24	44	0	0	0

We will need 588 machines for this layout.

Layout of each center and of the overall factory

As stated in introduction for this part, the centers are coincident with the different Steps for each process. The final layout for the Step Oriented factory is in Figure 48.

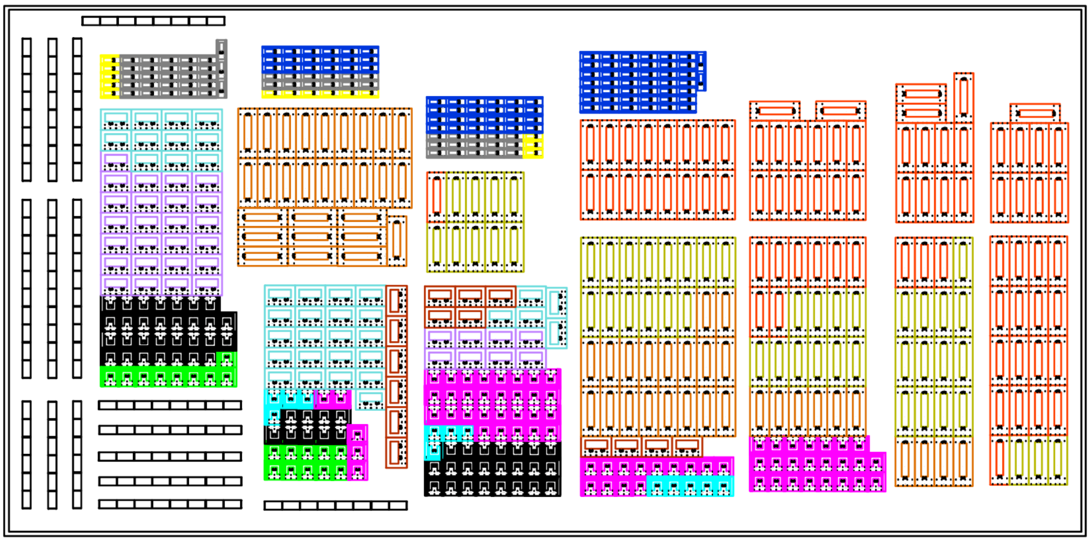


Figure 48: Step Oriented Layout

We included the appropriate number of racks for the storage of the materials as well as some isle to optimize the circulation between the different centers.
The color-grid is the following:

Estimated intra-center work and flow patterns and utilization profile in each center

In this section, we represented the flows with different arrows, following this color rule:

Value	**Arrow type**
$\geq$ 10% total flow	Red
between 5 and 10% total flow	Orange
$\leq$ 5% total flow	Green

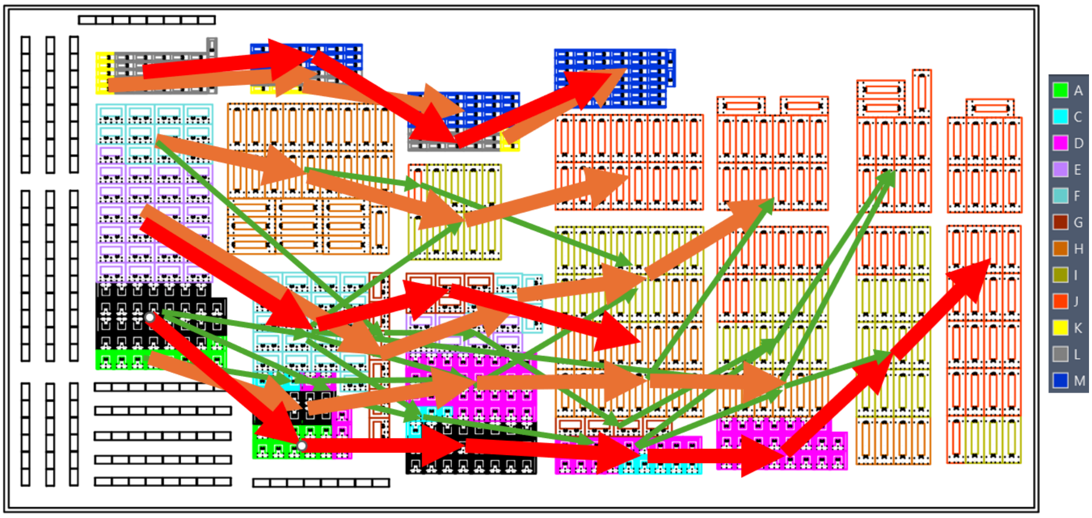


Figure 49: Step Oriented Layout - Flows

We can see that the flow is almost always directed from left to right making it easier for the traffic and facilitates the understanding of the different processes. The storage racks are located on the left of the machines, since it is the starting point for all the processes. We added some additional storage rack in case of an unforeseen events.

Estimated inter-center flows and travel distances and traffic

1. To calculate the estimated flows in the warehouse, we can study the amount of pieces per week transit through each set of machines. Since the facility is subdivided in different steps, it makes sense to calculate the flow from machine i (A,B,C,...) at step s to machine i at step s+1: $M_{i,s}$ to $M_{i,s+1}$. As an example, consider the flow through the machines from **Step 1** to **Step 2**:

		Step 2													
		A	B	C	D	E	F	G	H	I	J	K	L	M	S
Step 1	A	0	18584	12945	0	0	0	0	0	0	0	0	0	0	0
	B	37589	0	11479	5669	0	0	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	55401	31433	6438	0	0	0	0	0	0
	F	0	0	0	0	0	0	11479	19769	0	0	0	0	0	0
	G	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	J	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	K	0	0	0	0	0	0	0	0	0	0	0	26503	0	0
	L	0	0	0	0	0	0	0	0	0	0	23641	0	29279	0
	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 50: Flow from Step 1 to Step 2

The rest of the flow calculations are available on the Excel file associated with this task.

2. To estimate the number of maintenance workers required in the warehouse, we will combine data analysis with realistic hypothesis. First of all, since this is a step oriented layout, we can simplify the calculations by considering the number of maintenance workers in each section. Secondly, we will suppose that the employee in his section can carry up to 20 pounds of different equipment parts to the other section per trip. This greatly reduces the travel distance for the workers, as well as improving their efficiency. We can theoretically evaluate the travel distance for each worker by using the Manhattan distance. Using the Manhattan distance in this precise case makes even more sense since the worker has to make multiple stops to unload their 20 pound equipment parts. Telling them exactly where they need to pick up and unload their equipment can be done with a ear piece connected to a WMS. The following example illustrates how multiple paths taken by employees can lead to the same total distance.

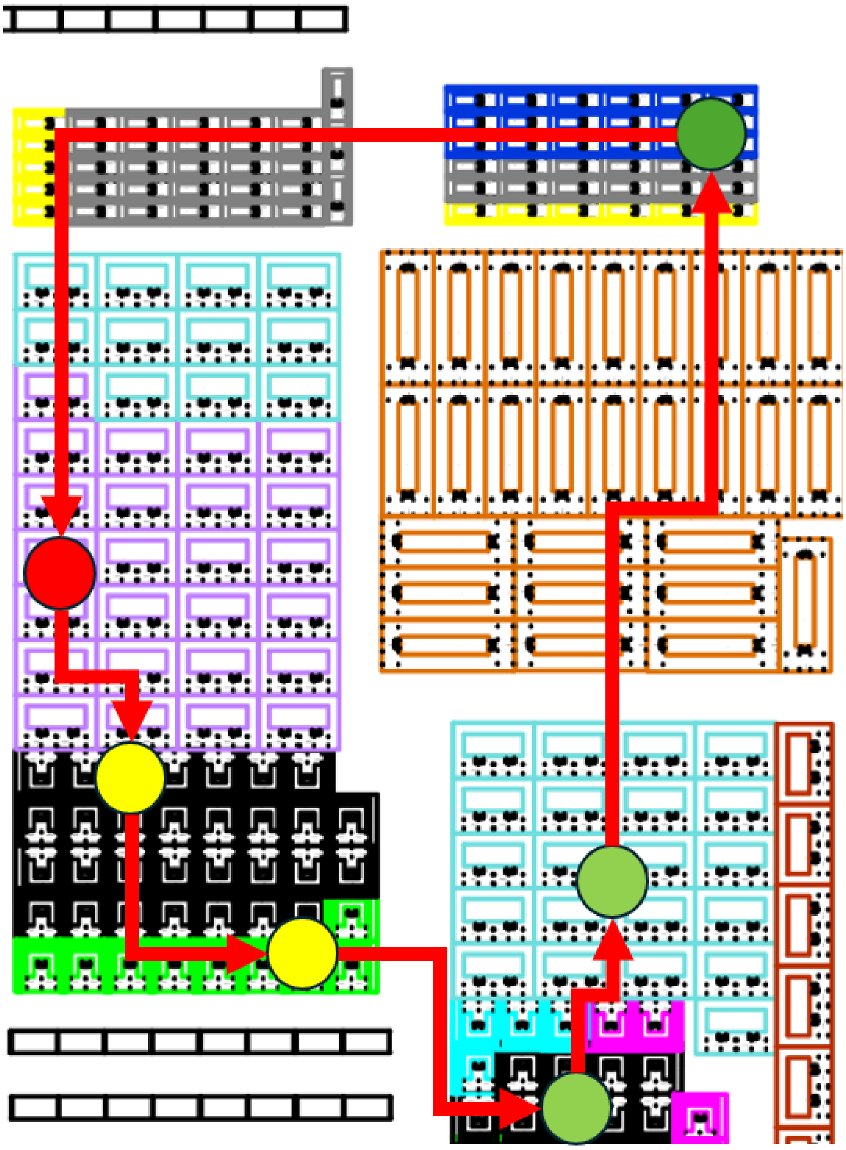


Figure 51: Optimal path for maintenance worker between section 1 and 2

In this example the worker starts his path at the red dot. He then loads the different equipment parts at the yellow dots, and unloads in the green. The more the stops, and the more the travel distance required.
Now let's calculate how many loops can a maintenance worker can do in a week. To do so, we will calculate the Manhattan distance between all the centers of mass for the different types of machines in a group. This will calculate the distance traveled by the maintenance worker if he has to go through all the family of machines for a given group (which is highly unlikely, but gives us the worst case scenario).
We also need to take into consideration the time lost by loading and unloading the

different parts. Therefore, we will assume that the worker only walks 60 % of the time. The following example will help to better illustrate this situation:
Let's consider the maintenance workers supposed to bring the ongoing parts from S1 to S2.

The table below presents the center of mass coordinates (X, Y) for each group, along with the total displacement in the X and Y directions and the total distance traveled in feet.

Group	X	Y
A1	254	109
B1	255	142
E1	252	217
F1	253	280
K1	211	328
L1	259	328
M2	370	340
L2	370	323
K2	370	317
H2	375	235
F2	374	140
G2	424	116
D2	395	81
C2	345	92
B2	361	75
A2	362	51
A1	254	109
Total (feet)	**1603**	

Table 11: Center of Mass Coordinates and Total Distance

The total distance covered is computed by summing the Manhattan distances between consecutive points, with the total displacement in the X and Y directions being 358 and 542 units, respectively. The total distance covered, including all stops, is 1603 feet.

The Manhattan distance between two points (x_1, y_1) and (x_2, y_2) is calculated as:

$$d = |x_2 - x_1| + |y_2 - y_1|$$

Given the coordinates of each group, the total path length is summed across all the points.
A1 appears twice because the maintenance worker has to go back to the origin.

We may now calculate the number of loops a worker can do per week, assuming he walks at a speed of 18000 feet per hour 60 % of the time: he can do at minimum 269 loops per week. The total mass flow per week from S1 to S2 is 1,079,767 pounds, assuming a worker can carry up to 20 pounds per travel, we calculate the total number of loops per week required to pass the products from S1 to S2: 53988. Thus resulting in the need for 200 maintenance employees for this section uniquely.
By following a similar process for S2-S3, S3-S4, -S4-S5, S5-S6, S6-S7, we obtained the following results:

Section	# Employees (Maintenance)
S1 - S2	200
S2 - S3	197
S3 - S4	131
S4 - S5	64
S5 - S6	9
S6 - S7	6
Storage - S1	200
Total	**807**

Table 12: Number of maintenance employees required

Let's note that we supposed that the assembly for the products A1 to A5 line is located behind the Storage area. Therefore, once they unloaded the product materials, the workers load the finished parts and bring them up the chain with the same methodology. This means that a maintenance employee almost never travels with an empty cart. However, the downside with this method is that the finished product will have a lot more touches than by using a standard method (hiring maintenance employees to bring the products to the assembly line). This saves expenses but can decrease the overall efficiency in the facility.

Expected key factory performance indicators

An interesting KPI for this layout is to determine the amount of distance a maintenance worker will travel during a day. We can also calculate the total weight of product material that a worker have to carry in a week.

Maintenance worker	Total distance (mi/day)	Loops (/week)	Weight (klbs/week)
S1-S2	16	269	5.4
S2-S3	16	274	5.5
S3-S4	16	365	7
S4-S5	16	505	10
S5-S6	16	684	13.5
S6-S7	16	735	14.7
Storage-S1	16	269	5.5

Table 13: KPIs for maintenance Workers

The first key observation is that all the maintenance workers are walking the same distance per day. This is normal since the number of workers is calibrated in function of the distance they can walk. Secondly, we can see that the number of loops per week increases alongside the manufacturing chain progresses. This is due to the fact that there are fewer machines in the last sections, thus less points to visit This implies that the Manhattan distance to visit all of the points is smaller. The worker can do more loops. This explains the third KPI, if the workers can do more loops, they can transport more products, therefore the amount of weight they transport a week increases. Another KPI that might be interesting to study is the amount of times a product is touched throughout the manufacturing process, as we know that the more a product is touched, the lesser the supply chain process is efficient. We will count as one touch each time a product goes through a machine, and one touch when it is transported to another machine/storage/assembly line.

Part	# touches	Part	# touches
P1	21	P11	15
P2	15	P12	15
P3	15	P13	21
P4	15	P14	12
P5	12	P15	15
P6	21	P16	12
P7	18	P17	9
P8	12	P18	12
P9	18	P19	12
P10	12	P20	9

Table 14: # touches per product

We immediately see that the longer the process, the more a part is touched. In this case, each additional steps leads to 3 additional touches. On of the most efficient process is the manufacturing of part 20: few touches and high volume.

Overall expected investment and direct operating costs

Knowing the cost of material, the amount of workers, their wage, the number of machines as well as their cost, the number of racks required and the facility cost, we can estimate the overall cost of operating this facility per year.

- The table below shows the number of operators for different categories (C1, C2, C3, M) along with their respective costs, followed by the total cost.

Category	Operator Number	Operator Costs (M$/Y)
C1	500	$39.2 MM
C2	236	$34.7 MM
C3	822	$161 MM
M	807	$62.0 MM
Total	**1618**	**$298,000,000**

Table 15: Operator Numbers and Costs

- To this amount we can compute the yearly cost of material for manufacturing.

  The table below shows the material prices for each product (P1 to P20), along with the total cost at the bottom.

Product	**Cost (M$ /Y)**
P1	$22 MM
P2	$63 MM
P3	$14 MM
P4	$86 MM
P5	$28 MM
P6	$3 MM
P7	$14 MM
P8	$6 MM
P9	$23 MM
P10	$7 MM
P11	$19 MM
P12	$23 MM
P13	$10 MM
P14	$29 MM
P15	$4 MM
P16	$19 MM
P17	$30 MM
P18	$78 MM
P19	$115 MM
P20	$93 MM
Total	**$680,000,000**

Table 16: Material Prices for Products P1 to P20 and Total Cost

This is the most costly operation in the facility.

- We can compute the installation cost, taking into account the depreciation.

Category	Cost (M$ /Y)
A	$0.285
B	$1.240
C	$0.325
D	$2.100
E	$0.825
F	$1.036
G	$0.560
H	$1.120
I	$1.307
J	$2.107
K	$0.650
L	$2.750
M	$4.838
Total	**$ 19.1**

Table 17: Installation Costs in M$ for Categories A to M

- We may take into account all the additional expenses: racking installation cost and the building implementation cost of $250.00/$ft^2$

  The table below shows the dimensions of the facility (length and width), the surface area in square feet, and the associated cost.

Attribute	Value	Unit
Length (l)	780	ft
Width (L)	378	ft
Surface Area	294,840	ft^2
Cost	**73,710,000**	**$**

Table 18: Facility Dimensions and Costs

Once we add all the expenses, we find that the facility operating cost is **$ 1.07 B**.

We now have the costs for each of our layouts, they are displayed in figure 52.

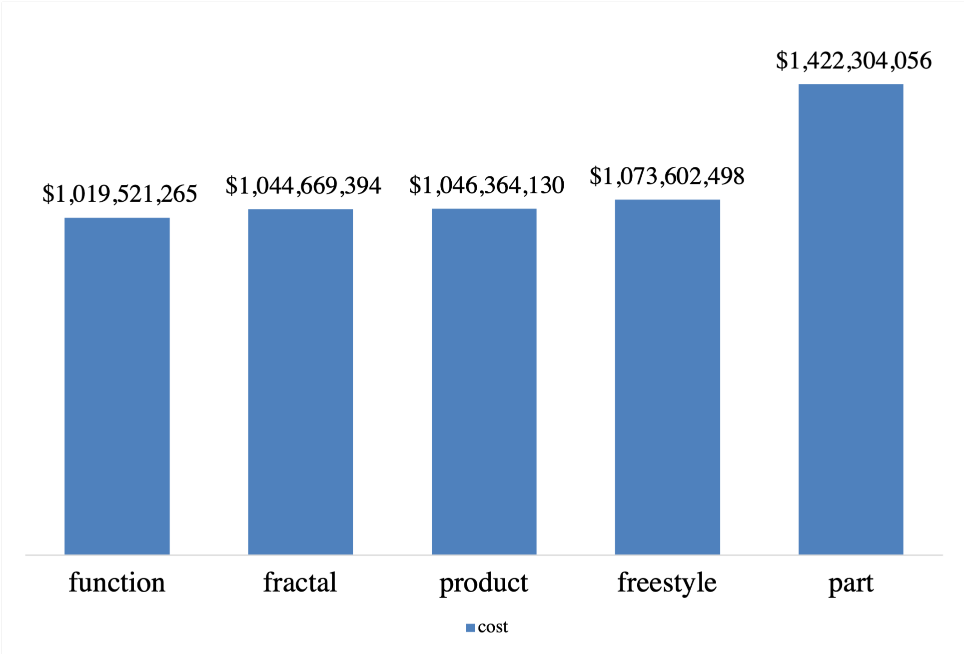


Figure 52: Total costs for each layout

We notice that the function layout is the cheapest. Indeed in this case we use our machines to their full capacity since they can be used for any part. The fractal is then the cheapest option among Part, Product and Fractal. Indeed this organization functions as several small function organizations put together.

TASK 3

Function-organization-based factory design from task 2.a

Network organization

The products A6 to A8 uses the same machines and processes as the previous products. The network organization is not impacted when compared to the layout for the previous Task. However, the flow and the amount machines for each section will increase. The network organization shall remain the same as in task 2 and is recalled here in figure 53.

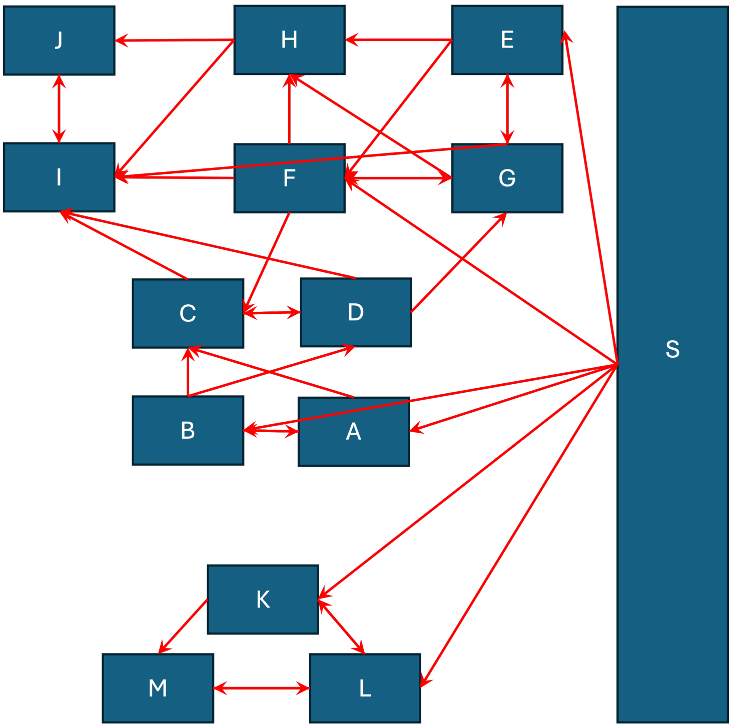


Figure 53: Network organization in a function based organization

Yearly center-specific and overall resource requirements plan

We use the same method as in task 2 to find the yearly number of equipment and workers needed. Table 19 shows the total number of equipment required each year. In Figure 2 we can see the additional number of equipment that are required for each center for the 4 years.

	2026	2027	2028	2029
A	20	21	21	22
B	72	75	79	83
C	16	18	20	22
D	86	94	102	112
E	50	58	66	79
F	51	57	62	70
G	20	23	26	31
H	67	73	80	90
I	63	71	80	91
J	101	112	122	137
K	16	18	19	21
L	67	72	77	83
M	108	115	122	132

Table 19: Total number of equipment in the function organization

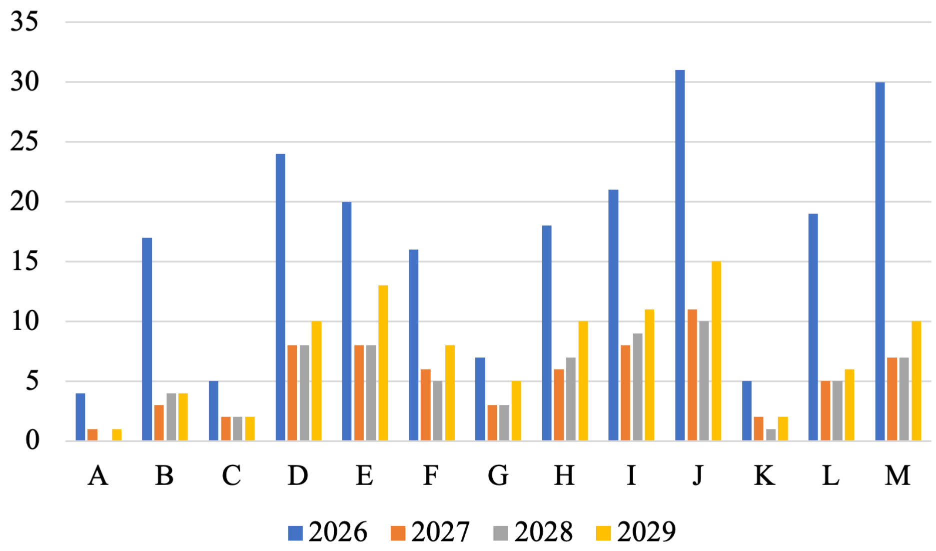


Figure 54: Additional number of equipment for each center

In Table 20 we can see the total number of workers for each year. The detailed center specific workers can be found in the excel.

	2026	2027	2028	2029
C_1	704	771	838	933
C_2	382	345	369	400
C_3	1163	1294	1427	1615

Table 20: Number of workers in the function organization

The total number of racks can be found using the new demand. The rack dimensions are the same as in task 2. Table 21 tells us the total number of racks required.

year	2026	2027	2028	2029
Number of racks	248	275	307	345

Table 21: Total number of racks in the function organization

Yearly layout of each center and of the overall factory

The yearly layouts can be found in the below figures. We add the new additional equipments and relocate the machines as necessary to accommodate the flow. We have efficiently used the space so that the relocation cost is less. The layout in year 2029 is such that we can add more equipment to the centers if required without much relocation.

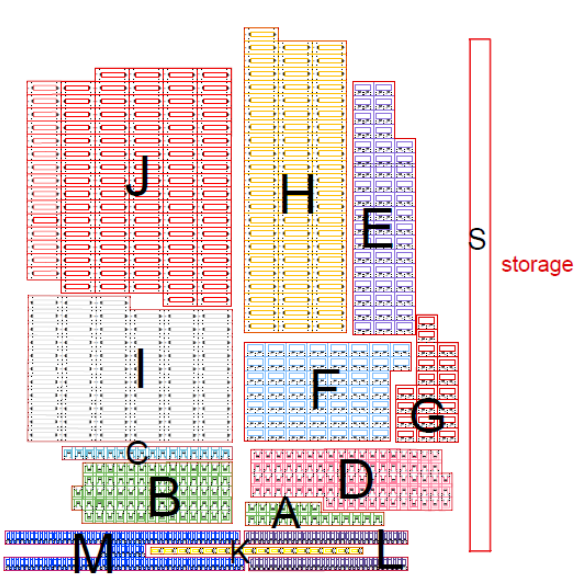


Figure 55: Facility Layout 2026 - Function Organization Layout

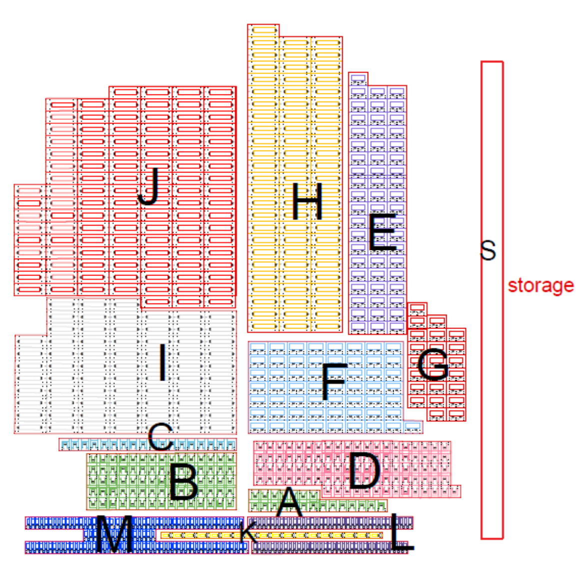


Figure 56: Facility Layout 2027 - Function Organization Layout

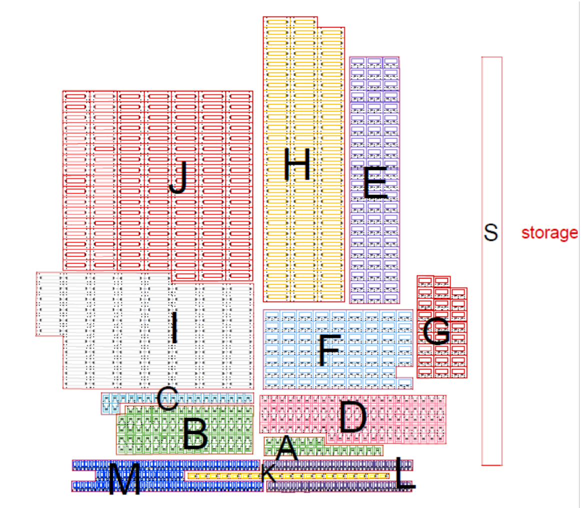


Figure 57: Facility Layout 2028 - Function Organization Layout

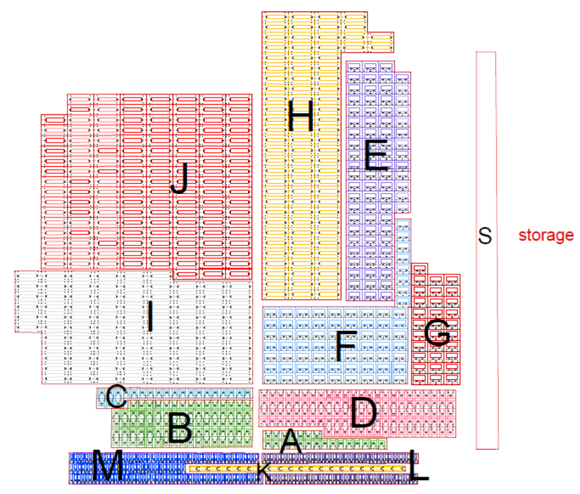


Figure 58: Facility Layout 2029 - Function Organization Layout

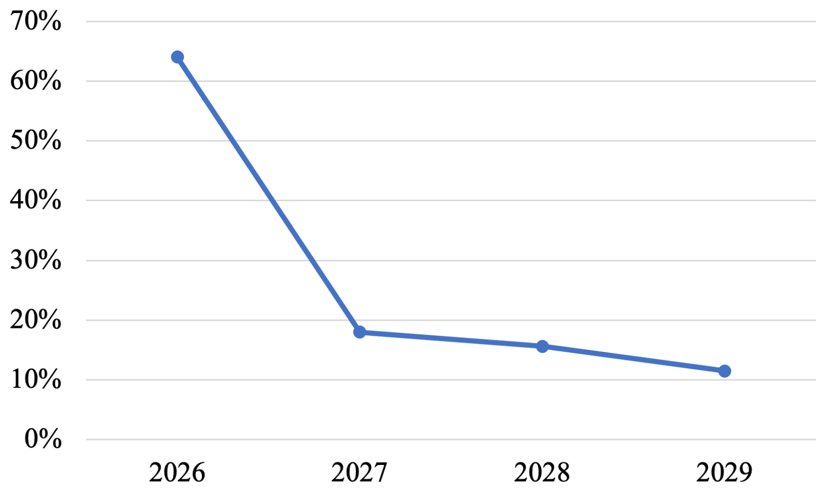


Figure 59: Percentage increase in area each year

We can see the percentage increase in area of the facility in figure 59. Year 2026 has the highest increase owing to the production of parts for 3 new products.

Yearly relayout of each center and of the overall factory

We can find the layouts of each year in figures 55, 56, 57, 58. From the table 22 we can find the total number of equipments per center that are relocated each year.

	2026	2027	2028	2029
A				
B				
C				
D	4			
E				
F			8	
G	13	6		
H				
I				
J				
K				
L	5			
M	6			

Table 22: Total number of equipment that are relocated each year in the function organization

Figure 60 tells us that G is relocated the most. But the cost of relocation is lowest compared to the others. We avoid relocating the machines with high relocating cost. The layouts were designed so that we avoid relocation of the equipment as seen in year 2029, no machines were relocated.

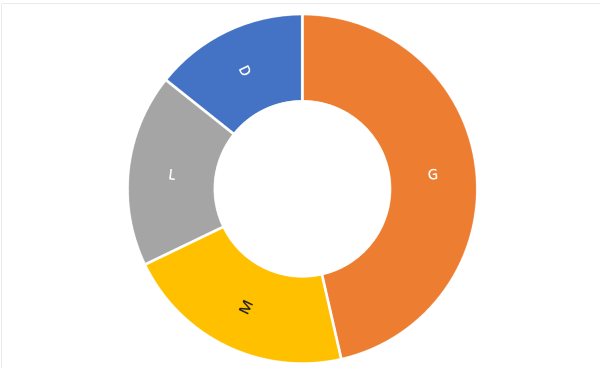


Figure 60: Relocated equipment in the function organization

For each year, estimated intra-center work and flow patterns and utilization profile in each center

In a function organization, there will only be flow in and out inside each center since one center is dedicated to one equipment.

For each year, estimated inter-center flows and travel distances and traffic

To find the flow and the travel distances, we use the same calculation method as in task 2. The figures here after show the flow and travel distances for each year. We can see that the pair IJ has the highest flow in the first year and then the pair SE is the highest for the next consecutive years. We designed the taking into consideration of the flow by keeping IJ close to each other and by making the storage closer to center E.

But we do see that the maximum distance is for the pair SB but since the flow for SE is very much higher we will be willing to place it closer to E.

PAIR	FLOW	Distances
IJ	160044	2450.5
SE	158255	2237.9
CD	103690	2951.1
EG	100002	2812.7
LM	90167	2579.7
FG	86447	1379.9
EF	83354	2987
DI	80452	4228.1
SB	76967	6627.7
GH	70938	4322.5
AB	70006	2187.3
BC	68670	606.2
SL	68634	5178.4
KM	59788	1686.1
LK	59788	893.6
GF	52552	1379.9
BA	47208	2187.3
HI	44691	4496
KL	44671	893.6
SK	44671	6072
HJ	40148	2060.5
GE	39567	2812.7
GI	39567	4063.5
SA	39413	5005.8
FI	36826	2884.6
ML	36850	2579.7
SF	36062	3225.5
BD	31095	2723.1
FH	30290	2943.6
DH	23238	4487.1
FC	18405	2998
AC	16615	2793.5
DG	16175	2059
CI	14920	1277
DC	14920	2951.1
EH	14466	1509.8
JI	14466	2450.5

Figure 61: Inter center Flow and Travel distances for year 2026

PAIR	FLOW	Distances
SE	183292	2824.4
IJ	174961	2432.7
EG	120158	2952.7
CD	108898	3192
FG	96054	1789.3
LM	95839	2689.7
EF	91069	3142
SB	84911	6978.1
DI	84100	4482.5
GH	76576	4424.5
SL	71282	5404.6
AB	71034	2288.9
BC	70798	690.2
KM	63918	1885.8
LK	63918	803.9
GF	63779	1789.3
KL	50866	803.9
SK	50866	6208.5
HI	50465	4855.4
HJ	48870	2422.7
BA	47436	2288.9
GE	47212	2952.7
GI	47212	4280.1
SA	41365	5260.2
FI	40966	2967.4
SF	38051	3445.8
BD	37711	2878.4
ML	37609	2689.7
FH	33546	3249.8
DH	24798	4764.9
CI	21144	1290.5
DC	21144	3192
FC	20333	3214.7
EH	19277	1471.8
JI	19277	2432.7
AC	17767	2979.1
DG	16567	2443.2

Figure 62: Inter center Flow and Travel distances for year 2027

PAIR	FLOW	Distances
SE	208327	3161.8
IJ	189880	2523.9
EG	140314	3425.2
CD	114107	3281.5
FG	109658	1973.2
LM	101512	2809.9
EF	98783	3275.4
SB	92855	7556.8
DI	87748	4716.4
GH	82212	4857.3
GF	75005	1973.2
SL	73931	5849.7
BC	72927	737.5
AB	72063	2342.4
KM	68049	2019.4
LK	68049	791.5
HJ	57592	2644.2
KL	57062	791.5
SK	57062	6641.2
HI	56240	5168.1
GE	54857	3425.2
GI	54857	4688.6
BA	47664	2342.4
FI	45106	3292.6
BD	44327	2937.4
SA	43318	5776.6
SF	40041	3854.2
ML	38568	2809.9
FH	36804	3524.7
CI	27368	1434.9
DC	27368	3281.5
DH	26359	4948.5
EH	24087	1432.1
JI	24087	2523.9
FC	22261	3461.9
AC	18919	3079.9
DG	16959	2738.4

Figure 63: Inter center Flow and Travel distances for year 2028

PAIR	FLOW	Distances
SE	245130	3135.8
IJ	209782	2535.8
EG	172162	3474.1
FG	125730	1654.8
CD	120214	3515.5
LM	109594	3021.4
EF	108882	3176.1
SB	103315	7733.5
DI	92341	5072.3
GF	91842	1654.8
GH	89879	5059.3
SL	77465	5880
BC	75599	778.4
KM	72999	2311.1
LK	72999	710.3
AB	72723	2454.8
HJ	70189	3164.3
GE	66761	3474.1
GI	66761	4876.4
KL	65221	710.3
SK	65221	6590.3
HI	63515	5700.1
BD	52892	3130.9
FI	51360	3505.2
BA	47547	2454.8
SA	45224	5841.1
SF	42942	3682.5
FH	42009	3688.9
ML	39907	3021.4
CI	35541	1556.8
DC	35541	3515.5
EH	30847	1585.2
JI	30847	2535.8
DH	27873	5256
FC	24567	3858.2
AC	20048	3233.2
DG	17351	2574.9

Figure 64: Inter center Flow and Travel distances for year 2029

Yearly and overall, expected key factory performance indicators

The figures here after show the capacity utilization of the equipments for the 4 years. Centers I and J are almost always at 99% or 100%. We can also see that year 2029 has the highest combined utilization of all the centers. The lowest capacity utilization is at 95% which is very efficient as any equipment in a center can perform processing for any part.

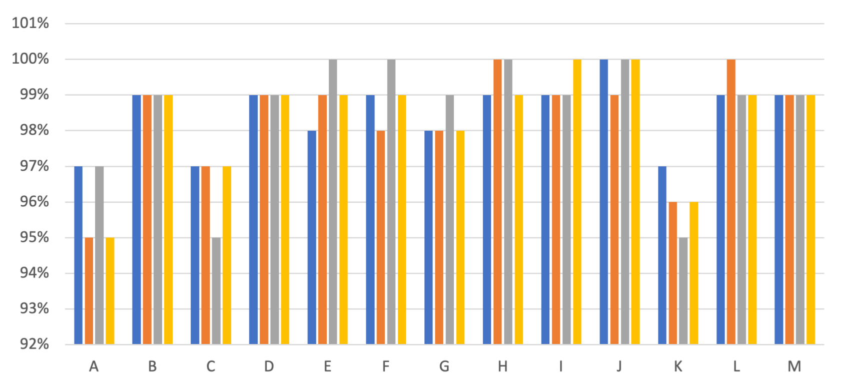


Figure 65: Capacity utilization of each center for 4 years

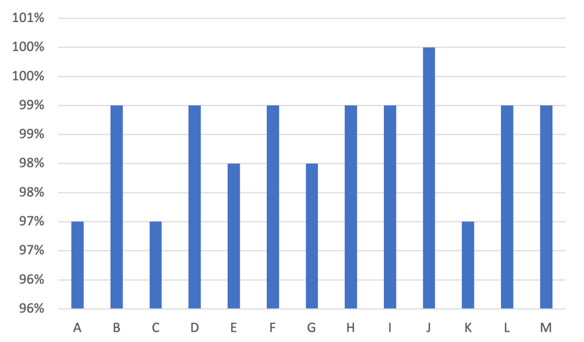


Figure 66: Capacity utilization of each center for the year 2026

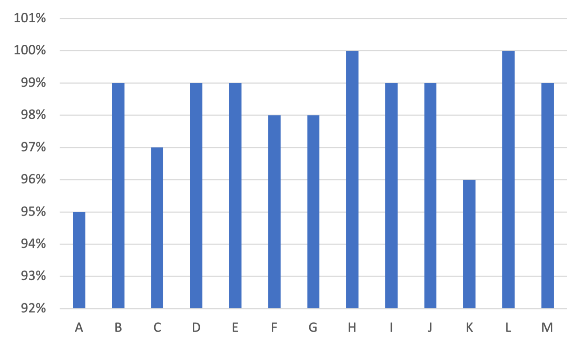


Figure 67: Capacity utilization of each center for the year 2027

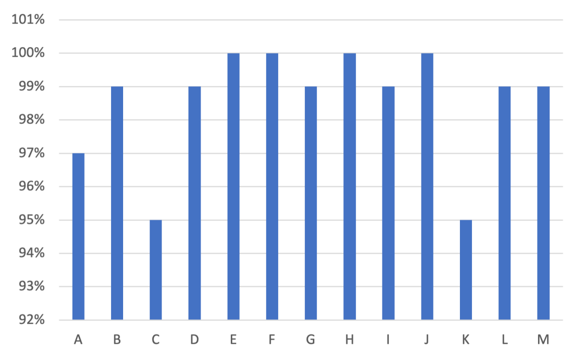


Figure 68: Capacity utilization of each center for the year 2028

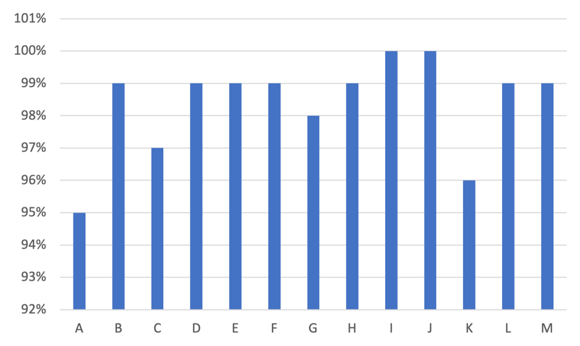


Figure 69: Capacity utilization of each center for the year 2029

The overall capacity utilization for all the years combined for each center can be seen in figure 70. The average utilization is 98.5% making it very robust.

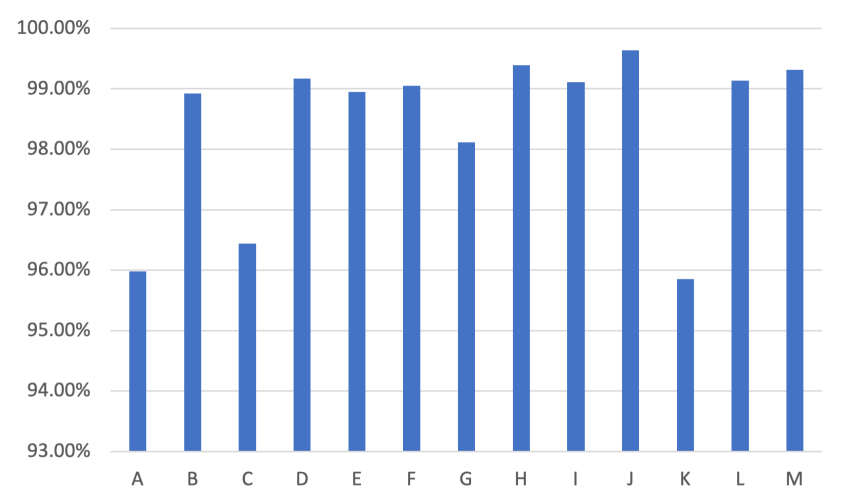


Figure 70: Overall capacity utilization of each center

Yearly and overall expected investment and direct operating costs

The yearly costs can be found in the below table. The values are in millions.

Year	Installation Cost With Depreciation	Relocation Cost	Operator Cost	Material-Handling Cost	Material Price	Building Costs	Total Cost
2026	$6	$0.7	$330	$52.83	$967	$29	$1,387
2027	$2	$0.3	$364.79	$62.33	$1,064	$14	$1,508
2028	$2	$0.4	$400	$74	$1,161	$14	$1,651
2029	$3	$–	$448	$85	$1,293	$12	$1,841

The highest costs are for the materials which cannot be reduced. The relocation cost are reduced to the maximum and we can also see that the building costs are reduced in the year 2029.

The below figure shows the representation of the total costs for all the years. The material costs are higher owing to the increase in demand for the years as shown in figure. We can also see that the years 2028 and 2027 has almost the same costs.

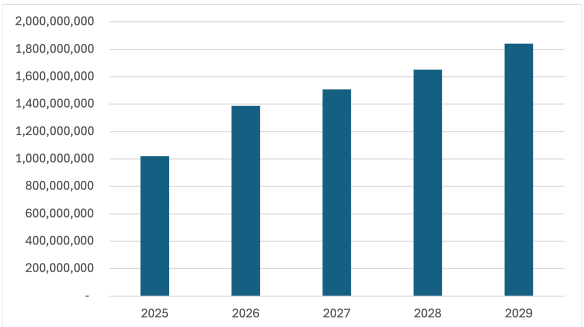


Figure 71: Total costs for the function organization

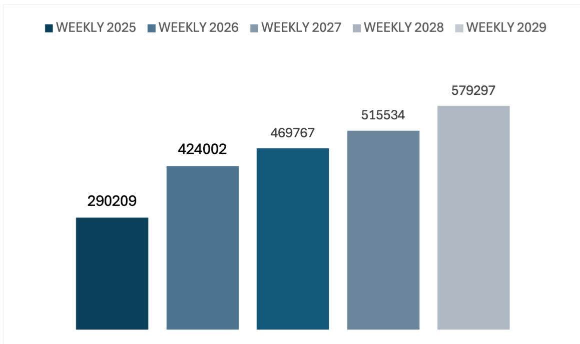


Figure 72: Maximum total demand for the function organization

Despite rising costs over the years, the proportional increase in demand suggests that the company has the potential to achieve profitability. To optimize efficiency, we can evaluate and compare the costs and space requirements of all available layouts. By analyzing these factors, we can identify and select the layout that offers the lowest overall cost, ensuring the most cost-effective solution for the company.

Top-ranked factory design among those produced in tasks 2.b to 2.g - Fractal Layout

Network organization

The network organization will be the same as in task 2. It is reminded in figure 73

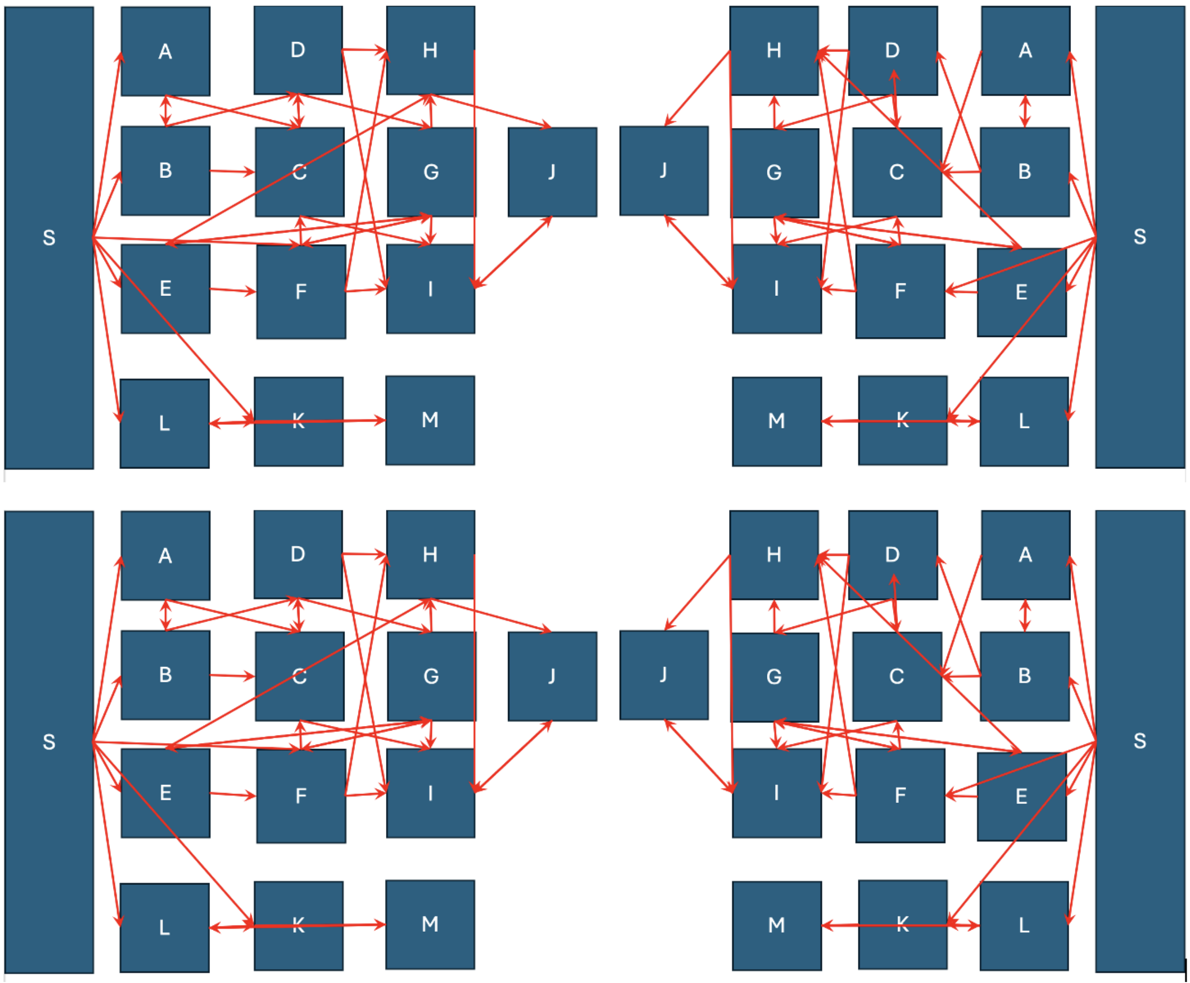


Figure 73: Network organization in a fractal based organization

Yearly center-specific and overall resource requirements plan

In the excel fil *Task 3*, we have computed the number of equipment and workers required as in task 2, the exact numbers per center are displayed on the file.

	2026	2027	2028	2029
A	20	24	24	24
B	72	76	80	84
C	16	20	20	24
D	88	96	104	112
E	52	60	68	80
F	52	60	64	72
G	20	24	28	32
H	68	76	84	92
I	64	72	80	92
J	104	112	124	140
K	16	20	24	24
L	68	72	80	84
M	108	116	20	132

Table 23: Total number of equipment in the fractal organization

We notice that it was not necessary to buy additional machines A since 2027 while it is compulsory to buy a lot more of machines J every year. Indeed, we do not use machines A to their full capacity in 2027 so we can still load them with more demand while machines J are used to more than 95% of their capacity so we need to buy more every time the demand raises.

	2026	2027	2028	2029
C_1	720	820	876	964
C_2	330	362	390	414
C_3	1200	1324	1464	1656

Table 24: Number of workers

Numbers of workers increases linearly with the number of machines.

Yearly layout of each center and of the overall factory

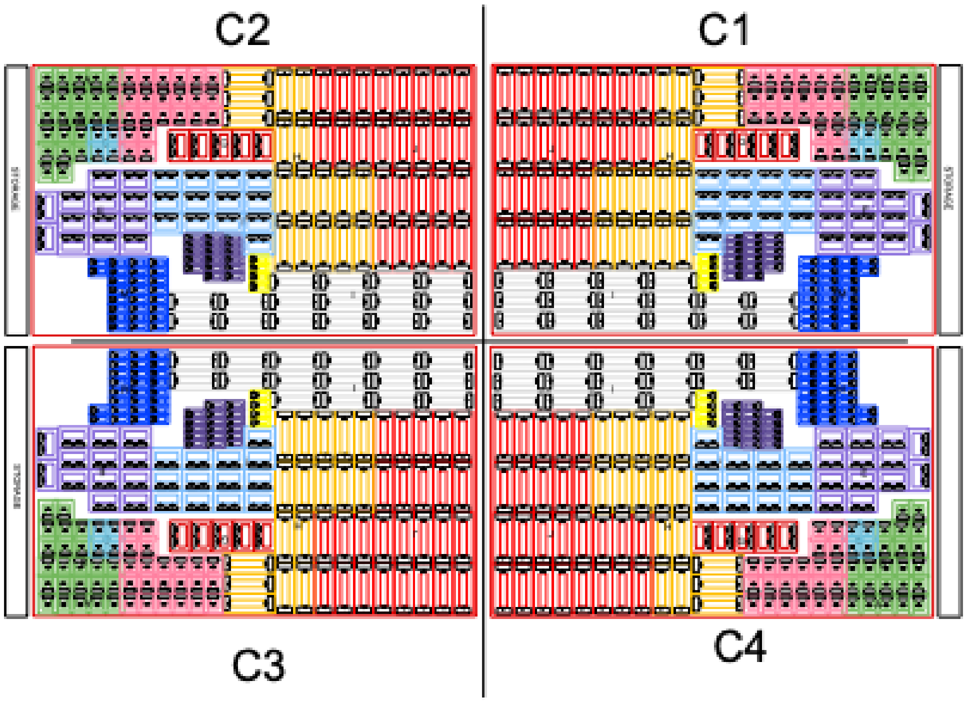


Figure 74: Fractal layout for 2026

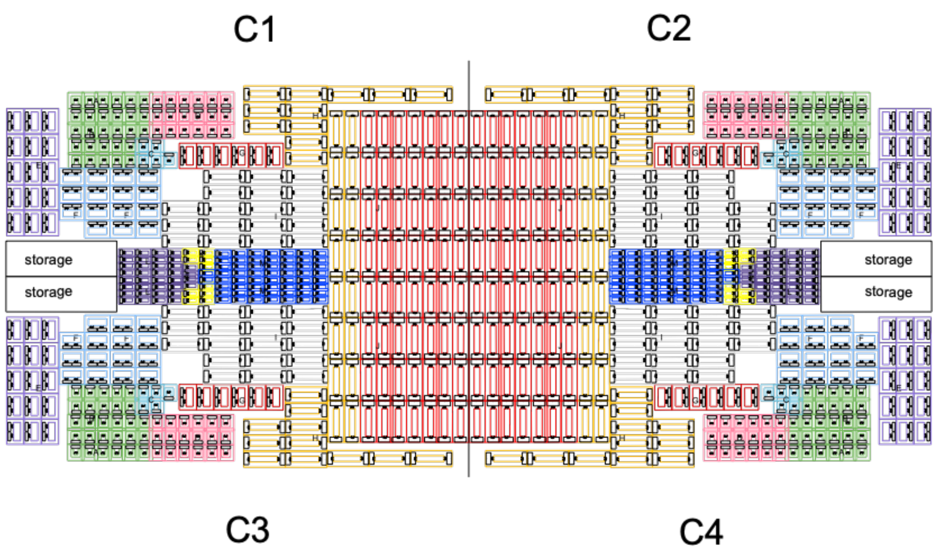


Figure 75: Fractal layout for 2027

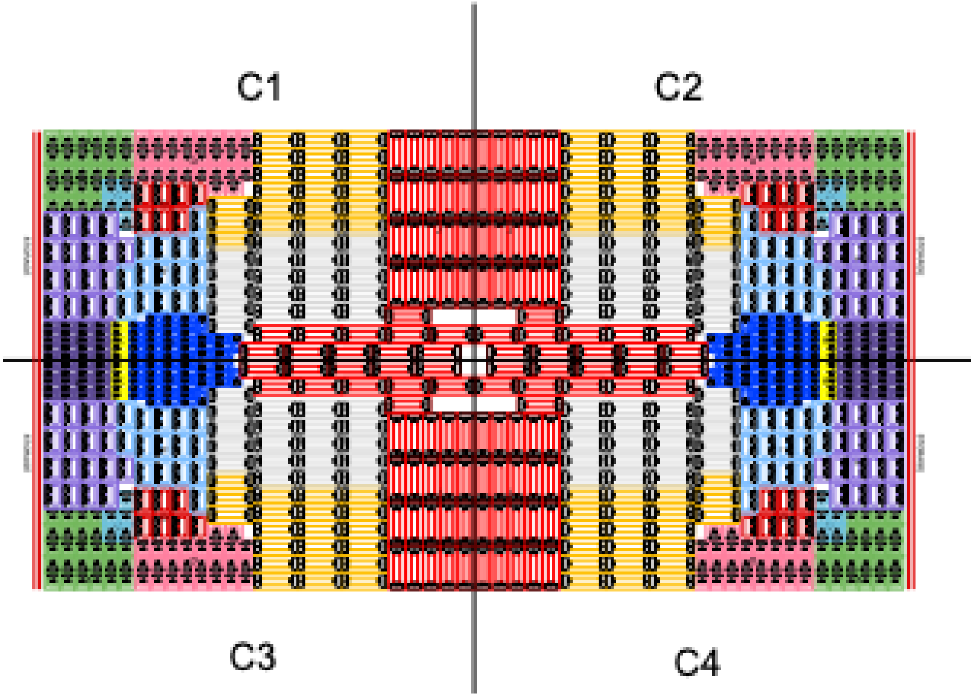


Figure 76: Fractal layout for 2028

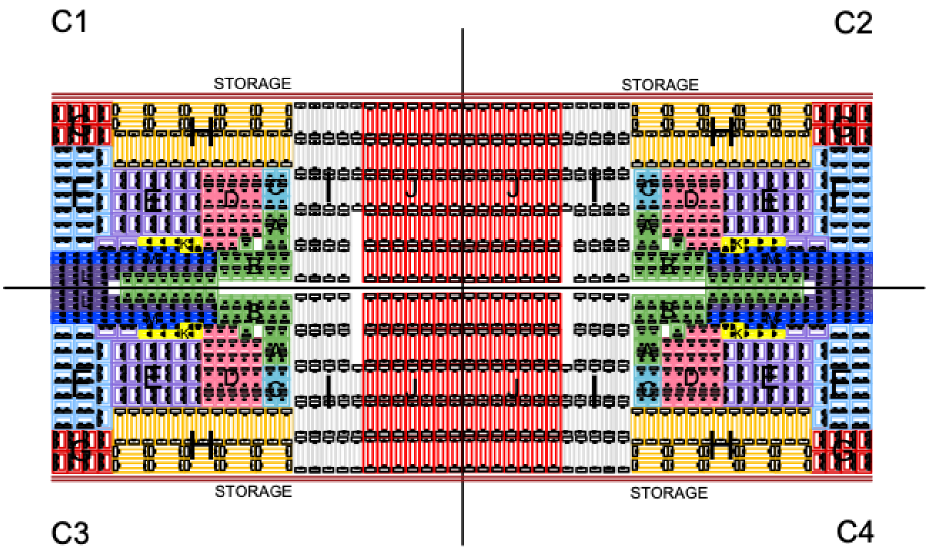


Figure 77: Fractal layout for 2029

Yearly relayout of each center and of the overall factory

Every year we have relocated some equipments. The number of relocations are displayed in table 25

	2026	2027	2028	2029
A	0	0	6	6
B	0	0	19	20
C	0	0	5	5
D	4	4	4	4
E	11	13	3	17
F	8	13	3	16
G	4	0	2	6
H	15	6	11	15
I	0	16	0	20
J	10	6	0	11
K	3	4	5	5
L	12	17	18	8
M	20	27	29	19

Table 25: Number of equipment being relocated in each fractal center

We notice that we have quite a number of relocations, this might be pretty expensive at the end. We have done this to minimize space but maybe we might have better kept as many equipment as possible in the same spot so as to minimize relocation costs even if this means our factory would have been bigger.

For each year, estimated intra-center work and flow patterns and utilization profile in each center

The flows for 2027 are displayed in figure 78

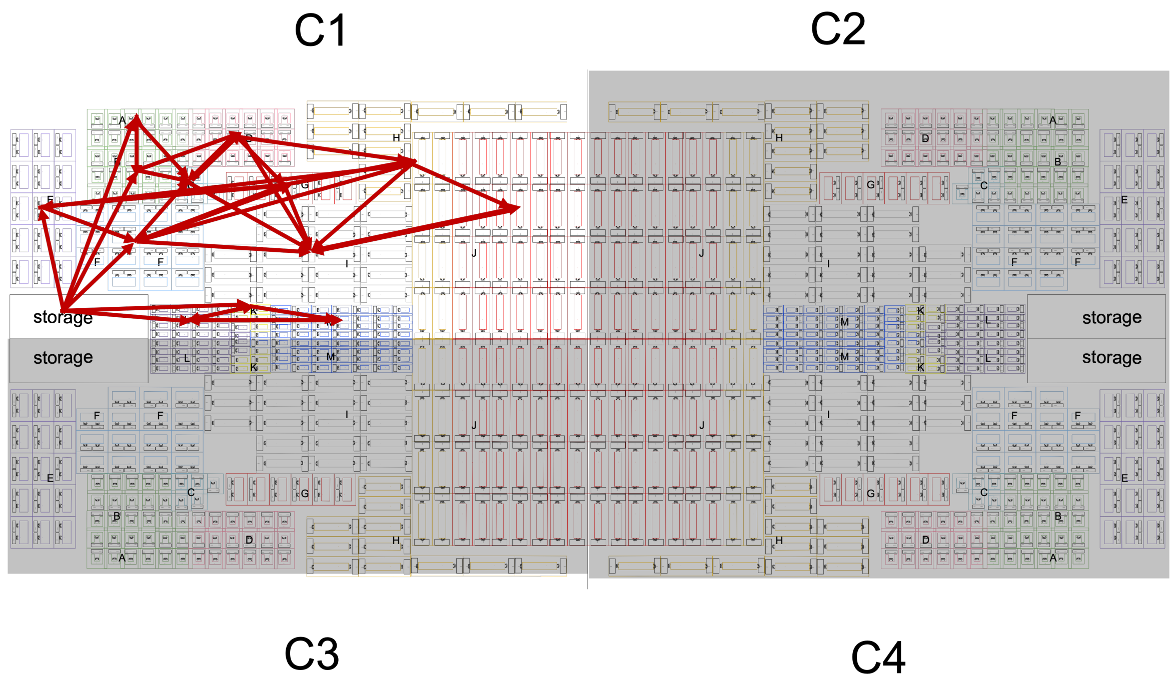


Figure 78: Flows in one center of the Fractal layout for 2027

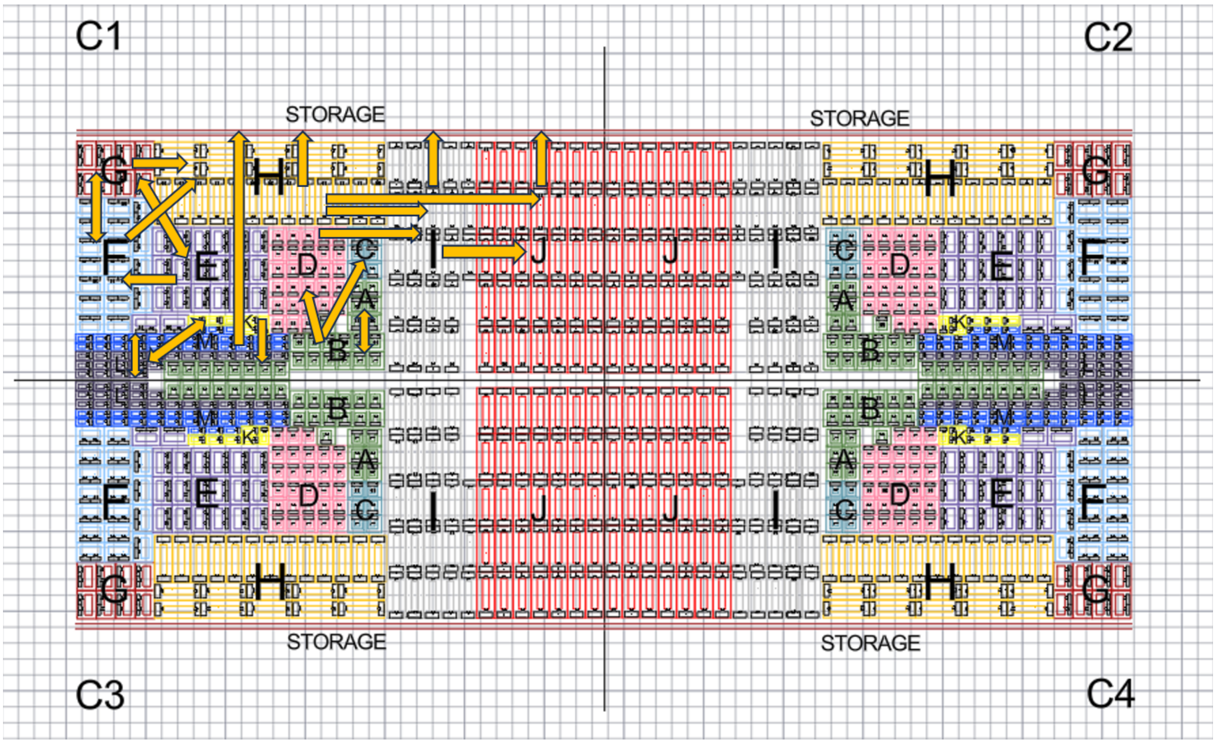


Figure 79: Flows in one center of the Fractal layout for 2029

Our flow from 2026 to 2029 would look similar to what was shown in figure 78 but our flow in 2029 may display a significant change. The reason for this is that we are having significantly more demand than previous years and significantly more flows from process center. Therefore, we need to switch our storage to a position that can hold more demand and at the same time process stations such as H, I, J should be near the storage since many parts will finish their process at those stations, meaning that the flow from H, I and J to storage will be higher. In designing this way, we can save more traveling distance from those end stations to storage and possibly reduce handling cost at the end.

We have also determined the coordinates of each sub center in one fractal center. We use them to determine the total distances traveled in the warehouse as done in task 2. We use the travel distance as well as the speed to determine the number of handlers as in task 2.

	2026	2027	2028	2029
handlers	1610	1991	1879	1712

Table 26: Number of handlers in the fractal organization

For each year, estimated inter-center flows and travel distances and traffic

Each center operates individually, so we don't have any inter center flows.

Yearly and overall, expected key factory performance indicators

Let's look at the costs we need to hold on every year and see how they evolve comparing to the demand.

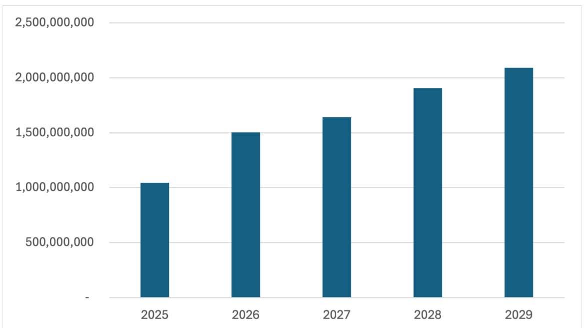


Figure 80: Total costs for the fractal organization

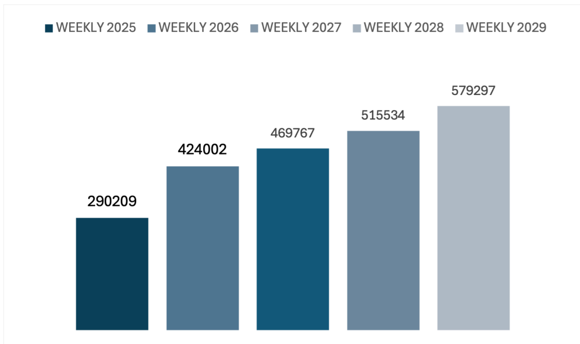


Figure 81: Maximum total demand

To be able to compare more efficiently these two datas, let's consider the percentage of variation in costs and demand from one year to another (figure 82).

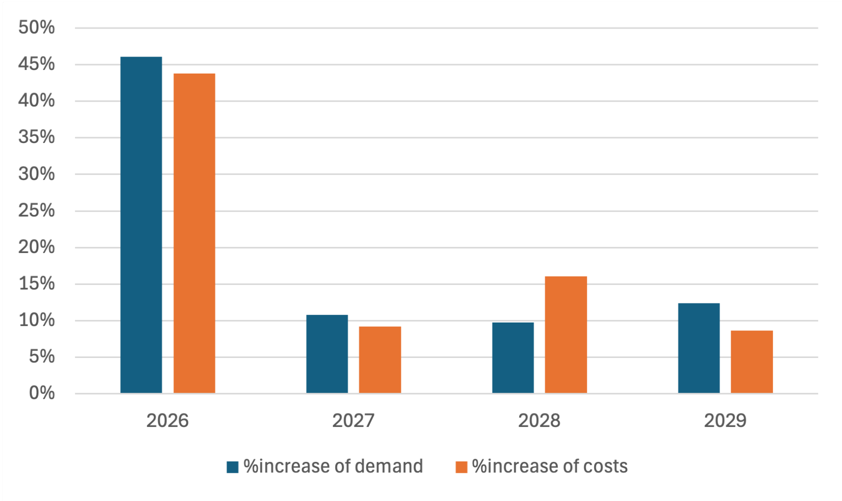


Figure 82: Variation of the demand and costs for each year

We notice that our costs do not increase the same way as the demand. When the costs increase less than the demand, this means we will probably make profit. This is the case for 2026, 2027, 2029. But in 2028, our costs raise more than the demand. So we might need to increase prices to still make profit.

Let's look at the number of workers every year in figure 83

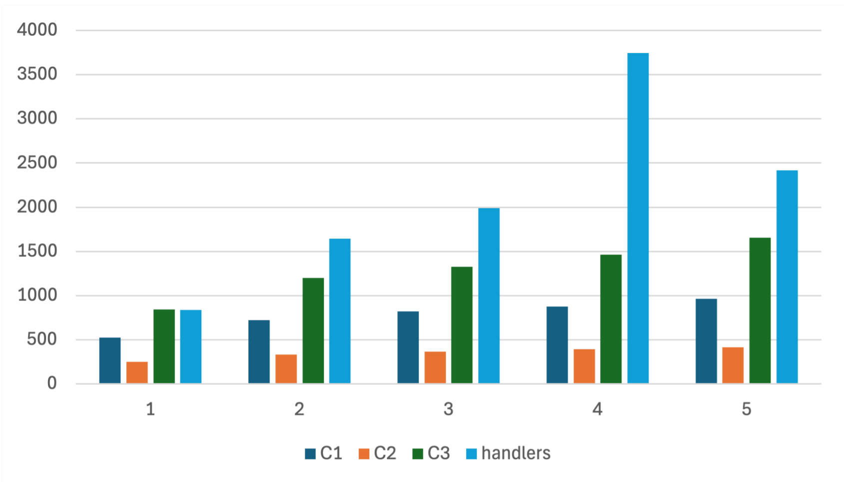


Figure 83: Number of workers for each year in the fractal organization

The number of workers C1, C2, C3 increases slowly every year following the increase in the number of equipments. However the number of handlers raises exponentially from 2025 to 2028 and decreases in 2029. This is because we have done some relayouts and increased the number of machines within one center. In 2029, the relayout is very different from the previous years, reducing travel distances and so the number of handlers as well.

Guillaume Eymery - Nathalia Gonzalez - Yong Suk Hong - Yaojie Huang - Anjulakshmi Karthikeyan - Louise Lacroix

We have decided to keep on having a fractal center with 4 centers but it actually might have been better to create a first layout with 12 fractals for instance, having only to add one or more centers every year when we needed to expand, instead of changing the total layout every year. This would have saved us some handlers and might have reduced total costs.

Yearly and overall expected investment and direct operating costs

Considering that the area of the building cannot change, we will consider the biggest area required, so the one of 2029 since it is when the demand is bigger. The final building cost at the end of the year 2029 is calculated by the following:

Attribute	Value	Unit
Length (l)	826	ft
Width (w)	425	ft
Surface Area	351,050	ft^2
Cost	**87,762,500**	**$**

Table 27: Fractal Organization Dimensions and Costs

Attributes	2025	2026	2027	2028	2029
Length(ft)	502	678	810	719	826
Height(ft)	322	390	366	374	425
Area(ft^2)	161,644	264,420	296,460	268,906	351,050
Total Building Cost	$40,411,000	$66,105,000	$74,115,000	$67,226,500	$87,762,500
Yearly Increment Cost	$-	$25,694,000	$8,010,000	$-	$20,536,000

Table 28: Yearly Incremental Building Cost for Fractal Layout

Since demand for each process station for each year is different, it is essential that we relocate process stations in each fractal each year to reach maximum efficiency. Therefore, we will have different relocation cost for each year:

	Number of machines to relocate in one center	Total cost of relocation($)
A	0	0
B	0	0
C	0	0
D	4	160,000
E	11	2,200,000
F	8	1,600,000
G	4	800,000
H	15	6,000,000
I	10	4,000,000
J	3	24,000
K	12	96,000
L	20	160,000
Total	**87**	**15,040,000**

Table 29: Relocation Cost for Fractal Organization in 2026

	Number of machines to relocate in one center	Total cost of relocation($)
A	0	0
B	0	0
C	0	0
D	4	160,000
E	13	2,600,000
F	13	2,600,000
G	0	0
H	6	2,400,000
I	16	6,400,000
J	6	2,400,000
K	4	32,000
L	17	136,000
M	27	216,000
Total	**106**	**16,944,000**

Table 30: Relocation Cost for Fractal Organization in 2027

	Number of machines to relocate in one center	Total cost of relocation($)
A	6	240,000
B	19	760,000
C	5	200,000
D	4	160,000
E	3	600,000
F	3	600,000
G	2	400,000
H	11	4,400,000
I	0	0
J	0	0
K	5	40,000
L	18	144,000
M	29	232,000
Total	**105**	**7,776,000**

Relocation Cost for Fractal Organization in 2028

	Number of machines to relocate in one center	Total cost of relocation($)
A	6	240,000
B	20	800,000
C	5	200,000
D	4	160,000
E	17	3,400,000
F	16	3,200,000
G	6	1,200,000
H	15	600,000
I	20	800,000
J	11	4,400,000
K	5	400,000
L	8	640,000
M	19	1,520,000
Total	**152**	**27,856,000**

Table 31: Relocation Cost for Fractal Organization in 2029

We did all other cost category computations with same methodologies mentioned in previous task, this is the total cost metrics (in millions) for our fractal organization from 2026 to 2029.

year	installation cost with depreciation	operator cost	handlers cost	material price	building costs	total cost
2026	37	340	129	970	26	1,502
2027	40	377	156	1,067	8	1,648
2028	34	413	294	1,163	0	1,904
2029	57	461	190	1,295	20	2,023

Table 32: 2025 Total Costs for the fractal organization

Free-style factory design from task 2.h

Network organization

Knowing that products A6 to A8 uses the same machines and processes as the previous products. The network organization is not going to be impacted compared to the freestyle layout for the previous Task. However, the flow and the amount machines for each section will increase. Refer to Fig 48.

Yearly center-specific and overall resource requirements plan

This section will be similar to the others in this task. Once we computed the required number of parts per week to ensure production at a 99.5%, we may compute the required amount of machines for each year (knowing their weekly capacity).

Part	2026	2027	2028	2029
P1	47208	47436	47664	47547
P2	16615	17767	18919	20048
P3	14920	21144	27368	35541
P4	16175	16567	16959	17351
P5	14839	16331	17823	20227
P6	6623	7031	7440	7825
P7	18405	20333	22261	24567
P8	14466	19277	24087	30847
P9	14839	16331	17823	20227
P10	10186	10727	11269	11787
P11	24728	30881	37034	46534
P12	26640	30239	33837	39573
P13	16845	21714	26582	32975
P14	37918	38295	38671	39553
P15	9067	11826	14586	19294
P16	21223	21720	22218	22715
P17	16867	20621	24376	29780
P18	27804	30245	32686	35441
P19	36650	37609	38568	39907
P20	31984	33673	35363	37558

Table 33: Part Demand Forecast (2026-2029)

Below is the amount of machines required in 2026 & 2029 (see 2027 & 2028 in the Excel file). The last table represent the difference between the amount of machines in 2029 and 2026. This will help to have a better understanding on the evolution of the facility throughout the years, and enable us to dimension the layout in 2026 so that it could better integrate the new machines for the years to come.

2026	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 5**	**Step 6**	**Step 7**
A	11	12	0	0	0	0	0
B	41	10	29	0	0	0	0
C	0	5	7	6	0	0	0
D	0	11	35	21	29	0	0
E	43	0	13	0	0	0	0
F	13	31	10	0	0	0	0
G	0	11	7	5	2	0	0
H	0	33	0	26	7	9	0
I	0	0	10	24	15	17	6
J	0	0	2	18	40	20	34
K	9	6	4	0	0	0	0
L	36	21	18	0	0	0	0
M	0	23	38	59	0	0	0

Table 34: Steps distribution for 2026

2029	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 5**	**Step 6**	**Step 7**
A	12	12	0	0	0	0	0
B	52	11	29	0	0	0	0
C	0	7	12	6	0	0	0
D	0	26	43	27	29	0	0
E	67	0	21	0	0	0	0
F	16	39	16	0	0	0	0
G	0	17	9	7	3	0	0
H	0	43	0	34	8	17	0
I	0	0	11	42	23	17	11
J	0	0	4	20	68	27	35
K	12	7	5	0	0	0	0
L	41	33	20	0	0	0	0
M	0	25	53	69	0	0	0

Table 35: Steps distribution for 2029

2029-2026	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7
A	1	0	0	0	0	0	0
B	11	1	0	0	0	0	0
C	0	2	5	0	0	0	0
D	0	15	8	6	0	0	0
E	24	0	8	0	0	0	0
F	3	8	6	0	0	0	0
G	0	6	2	2	1	0	0
H	0	10	0	8	1	8	0
I	0	0	1	18	8	0	5
J	0	0	2	2	28	7	1
K	3	1	1	0	0	0	0
L	5	12	2	0	0	0	0
M	0	2	15	10	0	0	0

Table 36: Difference in # machines between 2029 and 2026

Yearly layout of each center and of the overall factory

In this section, will will show the yearly layout of the facility. The main hypothesis and difficulty in planning layouts throughout the years is that the walls cannot be extended. This would imply that the total amount of ground space will stay constant from 2026 to 2029. Secondly, we will try to save expenditures by reducing as much as possible the number of relocation of machines, therefore saving up to $ 50 k per relocated machine per year. This should explain the considerable amount of empty ground space remaining in the 2026 layout, which is filled up by 2029 (we used the previous table).
We have also taken into consideration the evolution of the amount of storage space throughout the year, as well as their cost (which will prove to be negligible):

Year	2026	2027	2028	2029
Total	248	275	307	344

Table 37: Number of Racks per year (2026-2029)

Yearly relayout of each center and of the overall factory

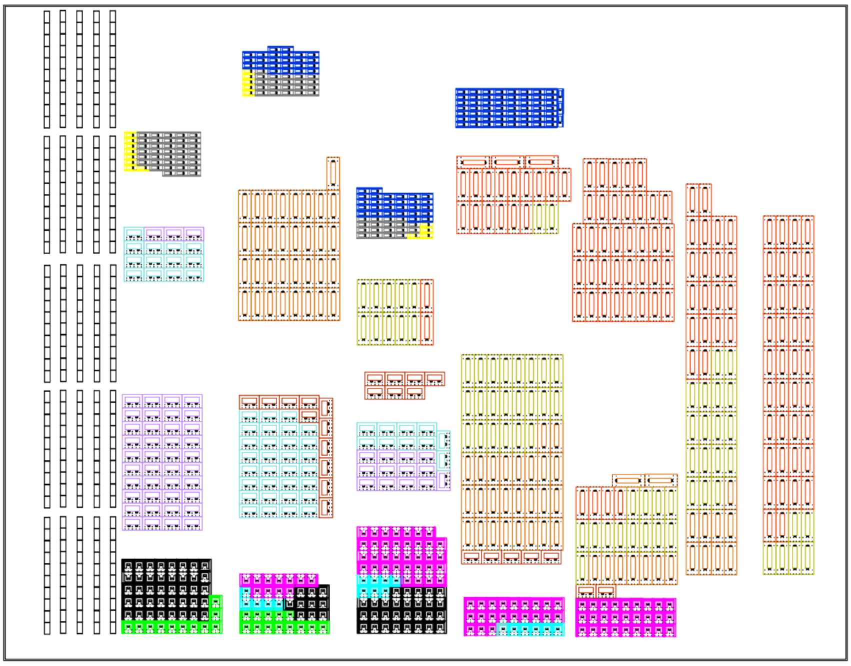


Figure 84: Facility Layout 2026 - Freestyle Layout

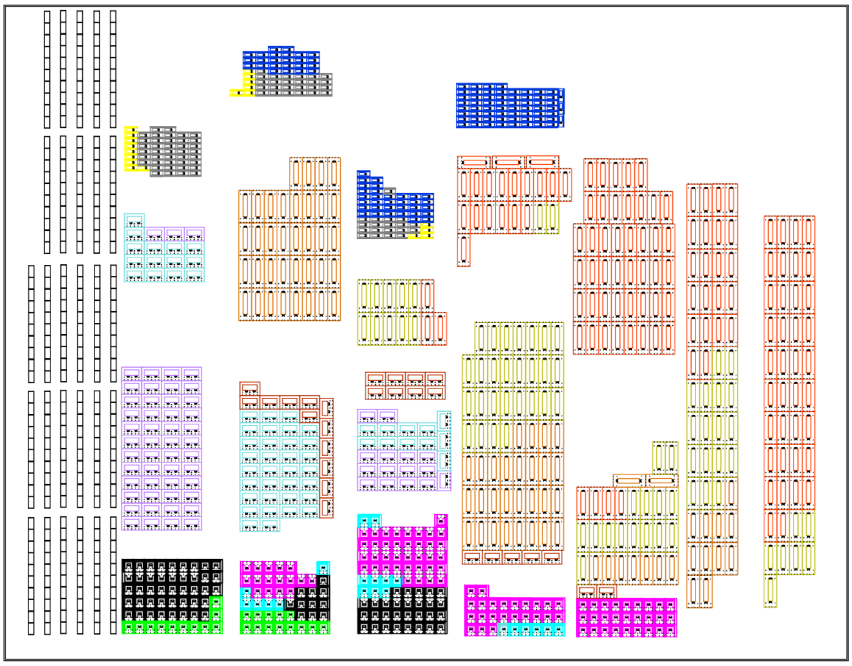


Figure 85: Facility Layout 2027 - Freestyle Layout

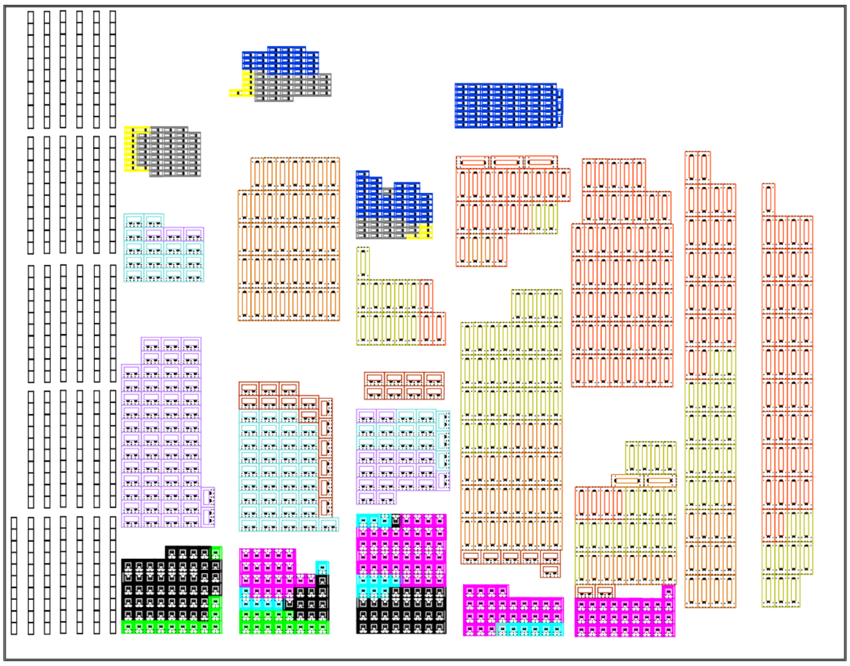


Figure 86: Facility Layout 2028 - Freestyle Layout

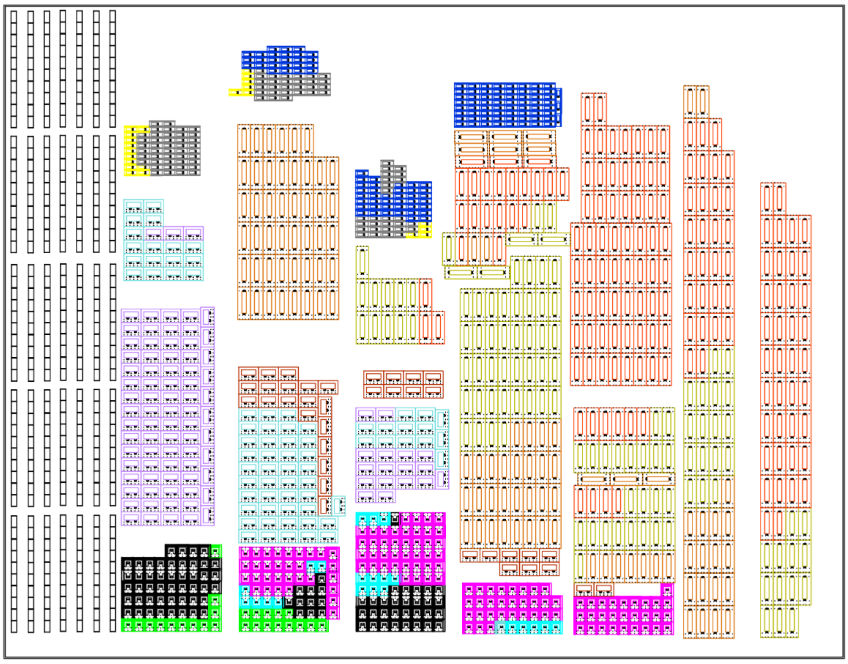


Figure 87: Facility Layout 2029 - Freestyle Layout

Key learning and potential improvements:

- Section 4 has been underestimated: despite the table of machines required for the following years, the section 4 got rapidly filled up with I & J machines. Even though all the machines were able to fit in their group, one might consider moving the M4 group as well as some I4 and J4 up a couple of feet. If this relocation is performed cleverly, the cost associated would be estimated at $ 1.2 M.

- Un-optimized storage space: the storage space takes up a lot of space in the facility. It might be relevant to change the storage method (2 lane deep, more stories). However, this would imply more expenditures since it would require an investment in warehousing equipments (forklifts...).

For each year, estimated intra-center work and flow patterns and utilization profile in each center

Even though its value will change over the years, the direction of the flow will remain the same from 2026 to 2029. The reason for this is because we tried as much as possible not to modify the 2026 (original) layout through the years. Similarly as in 2025, we can calculate the value of this flow for each section/group and represent it using a matrix:

		Step 2													
		A	B	C	D	E	F	G	H	I	J	K	L	M	S
Step 1	A	0	22798	16615	0	0	0	0	0	0	0	0	0	0	0
	B	47208	0	14839	14920	0	0	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	83354	60435	14466	0	0	0	0	0	0
	F	0	0	0	0	0	0	14839	21223	0	0	0	0	0	0
	G	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	J	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	K	0	0	0	0	0	0	0	0	0	0	0	44671	0	0
	L	0	0	0	0	0	0	0	0	0	0	31984	0	36650	0
	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 88: Matrix of Flow from S1 to S2 in 2026

The direction of the flow can be represented on the layout by different arrow patterns:

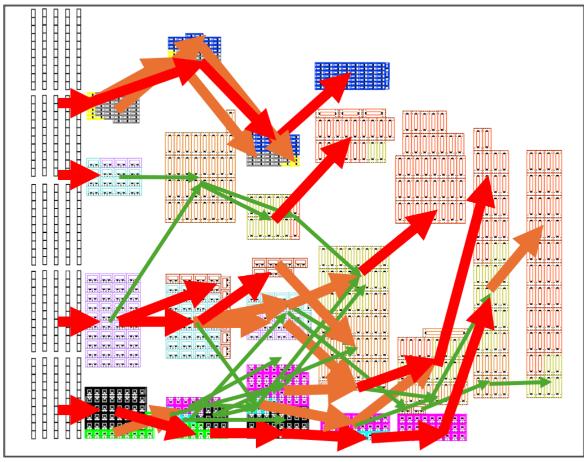


Figure 89: Intra center flows for 2026

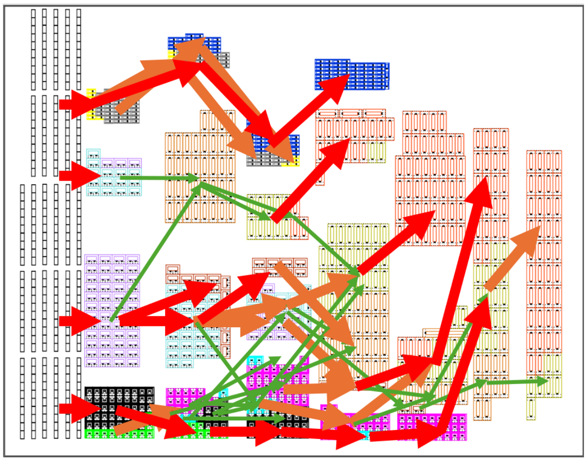


Figure 90: Intra center flows for 2027

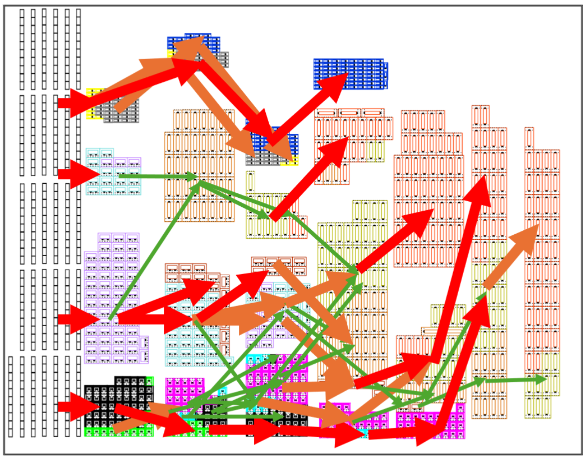


Figure 91: Intra center flows for 2028

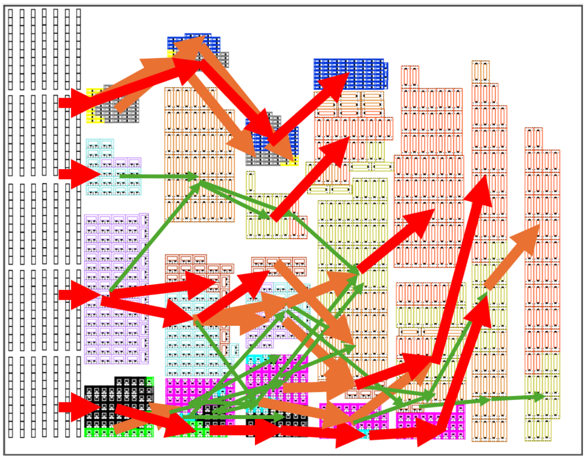


Figure 92: Intra center flows for 2029

For each year, estimated inter-center flows and travel distances and traffic

Similarly as in Task 2 in the freestyle layout, we determine the centroids for each section. We can then determine the length of a loop (path):

Center of Mass	X	Y
A1	124	86
B1	124	127
E1	124	273
F1	124	490
K1	79	612
L1	124	613
M2	245	706
L2	245	689
K2	209	690
H2	245	501
F2	245	265
G2	266	314
D2	245	135
C2	230	113
B2	280	111
A2	245	88
A1	124	86
Total (feet)		**1886**

Table 38: Center of Mass for Each Group with Total Distance in Feet

The rest of the distances are available in the Excel file at *Freestyle ORG 2026*. We see that the length of a loop increased in comparison to Task 2: this is because the facility is larger than the previous one.

Segment	Metric	Value	Unit
S1-S2	Walking Speed	18000	feet/hour
	Weekly Distance	432000	feet/week
	Loops	137	loops
	Weekly Load	2749	lb/week
	Daily Distance	10	miles/day
S2-S3	Walking Speed	18000	feet/hour
	Weekly Distance	432000	feet/week
	Loops	108	loops
	Weekly Load	2158	lb/week
	Daily Distance	10	miles/day
S3-S4	Walking Speed	18000	feet/hour
	Weekly Distance	432000	feet/week
	Loops	157	loops
	Weekly Load	3142	lb/week
	Daily Distance	10	miles/day
S4-S5	Walking Speed	18000	feet/hour
	Weekly Distance	432000	feet/week
	Loops	193	loops
	Weekly Load	3863	lb/week
	Daily Distance	10	miles/day
S5-S6	Walking Speed	18000	feet/hour
	Weekly Distance	432000	feet/week
	Loops	201	loops
	Weekly Load	4025	lb/week
	Daily Distance	10	miles/day
S6-S7	Walking Speed	18000	feet/hour
	Weekly Distance	432000	feet/week
	Loops	342	loops
	Weekly Load	6839	lb/week
	Daily Distance	10	miles/day

Table 39: Worker Walking KPI for Each Segment

Similarly as Task 2, the efficiency of the maintenance workers when walking their path is set to 60%, since they also have to pick up and deposit the parts in front of each machine

and navigate through the isles.
Now, we must calculate the weekly flow mass in each section. When dividing by 20 (max load per worker), we get the amount of loops per week that need to be done. Finally, when dividing this number by the length of a loop, we obtain the number of maintenance workers per section.

Segment	Total Massic Flow	Number of Loops/Week
S1-S2	1,492,221	74,611
S2-S3	1,492,221	74,611
S3-S4	1,296,817	64,841
S4-S5	918,931	45,947
S5-S6	179,213	8,961
S6-S7	117,884	5,894

Table 40: Total Massic Flow and Number of Loops per Week for Each Segment - 2026

Segment	Number of Employees
S1-S2	543
S2-S3	691
S3-S4	413
S4-S5	238
S5-S6	45
S6-S7	17
Storage-S1	543
Total	**2490**

Table 41: Number of Employees (Maintenance) for Each Segment - 2026

Yearly and overall expected investment, direct operating costs and KPIs

With all the information provided, we can estimate the yearly overall expected investment.

Table 42: Expenditures Summary in $M

	2026	2027	2028	2029
Equipment Amortization	$27.0	$29,4	$31,8	$35,1
Facility Expenditures	$94.9	-	-	-
Material Price	$967,2	$1,064	$1,161	$1,293
Operator Salary	$528,8	$533,8	$629,8	$703,9
Relocation Costs	$0	$0	$0	$0
Total	**$1,618**	**$1,627**	**$1,822**	**$2,032**

Table 43: Financial Data for 2026 to 2029, in Millions of Dollars

A KPI that may be interesting to calculate would be the Demand over Total Expenditures ratio:

Year	**2026**	**2027**	**2028**	**2029**
Demand/Expenditure	3.72×10^{-4}	4.25×10^{-4}	4.13×10^{-4}	4.15×10^{-4}

This ratio provides a insight into the efficiency of spending in generating demand.It essentially measures how much demand is generated for every dollar spent. A higher ratio suggests that expenditures are being used more effectively to stimulate demand, while a lower ratio could indicate less efficient spending or areas where cost savings may be possible. For organizations aiming to maximize their returns on investment, tracking changes in this ratio over time is crucial.

Observing this ratio across different years, as in this table, allows for benchmarking across time. For example, if the ratio increased from 2026 to 2027, it could imply that new strategies, investments, or operational changes made during that period positively impacted demand. Conversely, a declining ratio might indicate challenges or inefficiencies, prompting a deeper look into expenditures. In our case, this ratio is constant throughout the years. This shows that the expenses grows linearly as the demand increases.

This statement is verified by the following graph, showing the evolution of the demand (in product units) and yearly expenditures (in k$) throughout the years:

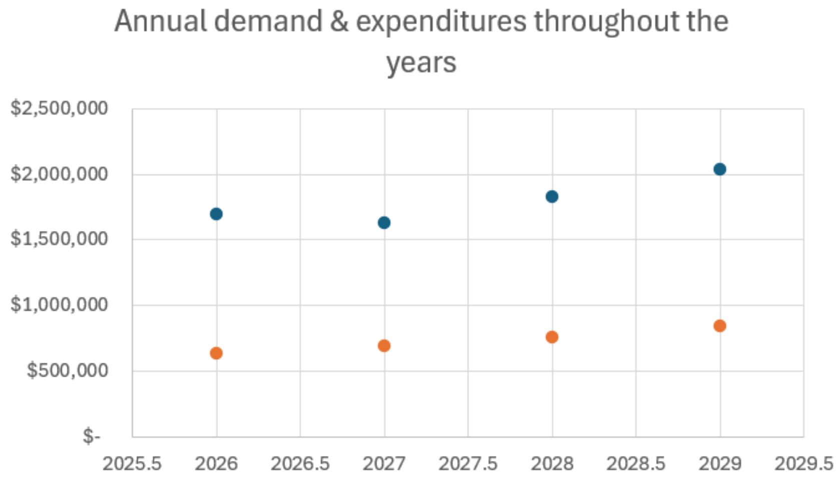


Figure 93: Demand (in product units) and yearly expenditures (in k$) throughout the years

Table 44: Evolution of Demand and Price

	2026-2027	**2027-2028**	**2028-2029**
Evolution of Demand	10%	9%	12%
Evolution of Price	-4%	12%	11%

The negative value for years 2026-2027 can be explained because their is no more building expenditures.

TASK 4

Let's compare the costs of each of our layouts from task 3. The results are displayed in figure 94.

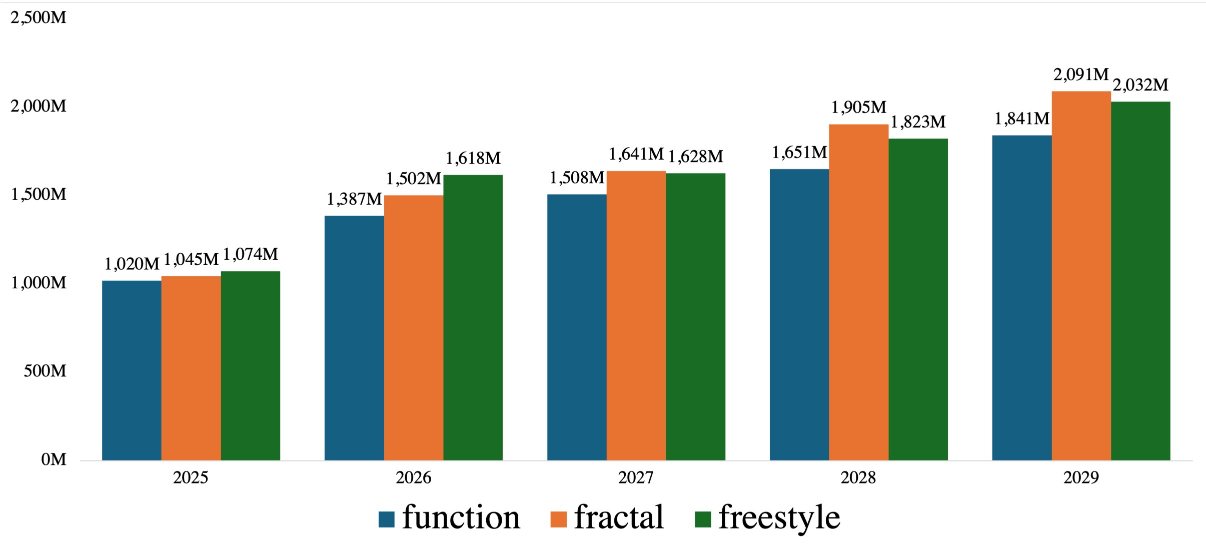


Figure 94: Total costs for each layout and each year

The function layout is always the cheapest option in this scenario. Nevertheless, the fractal layout is not a lot more expensive and actually about 30 millions a year are due to relocations and 200 millions to handlers cost in this type of layout while we allocate almost nothing to relocation in the function and handlers cost less than a hundred millions. So if we'd have better designed the fractal with more fractal centers and not having to relocate any of our equipment, fractal would have been the cheapest option. This makes sense since the fractal layout is the most adapted to expansion since theoretically we would just need to add some centers every year that we expand.

TASK 5: Key Learnings

- Layout Designs: the main purpose of this project is for us supply chain engineers to familiarize with various types of factory layouts and the trade-offs between them. In this project, we chose to do analysis for YubWeng's Factory on how well the factory performs(fulfill its yearly demand) when following function, parts, product, fractal and freestyle organization. After completing the analysis, we have a deeper understanding of the nuances between how each layout works. For instance, parts organization method propose that we create 20 different part centers that can create different parts. Therefore, the end products for this layout would be parts of certain product, without organization. On the other hand, in part organization, we are taking the extra step of organizing the parts products in a way so that our shipment to our client will include all parts needed for assembling a specific product.

- Cost Trade-offs: to create decision metrics in determining which layout would be the best in the case of YubWeng's Factory, we need to understand the intuition behind different type of costs. In the analysis we did, we had implemented factory building costs, process station installation costs, operator costs, material costs and racking costs. Every layout has its own advantage, but usually it would come with a price. For instance, parts organization significantly decreases handler costs due to the elimination of inter-center travels but its building costs would be significantly larger since part centers would take up more space. Rigorously analyzing cost trade-offs helped us develop better intuition in supply chain operations.

- Usage of Engineering Tools: before trying this project, none of our teammates had experience in engineering design software. To do this project, we decided to learn AutoCAD Autodesk to help visualizing our design principles. This experience has been extremely rewarding and I am sure that it is going to help us in the future along our supply chain engineering journey.