IE 312

FACILITIES DESIGN & PLANNING

Project Report

Part - II

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First look and first analysis of the project made by all 3 together. Egbelu Paper is investigated, all methods are examined, and calculations are executed. Task distribution is made afterward. Explanations of the 4 methods and their calculations are made by Saime. Melis focused on the discussion about the pros and cons of AGV use. Lastly, Kutay wrapped up the report by adding a comparison between methods and the conclusion part.

1) Introduction and Discussion About the AGV Use

With the development of technology and the increasing demand for new products, production facilities are getting larger and more complex. While this is the case, intelligent methods are required for transporting materials between workstations. There are several ways of conveying parts among departments, such as handcarts, forklifts, and automated guided vehicles which are investigated further in this report with a hypothetical facility layout (Appendix A, Figure 1).

Automated guided vehicles (AGVs) are automated vehicles that automatically transport products or materials through a manufacturing plant or warehouse. They follow a marked line on the floor in the facility or use some different navigation method. In the last century, the use of AGVs in manufacturing plants is skyrocketed. While the advantages of using AGV systems are obvious, the downsides of it cannot be denied.

To start with, one can maintain that using AGV systems reduce labor costs. Since AGVs can be replaced with some employees such as facility operators, the costs incurred as labor salaries will be decreased (Chris Benevides, 2020). In this way, work safety is also enhanced. In the same manner, AGVs can work longer hours than regular shifts of employees (Faieza et al., 2016). Thereby, the production volume can be increased with less labor cost.

Secondly, AGVs can be advantageous in terms of the space requirements in the facility. For example, using movable AGVs instead of constructing a conveyor in the facility is more desirable, especially in small facilities with limited space capacity.

Among the advantages, the flexibility of AGV systems should not be overlooked. Other systems, especially conveyors are inadequate in adapting a new route in the facility. However, AGVs can easily learn and adapt to a change in the facility since they are automated via some programming language (Faieza et al., 2016).

Last but not least, AGVs are very useful in inventory tracking. As Chris Benevides simply puts it: “Humans make mistakes”. AGVs can take part in the human element's potential for faulty processes, decreasing waste and increasing production, and improving the accuracy and productivity of operations (Chris Benevides, 2020).

While the upsides of AGV systems are obvious, there also exist some disadvantages. First of all, the high costs of initial investment are inevitable as with any new technology investment (Helen Adams, 2021). A well-prepared cost-benefit analysis should be made and fully understood before replacing to AGV system, which may also require some additional cost.

Another disadvantage rises as Faieza et al. discuss when AGVs are guided by optical or inductive guidelines. These rules are rigid when it comes to altering the routing and the requirement for installations on the ground. One main issue regarding this may be the fact that an AGV vehicle stops if it encounters an obstacle along its way and waits until the path is clear.

Lastly, using AGV vehicles may not be the best solution if the production process requires often changes. In a matter of minutes, a person can be briefed and change their work schedules. However, rerouting an AGV vehicle requires more effort and time.

2) Calculation of Automated Guided Vehicle Requirements

1st Method:

The general formula for the 1st case is as on right:

$$N = \left[2 \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{f_{ij} d(\beta_i, \alpha_j)}{V} + \sum_{i}^{n} \sum_{j}^{n} f_{ij} (t_l + t_u) \right] / (60T - t) e \quad (1)$$

Necessary elements to calculate the required number of vehicles are the flow matrix in a shift (16 hours), delivery to pick-up distance, the velocity of the vehicle, and load and unload times.

Below can be seen the flow matrix in a 16-hour period:

From-to Matrix	VTC1	UMC	CB	VMC	SHP	HMC	VTC2	Shipping	Total
Receiving	112	0	0	0	0	0	208	0	320
VTC1	0	0	0	32	80	80	0	0	192
UMC	0	0	0	0	0	0	80	0	80
CB	0	0	0	0	0	0	0	0	0
VMC	0	0	0	0	0	32	0	96	128
SHP	80	80	0	96	0	32	0	0	288
HMC	0	0	0	0	0	0	0	144	144
VTC2	0	0	0	0	208	0	0	80	288
Total	192	80	0	128	288	144	288	320	**1440**

Figure 1: From-to Matrix in a 16-hour period

Afterward, a comprehensive distance matrix consisting of distance from pick-up to delivery and distance from delivery to pick-up is calculated since delivery to pick-up distances will be used in the other methods:

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

Figure 2: Distance matrix including pick-up to delivery and delivery to pick-up distances.

Then, the distance matrix (from delivery to pick-up) is extracted from the matrix in Figure 2 as below:

Delivery to Pick-up	LOC1	LOC2	LOC3	LOC4	LOC5	LOC6	LOC7	Shipping
Receiving	0	0	0	0	0	0	0	0
LOC1	6	18	36	24	42	30	36	0
LOC2	30	6	36	12	42	30	24	0
LOC3	12	24	6	18	36	24	30	0
LOC4	36	48	30	6	36	24	18	0
LOC5	18	30	12	24	42	30	36	0
LOC6	30	42	24	36	18	6	48	0
LOC7	36	48	30	42	24	12	6	0

Figure 3: Matrix showing delivery to pick-up distances.

Afterward, total distance of the loaded travel matrix is calculated by summing the products of the from-to matrix (Figure 1) and delivery to pick-up distance matrix (Figure 3).

Loaded Travel	VTC1	UMC	CB	VMC	SHP	HMC	VTC2	Shipping	
Receiving	0	0	0	0	0	0	0	0	0
VTC1	0	0	0	768	3360	2400	0	0	6528
UMC	0	0	0	0	0	0	1920	0	1920
CB	0	0	0	0	0	0	0	0	0
VMC	0	0	0	0	0	768	0	0	768
SHP	1440	2400	0	2304	0	960	0	0	7104
HMC	0	0	0	0	0	0	0	0	0
VTC2	0	0	0	0	4992	0	0	0	4992
									21312

Figure 4: Matrix showing the total distance of loaded travels

The velocity of the vehicle and load and unload times are obtained from the problem definition as follows:

$t_u + t_l$	1	**T**	16	**V**	20	**e**	0,85

By plugging the necessary elements calculated in Figure 1, Figure 2, Figure 3, Figure 4, and data from the problem definition into the formula (1), the equation below is obtained:

$$\frac{\left(2\cdot\frac{21\,312}{20}+1\,440\cdot 1\right)}{(60\cdot 16-60)\cdot 0.85} = 4.668235294$$

This result will be rounded up to 5, and it is concluded that **the number of required AGVs is 5 according to the first method.**

2nd Method:

In this method, $\overline{D}$, t_A, and $\bar{t}$ need to be calculated for the required number of AGV formulas. $\overline{D}$ is calculated via formula (2) below.

$$\overline{D} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} f_{ij} d(\beta_i, \alpha_j)}{\sum_{i=1}^{n}\sum_{j=1}^{n} f_{ij}}. \qquad (2)$$

The formula (2) uses delivery to pick-up distance matrix which is extracted from Figure 2 as in Figure 3, and the from-to-flow matrix in Figure 1. In this way, the total distance of loaded travels is obtained as in Figure 4. Therefore, $\overline{D}$ is calculated as 21312/1440 = 14.8.

$$t_A = \overline{D}/V. \qquad (3)$$

Then, t_A is calculated by dividing $\overline{D}$ = 14.8 by the velocity given in the problem definition as 20. Therefore, t_A is 14.8/20 = 0.74.

Finally, $\bar{t}$ is calculated with the formula below where b is the blocking time factor, c is the delay factor and e is the efficiency given in the problem definition.

$$\bar{t} = \frac{(1+b+c)t_A}{e} + t_l + t_u \qquad (4)$$

With the formula (4), $\bar{t}$ is calculated as 1.925.

The number of vehicles is then given by the formula below:

$$N = \left(\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} f_{ij}}{T}\right) \Bigg/ \frac{60}{\bar{t}} \qquad (5)$$

When the necessary elements calculated above are plugged into the formula (5), the equation below is obtained, which will be rounded up to 3.

$$\frac{\left(\frac{1440}{16}\right)}{\left(\frac{60}{1.925}\right)} = 2.8875$$

It can be concluded that **the number of required AGVs with the 2nd method is found as 3.**

3rd Method:

For the 3rd method, f_i is the net traffic flow into a work center, D_1 which denotes the total distance covered by empty runs between work centers, D_2 represents the distance due to empty vehicle transfer within work centers, and D_3 denotes loaded runs between work centers need to be calculated.

First, f_i needs to be calculated to obtain D_1 according to the formula below:

$$f_i = \sum_{j=1}^{n} f_{ji} - \sum_{j=1}^{n} f_{ij} \qquad (6)$$

Since f_i means the total net traffic flow into a work center, if it is positive, it implies that there are more deliveries into a work center than pick-ups.

Sum(f_i)	Receiving	VTC1	UMC	CB	VMC	SHP	HMC	VTC2	Shipping	
f_i	-320	0	0	0	0	0	0	0	320	**320**

Figure 5: Calculation of f_i, the total net traffic flow into a work center

Afterward, D1 is calculated according to the formula below.

$$D_1 = \left[\frac{\sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij} d(\beta_i, \alpha_j)}{\sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij}} \right] \left(\sum_{\forall i f_i > 0} f_i \right). \qquad (7)$$

For formula (7), the numerator represents the loaded travel that is calculated in Figure 4. The denominator represents the total flow as calculated in Figure 1.

When the necessary elements are plugged into the formula (7), D_1 can be found with the equation:

$$D_1 = (21312/1440)\ 320 = 4736$$

As a next step, D_2 is calculated with the formula below.

$$D_2 = \sum_{i=1}^{n} \left[\min\left\{ \sum_{j=1}^{n} f_{ij}, \sum_{j=1}^{n} f_{ji} \right\} d(\alpha_i, \beta_i) \right] \qquad (8)$$

To calculate D_2, pick-up to delivery distances need to be extracted from Figure 2. Figure 6 shows the distance matrix from pick-up to delivery:

Pick-up to Delivery	LOC1	LOC2	LOC3	LOC4	LOC5	LOC6	LOC7	Shipping	TOTAL
Receiving	12	24	6	18	36	24	30	42	192
LOC1	30	6	24	12	30	18	24	30	174
LOC2	30	42	24	36	30	18	12	30	222
LOC3	24	36	18	6	24	12	18	24	162
LOC4	24	36	18	30	24	12	6	24	174
LOC5	18	30	12	24	42	30	36	42	234
LOC6	18	30	12	24	6	30	36	6	162
LOC7	24	36	18	30	12	36	42	12	210
	180	240	132	180	204	180	204	210	

Figure 6: Matrix showing pick-up to delivery distances

min (fij, fji)	Receiving	VTC1	UMC	CB	VMC	SHP	HMC	VTC2	Shipping
f_i	0	192	80	0	128	288	144	288	0
Distance(p to d)	0	30	42	18	30	42	30	42	0
Product	0	5760	3360	0	3840	12096	4320	12096	0

Figure 7: Table showing the calculation of D_2 for the 3rd method

With the numbers given in the table in Figure 7, D2 is calculated as 41472.

$$D_3 = \sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij} d(\beta_i, \alpha_j) \qquad (9)$$

It can be seen from the formula (9) that D3 represents the loaded runs between work centers, which is calculated before in Figure 4, as 21312.

Finally, the formula for the number of required vehicles is given as follows:

$$N = \left[\frac{D_1 + D_2 + D_3}{V} + \sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij}(t_u + t_l) \right] \Big/ (60T - t) \qquad (10)$$

When the required elements are plugged into the formula (10), the below equation is obtained:

$$\frac{\left(\frac{(4736 + 41472 + 21312)}{20} + 1440 \right)}{(60 \cdot 16 - 60)} = 5.351111111$$

When this number is rounded up, the **required number of AGVs is founded as 6 by using the 3rd method.**

4th Method:

In the 4th method, to calculate the number of required vehicles, g_{ij}, the number of empty runs from center i to center j is calculated. By using g_{ij}, the total distance of empty runs that is represented by D'_{ij}, and the total distance of loaded runs is denoted as $\overline{D}_{ij}$ needs to be calculated.

g_{ij} is calculated by multiplying the expected number of deliveries to center i with the expected number of pick-ups from j over the expected total number of pick-ups as formula (11).

$$g_{ij} = \frac{\left(\sum_{k=1}^{n} f_{ki}\right)\left(\sum_{k=1}^{n} f_{jk}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} f_{ij}} \qquad (11)$$

In Figure 8, the numerator of the formula, the number of deliveries to center i, and the number of pick-ups from center j are calculated.

Work Center	Number of Deliveries	Number of Pick-ups
Receiving	0	320
VTC1	192	192
UMC	80	80
CB	0	0
VMC	128	128
SHP	288	288
HMC	144	144
VTC2	288	288
Shipping	320	0
		1440

Figure 8: The table composed of the expected number of deliveries to center i and the expected number of pick-ups from center j

Afterward, g_{ij} is calculated in a matrix called the “G matrix” in Figure 9.

Since the number of empty runs from center i to center j is obtained as g_{ij}, D'_{ij} which is the total distance of empty runs needs to be calculated with the formula (12).

$$D'_{ij} = g_{ij} d(\alpha_i, \beta_j) \qquad (12)$$

Since Figure 6 shows the distances from pick-up to delivery as the formula (12) required, D'_{ij} can be calculated easily in Figure 10.

D'	VTC1	UMC	CB	VMC	SHP	HMC	VTC2	Shipping
Receiving	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
VTC1	768,00	64,00	0,00	204,80	1152,00	345,60	921,60	0,00
UMC	320,00	186,67	0,00	256,00	480,00	144,00	192,00	0,00
CB	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
VMC	409,60	256,00	0,00	341,33	614,40	153,60	153,60	0,00
SHP	691,20	480,00	0,00	614,40	2419,20	864,00	2073,60	0,00
HMC	345,60	240,00	0,00	307,20	172,80	432,00	1036,80	0,00
VTC2	921,60	576,00	0,00	768,00	691,20	1036,80	2419,20	0,00

Figure 10: Calculation of D'_{ij}

It can be seen from the formula (13), $\overline{D}_{ij}$ the distances of loaded runs are calculated before in Figure 4.

$$\overline{D}_{ij} = f_{ij} d(\beta_i, \alpha_j) \qquad (13)$$

Figure 4 shows the $\overline{D}_{ij}$ calculation.

As the last element, D_{ij} is calculated with the formula (14).

$$D_{ij} = D'_{ij} + \overline{D}_{ij} \qquad (14)$$

Also, Figure 11 shows the D_{ij} values.

D	VTC1	UMC	CB	VMC	SHP	HMC	VTC2	Shipping	SUM
Receiving	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
VTC1	768,0	64,0	0,0	972,8	4512,0	2745,6	921,6	0,0	9984,0
UMC	320,0	186,7	0,0	256,0	480,0	144,0	2112,0	0,0	3498,7
CB	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
VMC	409,6	256,0	0,0	341,3	614,4	921,6	153,6	0,0	2696,5
SHP	2131,2	2880,0	0,0	2918,4	2419,2	1824,0	2073,6	0,0	14246,4
HMC	345,6	240,0	0,0	307,2	172,8	432,0	1036,8	0,0	2534,4
VTC2	921,6	576,0	0,0	768,0	5683,2	1036,8	2419,2	0,0	11404,8
									44364,8

Figure 11: Calculation of Dij according to formula (14)

Finally, the required number of AGVs is calculated with the formula (15) below.

$$N = \left[\frac{\sum_{i=1}^{n} \sum_{j=1}^{n} D_{ij}}{V} + \left(\sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij} \right) (t_u + t_l) \right] \Big/ (60T - t) \qquad (15)$$

When the required elements are plugged into the formula (15), the below equation is obtained.

$$\frac{\left(\frac{44364.8}{20} + 1440 \cdot 1 \right)}{60 \cdot 16 - 60} = 4.064711111$$

When the result is rounded up, it can be concluded that **5 is the required number of AGVs according to 4$^{\text{th}}$ method**.

Basic Calculation Differences

The first method and the second method do not consider the total distance covered by empty runs and empty runs caused by intra-work center empty vehicle assignments like in the D_1 and D_2 calculations of the third method. Also, 4$^{\text{th}}$ method considers the number of empty runs via g_{ij} calculation.

Another observation is that the efficiency "e" given in the problem definition as 0.85 is not used in 3$^{\text{rd}}$ method and 4$^{\text{th}}$ methods but used in the first and second methods.

3) Comparison and Conclusion

Since the focus of this project was to decide the number of AGVs that should be used in the given hypothetical flexible manufacturing system (FMS), 4 different methods in Egbelu's study are used in calculations.

The first case is based on total traveled time, total load pick-up, and delivery time. Then in the second case, the average required number of trips per hour is divided by the number of trips per hour to calculate the minimum necessary AGV number. While calculating these, per loaded trip, blocking time factor, idle time factor, efficiency, and load and unload times are taken into consideration. However, empty runes are ignored. In the third case, the total distance covered by empty runs between centers is determined in a more complex way by calculating inflows to each center. Then distance resulting from the empty vehicle transfer within centers is calculated. Finally, the distance of loaded runs between centers is used to calculate the total number of AGVs. On the other hand, efficiency is not considered in the formulation of the third case. The fourth case has the most complex calculations compared to the others. Empty runs are calculated via the g_{ij} matrix. In that matrix, the expected number of deliveries to i is multiplied by the expected number of pickups and divided by the expected total number of pickups. By using that matrix total distance of empty runs is calculated. The total distance incurred by loaded runs is summed up with the total distance of empty runs and the total distance traveled is obtained. Nevertheless, the fourth method also does not consider efficiency.

Before choosing one of these methods for a given FMS, an improvement is applied to the third and fourth methods with a heuristic approach. Results are calculated again by considering efficiency. As a result, the outcome of the fourth case remained the same while the number of AGVs in the third case increased by one. After efficiency is taken into consideration, it can be seen that method 3 and 4 is more compatible than method 1 and 2 for the given FMS. Ignoring empty runs is a solid reason not to use method 2 in that FMS. On the other hand, considering different delivery and pick-up stations in a method is crucial in such FMS. Therefore, the third method suits more than any other method. Forth method is also considering it but has so many complex calculations in it while the third method handles it more efficiently such as intra-workcenter empty vehicle assignment (which is used to calculate D_2 in the third method).

APPENDIX A

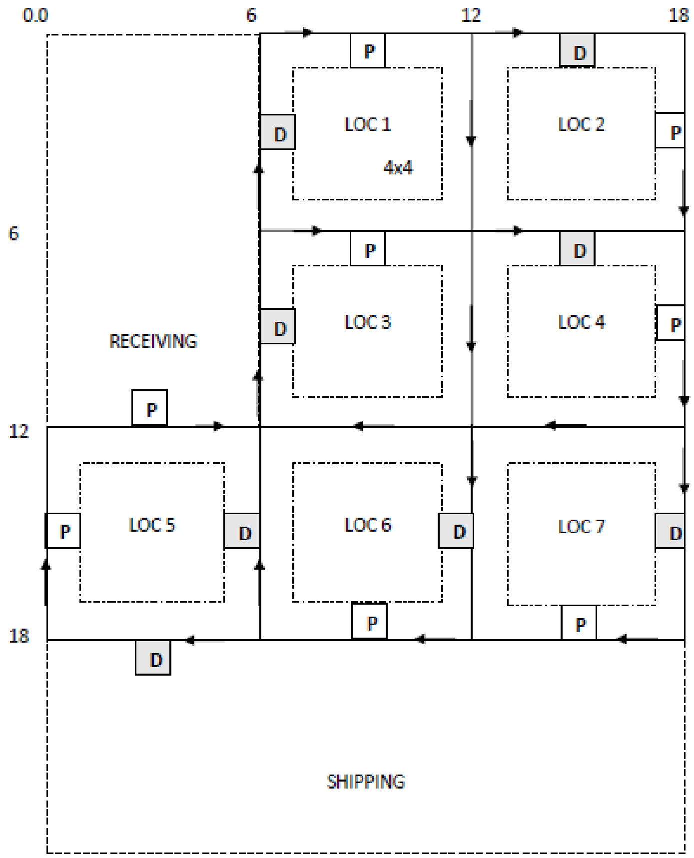

Figure 1: Hypothetical facility layout for calculations

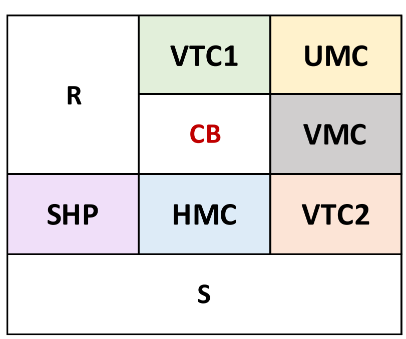

Figure 2 The locations of work centers

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