IE 312 PROJECT – PART 2 REPORT

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1- Introduction

Increasing efficiency has become one of the most important goals of all stakeholders in the manufacturing industry, which is constantly changing and transforming. One of the methods used to achieve this goal is to make transportation operations faster and more efficient by supporting them with advanced automation systems such as Automated Guided Vehicles.

This decision of using AGVS has been discussed a lot on several aspects; specifically whether AGVs should be used in facilities or not, and if so, how many of them should be used. The purpose of this paper is to determine the benefits and disadvantages of the use of AGVs for transportation in facilities, to understand when their use is necessary and when it is not, and to determine the number of AGVs that should be used when necessary.

In this paper, based on Egbelu's article "The Use of Non-Simulation Approaches in Estimating Vehicle Requirements in an Automated Guided Vehicle Based Transportation System", a wide range of analytical methods are used to calculate how many AGVs should be used in facilities and warehouses. By using the analytical results obtained from these methods together with the benefits and disadvantages of utilizing AGVs, detailed cost analyses were performed and the optimum vehicle number was determined accordingly.

The four methods mentioned in Egbelu's article are applied to a hypothetical manufacturing facility layout that can be seen in Figure 1. The flow and distance data that will be used can be seen in Table 1 in the appendix. Since there are some uncertainties in the given problem (such as the flow to the Central Buffer), some assumptions are made (the flow of CB is zero) during the calculations and the analytical results obtained are based on these assumptions in addition to the available data and the optimal result will be selected in accordance with them.

Figure1

Location	M/C
LOC1	VTC2
LOC2	UMC
LOC3	VTC1
LOC4	HMC
LOC5	CB
LOC6	SHP
LOC7	VMC

2.1 - Benefits and Disadvantages of Using AGVs

The authors will underline the pros and cons of the usage of AGVs, before starting the calculations with respect to the four methods.

Automated Guided Vehicles are portable and driverless robots that are primarily used for the transportation of materials inside a facility on certain paths that are determined by using a software system remotely. Their applications can be seen in many different areas, including -but not limited to- flexible manufacturing systems. Their usage comes with several advantages and disadvantages.

The economic advantage of using an AGV is a significant decrease in labor costs. Since AGVs replace some human jobs, this reduces the costs as the people who did the job of the AGV had several expenses such as salary, health insurance, and taxes. Also, in contrast with a human who works with a shift (of 8 hours generally) per day, an AGV can operate continuously as they are automated robots. On the other hand, the AGVs require a high initial investment cost, and therefore their purchase is economically feasible only when the profits of their utilization compensate for this fixed investment cost.

In addition to economic benefits, the AGVs have other benefits which make their usage superior compared to the conventional ways. As they are controlled by software and have sensors for safety precautions, they perform better than human operators in terms of safety. Also, they are capable of working in extreme conditions (for instance, in a place with high radiation levels where people can not work). By means of these additional benefits in terms of safety and efficiency, the AGVs decrease downtime and increase productivity, resulting in lower costs and higher profits.

On the other hand, the usage of AGVs has other drawbacks besides their high investment cost. From the operational perspective, they are only capable of performing repetitive operations. Thus, when the operations are unique or process changes occur frequently, it is more beneficial to use a human operator instead of an AGV. Also, the AGVs have some maintenance costs and they require trained personnel. In a workplace with a high turnover rate for jobs, training the workers frequently may cause extra costs.

To sum up; although the utilization of AGVs has certain indisputable advantages, the decision to use them should be made by analyzing the situation thoroughly, since they have some disadvantages as well. Based on this analysis, the optimum number of AGVs can be determined.

2.2 - Calculation of AGV Requirements - Method 1

This method assumes that the total distance covered by loaded trips is equal to the total distance covered by empty trips. This assumption makes the method's application easier and simplifies the calculations. According to this method, the number of required vehicles can be found by $N = \left[2 \sum_{i-1}^{n} \sum_{j-1}^{n} \frac{f_{ij} d(\beta_i, \alpha_j)}{V} + \sum_{i} \sum_{j} f_{ij}(t_l + t_u) \right] / (60T - t)e$

Based on this formula, N is calculated as 5.30824. Then, it is rounded up to find the required number of AGVs. In this case, it is equal to 6.

The main advantage of this method is its simplicity. It is very easy to apply the method and find the required number of AGVs. On the other hand, this simplicity is at the expense of a less accurate estimation, because of the assumption that made this method easy to use. In this method, it is assumed that the distance covered by empty runs is equal to the distance covered by loaded runs; whereas in reality, this is not very likely, which makes this method less advantageous.

2.3 - Calculation of AGV Requirements - Method 2

This method takes blocking and idle time factors as parameters to estimate AGV requirements. However, in order to start calculations, the total distance and number of trips must be known. Then, the Average Distance per Loaded Trip distance must be calculated. To acquire the Average Distance per Loaded Trip, the total distance must be divided by the total number of trips. The **Equation 2.1** is used in this manner and the Average Distance per Loaded Trip is calculated as 18.2 meters.

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

Equation 2.1

$$t_A = \overline{D}/V.$$

Equation 2.2

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

Equation 2.3

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

Equation 2.4

Then, Mean Travel Time Per Trip must be calculated. Since the calculation of the Mean Travel Time Per Trip does not include adjustments for blocking and idleness, only the Average Distance per Loaded Trip and the Average Speed of the Vehicle will be used. The Average Distance per Loaded Trip was already found as 18.2 meters, by using the equation **Equation 2.1**. To find Mean Travel Time Per Trip, Average Distance Per Trip must be divided by the Average Speed of the Vehicle, which is 20 m/min in this case. As a result, the Mean Travel Time Per Trip is estimated as 0.91 minutes. A mathematical representation of the calculation can be found in **Equation 2.2**

Mean travel time per trip affected by load&unload times per minute, idleness, and vehicle efficiency are calculated with **Equation 2.3**. Since vehicle collisions are avoided, the blocking factor is determined as 0. Additionally, every 16 hours, a vehicle must be recharged, which takes 1 hour. This information allows us to estimate the idleness to be 1/16 = 0.0625. Pickup and Delivery times are both stated as 0.5 minutes and Efficiency is stated as 85%. Using these parameters, the calculated Mean Travel Time is estimated as 2.1375 minutes.

In the final step of calculating the number of AGVs needed, the Number of Trips per hour must be divided by Mean Travel Time. The result is 3.20625, rounded up to 4. Thus, 4 AGVs will be sufficient to execute operations. **Equation 2.4 is used for the calculations.**

2.4 - Calculation of AGV Requirements - Method 3

For this method calculation of the net flow (inflow-outflow) is required. For a workcenter, the net flow is calculated by using **Equation 3.1**. If a workstation's net flow is greater than 0, it means there are more deliveries than pickups. If a workstation's net flow is lower than 0, it means pickups are greater than deliveries. For any Workstation, if the net flow is different from 0, it is assumed that there are empty runs on these workstations. And finally, if a workstation's net flow equals 0, inflows and outflows are leveled and there are no empty runs made from that Workstation.

As a first step for this method, net flows are calculated for each station. It can be seen from **Table 3.1** that Receiving and Shipping stations have non-zero net flows. In this case, it can be concluded that empty runs will occur in these stations. Then, the distance between these workstations must be calculated. This distance is referred to as D1 and by using **Equation 3.2** it can be calculated.

Location	Net Flow
Receiving	-20
VTC2	0
UMC	0
VTC1	0
HMC	0
CB	0
SHP	0
VMC	0
Shipping	20

Table 3.1

$$f_i = \sum_{j=1}^{n} f_{ji} - \sum_{j=1}^{n} f_{ij}$$

Equation 3.1

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

Equation 3.2

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

Equation 3.3

Secondly, if the delivery and the pickup points of a workcenter are at different locations, it will cause empty runs. Due to this difference, a new distance, D2 must be defined as the "empty interrun distance". D2 can be calculated with the formula **Equation 3.3**.

Finally, the total distance of loaded runs must be calculated via **Equation 3.4**. Then, the number of vehicles can be acquired by using the formula **Equation 3.5**. In this case, the required number of vehicles is calculated as 4,415. This means 5 AGVs are required for the operations after rounding up.

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

Equation 3.4

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

Equation 3.5

2.5 - Calculation of AGV Requirements - Method 4

In this method, it is needed to be considered that the machines are traveling distances in both loaded and empty runs. For this reason, the number of empty runs $g_{i,j}$ must be obtained priorly by multiplying the expected no. of deliveries to i with the expected no. of pickups from j and dividing it with the total no. of pickups as shown in Equation 4.1.

$$g_{ij} = (\text{Expected no. of deliveries to } i) \times (\text{Expected no. of pickups from } j) / (\text{Expected total no. of pickups} = \frac{\left(\sum_{k=1}^{n} f_{ki}\right)\left(\sum_{k=1}^{n} f_{jk}\right)}{\sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij}}$$

Equation 4.1 - The Number of Empty Runs $g_{i,j}$

Subsequently, the total distance of empty runs D' is calculated by multiplying the corresponding number of empty runs from one machine to another with the matching distances and summing them up as displayed in Equation 4.2, and 888,533 is the number it equates.

$$D' = \sum_{i=1}^{8} \sum_{j=1}^{8} g_{ij} d(\alpha_i, \beta_j)$$

Equation 4.2 - The Total Distance of Empty Runs D'

To find the number of AGVs, the total distance of empty runs D' is summed up with the total distance of loaded runs which is already computed in Method 1. Then it is divided by the speed of the vehicle. Afterward, the result of this division is added to the total no. of pickups which has a value of 90 multiplied by the delivery and pickup times sum which is 1. For unit conversion reasons, the obtained number is divided by 60, and for the general convention, the same operation is carried out for the efficiency parameter which is 0.85. The formula of this estimation of the number of AGVs is represented with Equation 4.3 and the outcome for N is 4,241 which leads up to a number of 5 AGVs needed to serve in the system.

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

Equation 4.3 - The Number of AGVs Estimated in Method 4

2.6 - Comparison of the Methods

Different approaches are made for the determination of the number of required AGVs by the 4 methods. A direct but not convincing vision is established by Method 1 with the indifference between the loaded and empty runs. Therefore the suggestion of this method is not preferable to follow. Moreover, the empty runs are replaced by the blocking factor and idle factor in Method 2. It is fair to say that the logic behind the assumptions of this factor, which are mentioned above, is superior to the previous method's way of thinking.

A resembling concept is shared by the last 2 methods. However, while a net traffic flow is calculated for every workcenter in Method 3, the fourth method is computing the number of empty loads for every route. Also, the distance caused by the empty travels between the delivery and pickup within a workcenter after a delivery has occurred is considered in Method 3 whereas Method 4 is only working with distances covered by empty and loaded trips between two different machines. Hence Method 3 is selected to be used and the number of AGVs that would be serving is 5 since the most comprehensive information is conveyed by the operations of this method.

3- Conclusion

All in all, AGV is an important technology that revolutionizes manufacturing and brings both benefits and drawbacks. The safety and durability of these vehicles cannot be ignored. However, the cost and operation aspects of AGVs may vary from facility to facility and it is not possible to make assumptions without acknowledging the mission specifically. For the best utilization of these vehicles, it is crucial to detect the number of vehicles needed in the facility. In this report, four methods are taken into account for this purpose and Method 3 is selected by virtue of providing a far-reaching approach when compared to its peers.

References

[1] Egbelu, P.J. (1987). The use of non-simulation approaches in estimating vehicle requirements in an automated guided vehicle-based transport system. Material Flow, 4, 17-32.

[2] Benedives, Chris (2020), The Advantages and Disadvantages of Automated Guided Vehicles (AGVs), Conveyco. https://www.conveyco.com/blog/advantages-disadvantages-automated-guided-vehicles-agvs/ (accessed May 15th, 2023)

[3] AGV Advantages and Disadvantages, Handling. https://www.handling.com/agv-advantages-and-disadvantages (accessed May 15th, 2023)

Appendix

Table 1: Flow, Distance, Cost Matrices, and Result found by Method 1.

From-to Matrix	VTC2	UMC	VTC1	HMC	CB	SHP	VMC	Shipping	Row Totals
Receiving	7	0	13	0	0	0	0	0	20
VTC2	0	0	0	5	0	5	2	0	12
UMC	0	0	5	0	0	0	0	0	5
VTC1	0	0	0	0	0	13	0	5	18
HMC	0	0	0	0	0	0	0	9	9
CB	0	0	0	0	0	0	0	0	0
SHP	5	5	0	2	0	0	6	0	18
VMC	0	0	0	2	0	0	0	6	8
								Sum -->	**90**

fi,j d(βi,αj)	VTC2	UMC	VTC1	HMC	CB	SHP	VMC	Shipping	Row Sum
Receiving	84	0	78	0	0	0	0	0	162
VTC2	0	0	0	90	0	90	48	0	228
UMC	0	0	120	0	0	0	0	0	120
VTC1	0	0	0	0	0	156	0	120	276
HMC	0	0	0	0	0	0	0	216	216
CB	0	0	0	0	0	0	0	0	0
SHP	90	150	0	48	0	0	216	0	504
VMC	0	0	0	60	0	0	0	72	132
								Sum -->	**1638**

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

Variables	Values
V	20
T	16
t	60
e	0,85
t_l	0,5
t_u	0,5

Result:	5,308235	= 6 AGVs

Table 2: Tables for Method 2

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

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

Total Distance	1638	
Number Of Trips(Flows)	90	
Average Distance Per Loaded Trip	18,2	
Mean Travel Time Per Trip	0,91	
Load, Unload, Blocking And Idleness	2,1375	
Number Of Vehicles	3,20625	Rounded Up To : 4 AGVs

AGV Specifics		Unit
Daily Availability	16	hours/day
Efficiency	0,85	percentage
Speed	20	m/min
Battery Operatic	0,06	1hr recharge/16hrs
Pickup Time	0,5	minute
Delivery Time	0,5	minute

Table 3: Tables for Method 3

VTC2	UMC	VTC1	HMC	CB	SHP	VMC	Shipping	
7	0	13	0	0	0	0	0	20
0	0	0	5	0	5	2	0	12
0	0	5	0	0	0	0	0	5
0	0	0	0	0	13	0	5	18
0	0	0	0	0	0	0	9	9
0	0	0	0	0	0	0	0	0
5	5	0	2	0	0	6	0	18
0	0	0	2	0	0	0	6	8
12	5	18	9	0	18	8	20	

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

Location	Net Flow
Receiving	-20
VTC2	0
UMC	0
VTC1	0
HMC	0
CB	0
SHP	0
VMC	0
Shipping	20

Location	Distance Between Pickup & Delivery Points
Receiving	0
VTC2	6
UMC	6
VTC1	6
HMC	6
CB	39
SHP	6
VMC	6
Shipping	0

Location	Flows
Receiving	0
VTC2	12
UMC	5
VTC1	18
HMC	9
CB	0
SHP	18
VMC	8
Shipping	0

D1	D2	D3	Number Of AGVs	Rounded Up To
364	420	1638	4,415163399	5 RGVs

AGV Specifics		Unit
Daily Availabil	16	hours/day
Efficiency	0,85	percentage
Speed	20	m/min
Battery Operati	0,06	1hr recharge/16hrs
Pickup Time	0,5	minute
Delivery Time	0,5	minute

Table 4: Flow, Distance & Number of Empty Runs Matrices, and Result found by Method 4.

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

Workcenter	No. of Deliveries	No. of Pickups
Receiving	0	20
VTC2	12	12
UMC	5	5
VTC1	18	18
HMC	9	9
CB	0	0
SHP	18	18
VMC	8	8
Shipping	20	0

Total Number of Pickups
90

stance Mat	LOC1	LOC2	LOC3	LOC4	LOC5	LOC6	LOC7	Shipping
Receiving	12	24	6	18	36	24	30	36
LOC1	0	6	24	18	30	18	24	30
LOC2	30	0	24	36	30	18	12	30
LOC3	24	36	0	6	24	12	18	24
LOC4	24	36	18	0	24	12	6	24
LOC5	18	30	12	24	0	30	36	42
LOC6	18	30	12	24	6	0	36	6
LOC7	24	36	18	30	12	36	0	12

	VTC2	UMC	VTC1	HMC	CB	SHP	VMC	Shipping
Receiving	0	0	0	0	0	0	0	0
VTC2	1,6	0,66666667	2,4	1,2	0	2,4	1,06667	0
UMC	0,666666667	0,27777778	1	0,5	0	1	0,44444	0
VTC1	2,4	1	3,6	1,8	0	3,6	1,6	0
HMC	1,2	0,5	1,8	0,9	0	1,8	0,8	0
CB	0	0	0	0	0	0	0	0
SHP	2,4	1	3,6	1,8	0	3,6	1,6	0
VMC	1,066666667	0,44444444	1,6	0,8	0	1,6	0,71111	0
Shipping	2,666666667	1,11111111	4	2	0	4	1,77778	0

stance Mat	LOC1	LOC2	LOC3	LOC4	LOC5	LOC6	LOC7	Shipping	
Receiving	84	0	78	0	0	0	0	0	162
VTC2	0	0	0	90	0	90	48	0	228
UMC	0	0	120	0	0	0	0	0	120
VTC1	0	0	0	0	0	156	0	120	276
HMC	0	0	0	0	0	0	0	216	216
CB	0	0	0	0	0	0	0	0	0
SHP	90	150	0	48	0	0	216	0	504
VMC	0	0	0	60	0	0	0	72	132
	174	150	198	198	0	246	264	408	1638

	VTC2	UMC	VTC1	HMC	CB	SHP	VMC	Shipping	D'
Receiving	0	0	0	0	0	0	0	0	888,533
VTC2	0	4	57,6	21,6	0	43,2	25,6	0	
UMC	20	0	24	18	0	18	5,33333	0	
VTC1	57,6	36	0	10,8	0	43,2	28,8	0	
HMC	28,8	18	32,4	0	0	21,6	4,8	0	
CB	0	0	0	0	0	0	0	0	
SHP	43,2	30	43,2	43,2	0	0	57,6	0	
VMC	25,6	16	28,8	24	0	57,6	0	0	
Shipping	0	0	0	0	0	0	0	0	

Effeciency	Speed m/min	Pickup Time	elivery Time
0,85	20	0,5	0,5

N	Needed N
4,241699346	5