IE 312: Facility Design & Planning

Project - Part 2

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Estimating the AGV Requirements for a Hypothetical Flexible Manufacturing System

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CONTENTS

0. Information Page

Hüseyin Emre BACAK - 2021402279 1/3

- ➔ Offered different approaches for developing 4 methods to calculate AGV requirements
- ➔ Writing the parts **Introduction**, **Advantages and Disadvantages of Using AGVs**, **Comparison of Methods**, **Conclusion** in report
- ➔ Helped the team for constructing necessary tables for parameters in each method
- ➔ Helped the team in calculation steps of each method

Tevfik Buğra TÜRKER - 2019402120 1/3

- ➔ Writing the parts **Requirements Calculation - Case 1** and **Case 2**
- ➔ Designing the **Tables** from **1** to **4**
- ➔ Preparation of the Excel file (first 4 pages)
- ➔ Helping the team in calculation steps of each method

Ömercan Mısırlıoğlu - 2020402261 1/3

- ➔ Writing the parts **Requirements Calculation - Case 3** and **Case 4**
- ➔ Designing the **Tables** from **5** to **8**
- ➔ Preparation of the Excel file (the last page)
- ➔ Helping the team in calculation steps of each method

Abstract

It is inevitable to state that developing economic and time-wise efficient ways of material-handling functions have been an essential part of manufacturing and warehouse facilities. In the last few decades, thanks to technological improvements, automated guided vehicles came into sight and became one of the most intriguing topics in the manufacturing area. To give more details, AGV is a type of mobile robot that follows a predetermined path or set of instructions for transportation or handling tasks within a manufacturing, warehouse, or distribution facility. AGVs are equipped with sensors and navigation systems that allow them to navigate around their environment and avoid obstacles. AGVs are costly items for these stated reasons. Therefore, it is a vital decision for manufacturing and warehouse owners whether or not AGVs are needed in their facilities. Even when the decision of using AGVs is taken, another crucial aspect is the quantity of AGVs to be used. Therefore, this paper aims to justify the usage of AGVs in manufacturing and warehouse facilities by suggesting different methods to decide on the quantity to be used.

1. Introduction

AGV stands for Automated Guided Vehicle. They are often used to move materials or products from one location to another within a facility, and can operate in a variety of environments, including warehouses, factories, and distribution centers. AGVs can be programmed to perform a wide range of tasks, including loading and unloading materials, picking and packing orders, and transporting goods between different areas of a facility. They are important tools in many industries and can help improve efficiency and reduce the need for manual labor. These perks of AGVs come with monetary costs, so an engineering economy analysis should be conducted to make a “go-no go” and amount of AGV decision for a manufacturing or warehouse facility.

In his paper, “The Use of Non-Simulation Approaches in Estimating Vehicle Requirements in an Automated Guided Vehicle Based Transportation System”, Egbelu came up with 4 different analytical solutions for calculating the amount of AGVs required in a facility. Although using simulation to solve this problem is the most reliable method, it is very expensive and time-consuming[1].

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[1] Egbelu, Pius J.. “The use of non-simulation approaches in estimating vehicle requirements in an automated guided based transport system.” (1987).

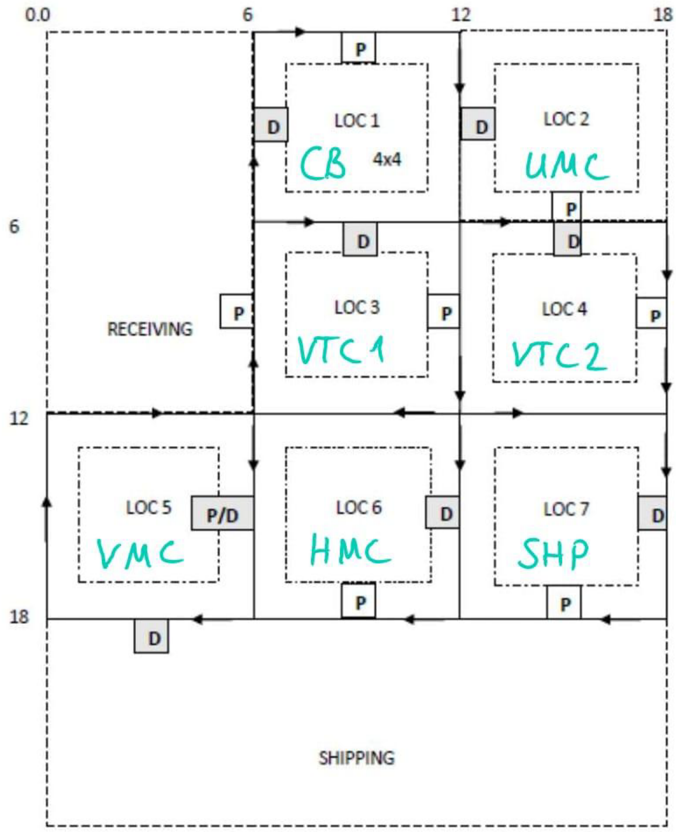

Figure 1. Given hypothetical facility

A hypothetical facility to perform these 4 analytical solutions is given in **Figure 1**. Sets of values and explanations of the variables used in these analytical solutions are given in **Table 1**. Distance matrix of the work centers and flow between work centers are also given in **Table 2.** and **Table 3.** It is important to state that distances between work centers are assumed to be rectilinear and flow between work centers are deterministic, which causes all flows from/to the central buffer to be zero. The best of these 4 analytical methods is going to be chosen by comparing their compatibility with these assumptions.

2. Advantages and Disadvantages of Using Automated Guided Vehicles (AGV)

There are several advantages of using AGVs in manufacturing facilities. First of all, AGVs can transport materials and products very quickly and accurately thanks to its sensors and navigation systems. The need for manpower in a manufacturing facility can be reduced significantly by using AGVs, which increases efficiency.

Secondly, by automating the tasks AGVs can reduce the risk of industrial accidents and worker injuries. By making AGVs carry heavy materials or hazardous products the risk of accidents can be minimized.

Thirdly, AGVs can perform a huge variety of tasks because they are reprogrammable and adaptive robots for changes in manufacturing. High flexibility can be achieved by using AGVs.

Lastly, by using AGVs, annual labor costs can be reduced significantly. For these stated advantages, expected AGV market in Europe by 2028 can be seen in **Figure 2**[2].

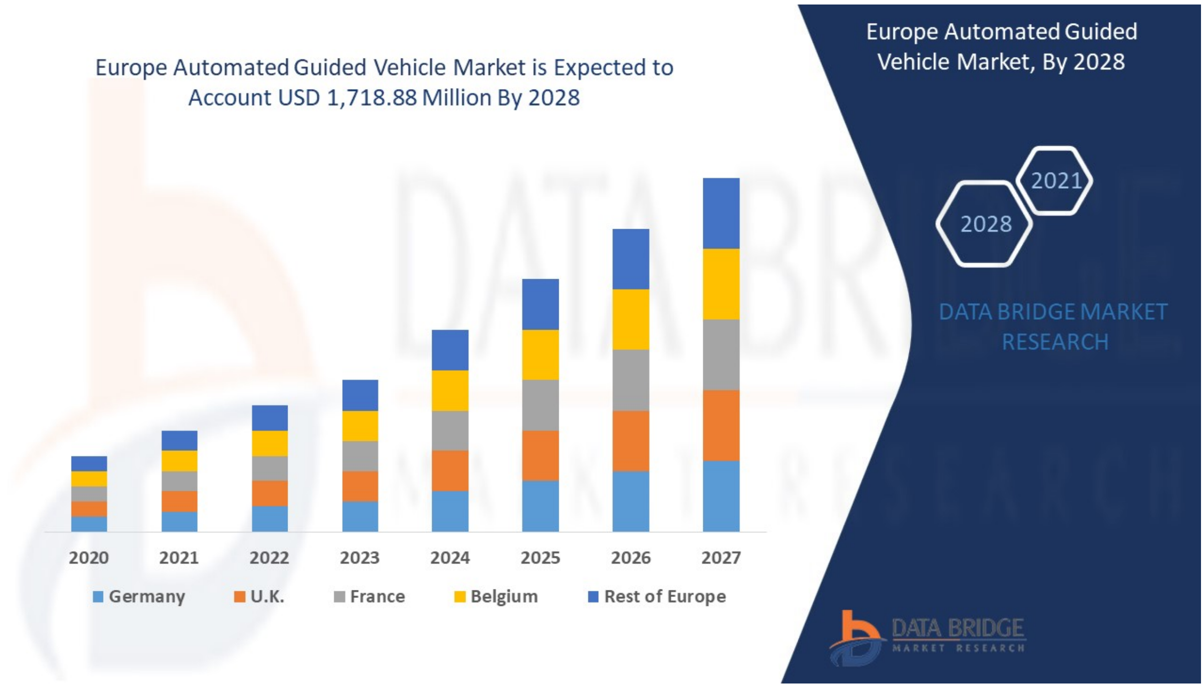

Figure 2. Expected AGV Market studied for Europe between 2020 and 2028

On the other hand, it is vital to state some disadvantages of AGV usage. First of all, installing and purchasing AGVs may be a very costly operation for some manufacturing facility owners.

Secondly, AGVs need periodic maintenance and repairs, which also upsets manufacturing facility owners because these maintenance and repairs may be very time-consuming and costly.

In addition to those costly and time-consuming disadvantages, all AGVs operating in a facility work in a hierarchical dependency system, which means failure of an AGV may cause breakdown for all of the facility.

[2] https://www.databridgemarketresearch.com/reports/europe-automated-guided-vehicles-market

3. Calculation of AGV Requirements

Before proceeding with the calculations, the symbols to be used, their explanations and values are provided in the table below.

Table 1. Values and explanations of the variables

Variable	Description	Value
n	number of work centers	9 (including CB)
β_i	node label corresponding to the pickup station at work center i	$\beta_{receiving}$, β_1, β_2, β_3, β_4, β_5, β_6, β_7
α_i	node label corresponding to the delivery station at work center i	α_1, α_2, α_3, α_4, α_5, α_6, α_7, $\alpha_{shipping}$
$f_{i,j}$	expected number of loaded trips required between workcenter i and workcenter j during the shift	**Table 2.**
T	length of the period or shift during which $f_{i,j}$ exchanges occur	16 hours
$d(\beta_i,\alpha_j)$	distance between node β_i and node a_j	**Table 3.**
V	average vehicle speed (m/min)	20
t_l	mean time to load a vehicle (min)	0.5
t_m	mean time to unload a vehicle (min)	0.5
e	efficiency of vehicle after accounting for breakdowns	0.85

Table 2. Expected number of loaded trips required between work centers (per hour)

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

Table 3. Distance between work centers

Distance Matrix	LOC1	LOC2	LOC3	LOC4	LOC5	LOC6	LOC7	Shipping
Receiving	6	18	6	12	24	18	24	30
LOC1	30	6	30	12	24	18	24	30
LOC2	54	66	54	0	48	66	12	30
LOC3	18	30	18	24	12	6	12	18
LOC4	48	60	48	54	42	60	6	24
LOC5	30	42	30	36	0	42	48	6
LOC6	30	42	30	36	24	42	48	6
LOC7	36	48	36	42	30	48	54	12

3.1. Requirements Calculation - Case 1

In the first method of estimation, it is assumed that the distance covered by vehicles making empty runs is equal to the distance traveled by loaded vehicles. Therefore, the number of required vehicles, N, is calculated by the given formula:

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

where: t is expected lost time by each vehicle during a time period of T due to battery change (t = 60 mins).

In the above formula**,** the $\mathbf{f_{i,j}\ d(\beta_i,\alpha_j)}$ part is calculated by multiplying **Table 2.** by **Table 3.** The calculations and results are shown in **Table 4:**

Table 4. Expected number of loaded trips multiplied by distance.

$f_{i,j}\ d(\beta_i,\alpha_j)$	CB	UMC	VTC1	VTC2	VMC	HMC	SHP	Shipping	Row Totals
Receiving	0	0	42	156	0	0	0	0	198
CB	0	0	0	0	0	0	0	0	0
UMC	0	0	0	0	0	0	0	0	0
VTC1	0	0	0	0	24	30	60	0	114
VTC2	0	0	0	0	0	0	78	120	198
VMC	0	0	0	0	0	84	0	36	120
HMC	0	0	0	0	0	0	0	54	54
SHP	0	240	180	0	180	96	0	0	696
								Grand Total:	**1380**

$$\sum_{i}^{n} \sum_{j}^{n} f_{ij}(t_l + t_u)$$

This part of the formula represents the time lost due to loading and unloading. According to the values that are provided in **Table 1.** and **Table 2.** the result of this part of the formula is **90**.

Outcome: After placing other variables in **Table 1.** and carrying out the calculations, the solution found is **4.7686**. After rounded up, the solution suggested by the first case is **5**.

3.2. Requirements Calculation - Case 2

The second method of requirements calculation requires that estimates of blocking time factor and idle time factor be made. The estimates on blocking and idle time factors are used to refine the estimate on N (vehicle requirement). Using this technique, first average distance per loaded trip, $\overline{D}$, is calculated, where:

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

Both the numerator and denominator of the $\overline{D}$ formula have already been calculated in Case 1. Using these values, $\overline{D}$ is found to be 1380 / 90 = **15.33333**.

Mean travel time per trip, t_a, with no adjustment for blocking and idleness is given by $t_a = \overline{D} / V$. Inserting the values, t_a = 15.33333 / 20 = **0.76666** mins.

where $\overline{D}$ is in meter and V is in meter / min.

Mean travel, and load and unload time per trip, $\overline{t}$, after accounting for blocking, idleness, and vehicle efficiency, is given by

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

where b is blocking time factor, c is idle time factor and e is vehicle efficiency. Blocking and idle time factors are facility dependent and have to be estimated for each facility. In literature, the ranges of values suggested are between 0.10 and 0.15 for both b and c.

In order to present a more comprehensive report, 3 different values for $\bar{t}$ will be defined and used in further calculations. These values will be $\bar{t}_{low}$ which assumes *b* and *c* as 0.10; $\bar{t}_{average}$ which assumes *b* and *c* as 0.125 and $\bar{t}_{high}$ which assumes *b* and *c* as 0.15.

After putting necessary values into the formula, the following results are obtained:

$\bar{t}_{low}$ = **2.0823** mins

$\bar{t}_{average}$ = **2.1274** mins

$\bar{t}_{high}$ = **2.1725** mins

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

The number of vehicles (N) is then calculated by the formula given on the left.

For each $\bar{t}$ found in the previous section, different N values will be calculated. When calculations are conducted, N values obtained are as follows:

N_{low} = **3.1234**

$N_{average}$ = **3.1911**

N_{high} = **3.2587**

Outcome: When rounded up, each value estimated for N gives the same result. The result suggested by the second case is **4** for each of the assumptions.

3.3. Requirements Calculation - Case 3

In this method, computation of the net flow of the workcenters is required for the AGV requirement calculation.

According to the formula given below, the net flow of workcenter i is the difference between the inflow to that workcenter from all other workcenter j, and outflow from workcenter i to all other workcenters j.

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

On one hand, $f_i > 0$ means that workcenter i has a net surplus of AGVs, whereas $f_i < 0$ means that there is a shortage of AGVs. The model assumes that the surplus of empty vehicles is going to satisfy the AGV demand of the closest workcenter with $f_i < 0$. For this layout, the net flow values are as in **Table 5.**

On the other hand, if $f_i = 0$, it is assumed that there will be no empty AGVs leaving this workcenter for another workcenter .

The total distance of empty runs between stations is approximately determined by the following formula:

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

Intra-workcenter activity is another source of empty AGV runs. Due to the separate delivery and pickup locations in a workcenter, AGVs that deliver at α_i will travel empty to β_i. The total distance of empty runs within workcenters is calculated according to the following formula:

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

The total distance traveled by loaded AGVs between workcenters is calculated with the following formula. The minimum flow amounts to workcenter i are specified in **Table 6.** The distances between each station's pickup point and its delivery point are listed in **Table 7.**

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

Finally the estimation of the number of vehicles required is calculated with the following formula.

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

After the calculations, a result of 6.344 is found. After rounding up, **it is suggested to use 7 vehicles with this method.**

Table 5. Net Flows

Net flows	
Receiving	320
CB	0
UMC	0
VTC1	0
VTC2	0
VMC	0
HMC	0
SHP	0
Shipping	-320

Table 6. Minimum flow amounts

Minimums	
Receiving	0
CB	0
UMC	80
VTC1	192
VTC2	288
VMC	128
HMC	144
SHP	288
Shipping	0

Table 7. Distance from α_i to β_i

Distances	
Receiving	0
CB	30
UMC	66
VTC1	18
VTC2	54
VMC	0
HMC	42
SHP	54
Shipping	0

With the exception of shipping and receiving stations, practically all of the above layout's net flow values are zero, indicating that there are no empty runs. However, the actual layout is probably going to have a lot more empty runs, and the central buffer is probably going to make the problem worse. Even if this method takes into account more complex information than the first and second methods, it is still not appropriate.

3.4. Requirements Calculation - Case 4

This method is based on the assumption that in a job shop environment the load pickup requests of the workcenters are random. The amount of pickups required from a center is equal to the requests from that center. In the long run, it is expected for the sequence of requests to be random too. When a vehicle is freed from its load at a delivery station, a decision that determines where the next destination will be is made.

The 7 + 2 (Receiving and Shipping) locations have a combined total of 90 arrivals and 90 shipments, which adds up to 180 transactions each hour as they all operate to produce parts simultaneously. In other words, one transaction happens roughly every 20 seconds. The reason why there isn't a match every 20 seconds is because events aren't exactly timed to create a perfect cycle. Depending on how well the system's components function together, it can be more or less at different times. As a result, randomness is created, and in the fourth method, the calculating formula accounts for the randomness.

AGVs will be available when they unload their loads at receiving stations. So as a delivery is completed an AGV will be assigned for another station. The number of deliveries will affect how many times an AGV will be available at that specific station. After an AGV unloads it will pick up from another station which can be formulated for all stations separately as below.

$$\frac{expected\ number\ of\ pickups\ from\ j}{expected\ number\ of\ pickups\ in\ total}$$

Multiplying this proportion with the number of deliveries to a station k (j, k are both integers from 1 to 9, as the indexes of stations.)

Total number of pickups is 1440 according to the calculations made. The total number of deliveries for each cell is multiplied by the number of pickups from that cell then it is divided by total number of pickups (1440). As a result, **Table 8**. is created.

Table 8. Delivery of i times pickup j divided by total pickups

Delivery(i)*Pickup(j)/totalPickup	Rec	UMC	VTC1	VTC2	VMC	HMC	SHP	SHIP
Rec	0	0	0	0	0	0	0	0
UMC	17,777	4,444	10,666	16	7,111	8	16	0
VTC1	42,666	10,666	25,6	38,4	17,066	19,2	38,4	0
VTC2	64	16	38,4	57,6	25,6	28,8	57,6	0
VMC	28,444	7,111	17,066	25,6	11,377	12,8	25,6	0
HMC	32	8	19,2	28,8	12,8	14,4	28,8	0
SHP	64	16	38,4	57,6	25,6	28,8	57,6	0
SHIP	71,111	17,777	42,666	64	28,444	32	64	0

The values in **Table 8.** are multiplied by the distance between the delivery point and the pickup points of all nodes in the current layout. For the loaded AGVs total distance is calculated as 22080, for the empty AGVs it is calculated as 41288. Summing up these values and adding the load/unload times then dividing by the total time resulted as 6.024 considering the efficiency. Rounding up, **7 machines are required** with this method.

4. Comparison of Methods

All 4 methods of calculation for AGV requirements have different approaches to the same problem. As stated in the introduction, different assumptions are made to come up with an analytical solution that conforms with different real-life conditions. Thus, the accurate approach for solving AGV requirements for a hypothetical manufacturing facility can only be shaped with given data and assumptions. Therefore, the fourth method seems to be the best-fit approach because it uses given data and assumptions much more efficiently than other methods.

The main assumption in the first method is that the number of empty AGV runs is equal to the number of loaded AGV runs. In this case, assignment of a single AGV for delivery or pickup happens in different workcenters, which seems to be not realistic.

The second method for calculation requires estimation for 2 time factors which are called blocking time factor and idle time factor. However, the second method comes with fixed intervals for these factors as a rule of thumb in manufacturing literature. This assumption makes the second method ambiguous because of the variety of different manufacturing facilities. It can be seen that the results of the second method are 3.1234, 3.1911 and 3.2587 AGVs whereas 6.024 AGVs is achieved by the fourth method.

Finally, the third method suggests calculations of net flows for each workcenter. After this suggestion, 3 distances are calculated. Total distance of empty runs between workcenters is calculated by considering net flows, which is total outflow from a workcenter subtracted by total inflow to a workcenter, for each workcenter. This method considers intra-workcenter activity as a source of empty AGV runs also, therefore another distance is calculated for stating the total distance of empty runs within workcenters. After that, the total distance traveled by loaded AGVs is calculated. Therefore, the average of these 3 distances is used to calculate AGV requirements. This method seems to be comprehensive, but in a scenario where locations of workcenters' delivery and pickup points are much distant or close, the second distance described above diverges from other 2 distances which results in inaccuracy.

5. Conclusion

In a nutshell, the most important decision to make is whether to use AGVs in manufacturing facilities or not. After that, choosing the appropriate method by checking overlap between assumptions in each method and the existing conditions of the manufacturing facility must be conducted. The required number of AGVs can be calculated thereafter easily. Since AGVs are not always economically justified from every manufacturing facility owner's perspective, these calculations can be meaningful only if the usage of AGVs is decided.

Four methods offered by Egbelu are used in these calculations. All of these 4 methods are different from each other because each of these methods offer different estimation techniques for determining empty and loaded AGV runs between work centers. Method 4 is chosen as the “best” among these methods. The reason behind this choice is that it came up with the best estimation technique which seems to be more realistic considering manufacturing facilities. This technique uses the power of randomness of sequencing load pickup requests from different work centers. Since each AGV is available for assignment after a delivery has happened, that is the time when a reassignment decision of that specific AGV is made. Under a fair dispatching rule, the total number of empty runs between each workcenter is calculated and total number of AGVs needed in a given hypothetical manufacturing facility is calculated as 6.024 which can be rounded up to 7. The robustness of this method can be tested by the interval generated by Method 1 and Method 3 calculations which are 4.7686 and 6.344 (includes 6.024), where Method 1 seems to be “best-case” scenario for estimating empty runs whereas Method 3 seems to be the “worst-case” one.

6. 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] *Europe Automated Guided Vehicle Market Report – Industry Trends and Forecast to 2028 | Data Bridge Market Research*. (n.d.). Data Bridge Market Research, https://www.databridgemarketresearch.com, All Right Reserved 2022. https://www.databridgemarketresearch.com/reports/europe-automated-guided-vehicles-market