IE 312 - Facility Design & Planning

LAYOUT DESIGN FOR A HYPOTHETICAL FLEXIBLE MANUFACTURING SYSTEM

Part 2 Report

Bengü Yağmur Kaya (25%// Method 3, Comparison) - 2019402096

Ömer Osman Oğultürk (25%// Method 2, Research) – 2021402216

Yusuf Eren Bayhan (25% // Method 1, Introduction) - 2022402255

Zeynep Sude Terzioğlu (25%//Method 4,Conclusion)- 2021401288

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1. Introduction

Automated Guided Vehicle (AGV) systems have been recognized as a fundamental component of high-level efficiency for today's facility planning, driven by advancements in autonomous navigation and sensor technologies.

The main purpose of this study is to determine the optimal number of vehicles needed to serve the material handling requirements of a hypothetical Flexible Manufacturing System (FMS). Since elaborate simulation is time-consuming and expensive in the preliminary stages of planning, four analytic estimation approaches suggested by Egbelu (1987) are evaluated in this study.

This report attempts to calculate the number of vehicles required to ensure smooth transfer between workstations, shipping, and receiving nodes, by considering constraints such as material flow intensity, vehicle efficiency, and potential operational interferences (blocking and idleness)

2. Pros/Cons of AGV Usage

The Automated Guided Vehicle (AGV) systems have both operational advantages and disadvantages when compared to traditional manual handling equipment, such as forklifts and handcarts.

2.1. Advantages

- **Safety & Reliability:** AGVs ensure a safe working place as they have advanced sensors and collision avoidance technologies. On the contrary, manual forklifts can cause industrial accidents stemming from operators' errors and fatigue.
- **Operational Efficiency:** Unlike human labor, AGVs provide consistent and continuous operation (24/7) without any break or shift change requirement except charging times. Also, using AGVs eliminates the physical strain associated with handcarts and reduces direct labor costs over time.
- **Scalability & Tracking:** With the Warehouse Management Systems (WMS) and IoT devices, AGVs allow real-time tracking and scalability that manual systems cannot match.

2.2. Disadvantages

- **High Initial Cost:** The upfront investment of AGVs and required infrastructure is much higher than purchasing manual carts or forklifts, which can be prohibitive for smaller operations.
- **Flexibility Limitations:** Manual operators can still navigate in new environments or when encountered with unexpected obstacles by adaptation and the instant reaction mechanism humans have. On the other hand, AGVs require structured, predictable working places and can have a hard time while struggling with dynamic changes in the facility layout.
- **Maintenance & Complexity:** Unlike the simple mechanical maintenance of handcarts, AGVs introduce brand new problems such as battery management, software updates, and cybersecurity risks.

3. Analysis and Comparison

3.1. Outputs of Methods

In this section of the report, the required AGV fleet sizes are calculated and explained separately for each method. These computations are based on the facility parameters and AGV specifications detailed in Table 3.1.

Daily Availability (hr/day)	16
Efficiency	85%
Speed (m/min)	20
Battery Operation	Charge for 1 hour every 16 hours.
Pickup Time (minutes)	0.5
Delivery Time (minutes)	0.5

Table - 3.1 AGV Specifications

3.1.1. Method 1

The required fleet size was calculated according to the first analytical method introduced by Egbelu (1987). A basic assumption of this approach is that the empty vehicle distance is equal to the distance traveled by loaded vehicles. Based on this principle, the total transportation workload was derived by computing the loaded distance from the facility layout grid (converting grid units to actual meters) and then doubling this sum to account for the expected empty returns. To determine the total operation time, the aggregate distance was divided by the vehicle speed, and fixed pickup and delivery times were added for each trip. Finally, the required fleet size was obtained by dividing this total workload by the effective daily availability of a single AGV. This availability value adjusts the total shift time for battery charging intervals and applies the operational efficiency factor listed in the AGV Specifications Table. Through this approach, **theoretical requirement of 5.28** vehicles was derived. To ensure continuous operation without capacity shortages, this figure was rounded up to the next integer, resulting in a fleet size of **6 AGVs**.

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

Total Pickup Time (minutes)	720
Total Delivery Time (minutes)	720
Total Transportation Distance (meters)	52032
Speed (m/min)	20
Total Transportation Time	2601,6
Required Number of AGV	5,28
Table - 3.1.1 Method 1 Calculation	

3.1.2. Method 2

Method 2 extends the first analytical approach by incorporating operational interferences through blocking and idle time factors. In this method, the estimation is based on the average loaded travel per trip and adjusts the trip time to reflect additional delays caused by temporary congestion (blocking) and waiting periods (idleness). Consistent with the assignment requirement, the AGV efficiency factor is incorporated in the calculations similarly to Method 1.

First, the total number of loaded trips per day was obtained from the From-to Matrix as $\sum f_{ij} = 1440$trips/day. Next, the total loaded travel distance was computed using the Total Transport Matrix, resulting in a total loaded distance of $\sum f_{ij} d_{ij} = 26016$ meters/day.

Therefore, the mean loaded distance per trip was calculated as:

$$D^{-} = \frac{\sum f_{ij} d_{ij}}{\sum f_{ij}} = \frac{26016}{1440} = 18.1\, min/trip$$

Given the AGV speed $v = 20$m/min, the mean travel time per trip (without delays) becomes :

$$t_a = \frac{D^-}{v} = \frac{18.1}{20} = 0.903\ min/trip$$

To account for operational interferences, blocking and idle time factors were assumed as $b = c = 0.125$(moderate congestion and waiting). Under these factors and considering AGV efficiency $e = 0.85$, the mean time per trip after accounting for other factors was computed as:

$$t = \frac{(1+b+c)\,t_a}{e} + t_p + t_d$$

where $t_p = 0.5$min and $t_d = 0.5$ min are the pickup and delivery times, respectively. Substituting the values:

$$t = \frac{(1+0.125+0.125)\times 0.903}{0.85} + 0.5 + 0.5 \approx 2.33\ min/trip$$

Finally, the required number of AGVs was found by dividing the total daily workload (trips × adjusted trip time) by the effective operating time per day. Since the system requires one recharge within the 16-hour working period, the net operating time was taken as 900 minutes/day per vehicle. Thus:

$$N = \frac{(\Sigma f_{ij})\times t}{900} = \frac{1440\times 2.33}{900} = 3.73$$

Because the fleet size must be an integer, the result was rounded up, yielding a requirement of 4 AGVs for Method 2.

Mean Distance (m/trip)	18,1
Mean Trip Time (min/trip)	0,903
Mean Time per Trip After Accounting for Other Factors	2,33
Required Number of Agv	3,73
Table - 3.1.2 Method 2 Calculation	

3.1.3. Method 3

Method 3 estimates the AGV requirement by examining the imbalance of material flow among work centers. Since each station may process more outgoing loads than incoming ones, or vice versa, these differences result in empty vehicle movements that must be incorporated into the system's workload. Using the From–To matrix prepared for the layout, the net inflow–outflow values were calculated for every workstation, indicating that only the Receiving and Shipping areas create a non-zero flow imbalance. Directional empty travel distances were then determined through the Delivery-to-Pickup matrix.

After combining these empty movements with the **loaded travel distance of 26,016 meters** and the **handling workload of 1440 minutes**, the total travel demand was substituted into the formula shown below.

$$N = [\frac{D_1+D_2+D_3}{V} + \sum_{i=1}^{n} \quad \sum_{j=1}^{n} \quad f_{ij}(t_m + t_l)] \, / \, (60\text{T - t})$$

The **resulting requirement was 3.965 AGVs**, and therefore, the method suggests that **4 vehicles should be allocated** to maintain reliable system operation.

Loaded Travel Distance (meters)	26,016
Handling Workload (minutes)	1440
Required Number of Agv	3,97
Table - 3.1.3 Method 3 Calculation	

3.1.4. Method 4

Method 4 considers the randomness inherent in job-shop type manufacturing systems by explicitly incorporating empty vehicle movements into the estimation of the required AGV fleet size. In such systems, AGVs do not always follow symmetric travel patterns, and therefore, the distances traveled during empty returns after deliveries cannot be neglected. The empty travel distance between each origin–destination pair was calculated using the reverse distance formulation given by Egbelu (1987):

$$D_{ij}^{'} = g_{ij} d(a_i, \beta_j)$$

In addition to empty travel, the distances traveled by AGVs while carrying loads were also considered in the analysis. The loaded travel distance between each pair of locations was calculated based on the material flow and pickup-to-delivery distances as follows:

$$D_{ij} = D_{ij}^{'} + D_{ij}^{-}$$

After determining the total transportation distance, the overall AGV workload was converted into time by dividing the total travel distance by the AGV speed. In addition, pickup and delivery service times were included for each transportation task based on the total number of loaded trips in the system. Finally, the required number of AGVs was calculated using the analytical formulation proposed by Egbelu (1987):

$$D_{ij}^{-} = f_{ij} d(\beta_i, \alpha_j)$$

The total transportation distance for each origin–destination pair was then obtained by combining the loaded and empty travel distances:

$$N = [2+ \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} D_{ij}}{V} + (\sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij})(t_l + t_m)]/(60T - t)$$

Based on this formulation, **the total loaded travel distance was calculated as 27,300 meters**, while the **total empty travel distance was found to be 39,545.6 meters.** Using an AGV speed of 20 m/min, pickup and delivery times of 0.5 minutes each, and an **effective daily operating time of 765 minutes per vehicle**, the required AGV fleet size was determined to be 6.25 vehicles, and therefore, the method suggests that **7 vehicles should be allocated** to maintain reliable system operation.

Total Loaded Travel Distance (meters)	27,300
Total Empty Travel Distance (meters)	39,545.6
Effective Daily Operating Time (min/vehicle)	765
Required Number of Agv	6.25
Table - 3.1.4 Method 4 Calculation	

3.2 Comparison of Methods

The four analytical methods proposed by Egbelu approach the AGV fleet-sizing problem from different perspectives, which naturally leads to variation in the final estimates. Method 1 provides a straightforward and fully deterministic calculation that relies on fixed travel distances, handling times, and daily vehicle availability. Its estimate of **6 AGVs** reflects a relatively conservative view, as the method assumes that empty travel is roughly equivalent to loaded travel and does not incorporate operational disturbances.

Method 2 refines this estimate by accounting for blocking and idle-time adjustments, resulting in a fleet size of **4 AGVs**. This reduction stems from the inclusion of moderate congestion and waiting assumptions, which allow the method to represent a more realistic trip duration without being overly pessimistic. However, its accuracy depends on how closely the assumed blocking and idleness levels match real system conditions.

Method 3 relies on flow asymmetries among work centers and therefore emphasizes the effect of empty vehicle repositioning. In this system, only the Receiving and Shipping stations generated non-zero net flows, which significantly reduced the overall empty-travel requirement and led to an estimate of **4 AGVs**, consistent with Method 2. The method is efficient when flow patterns remain stable, but it may be sensitive to changes in routing or throughput.

Method 4 differs from the previous approaches by incorporating the randomness of job-shop-like vehicle movements and the directional nature of loaded and empty travel. Because it does not assume symmetric paths or stable flow patterns, Method 4 captures a broader range of possible operating scenarios. As a result, it produced the highest estimate, recommending **7 AGVs** to ensure robustness under variable and unpredictable workloads.

3.3 Recommended Decision

Given the potential for fluctuations in both loaded and empty travel within the system, Method 4 provides the most reliable basis for planning. Although it yields a larger fleet size than the other approaches, its more comprehensive treatment of randomness and directional travel ensures that the system can operate without delays even under adverse conditions. Therefore, adopting 6–7 AGVs would offer a balanced margin of flexibility while preventing bottlenecks caused by unexpected workload variations. For this analysis, a final recommendation of 7 AGVs is proposed to ensure sustained operational stability.

4. Conclusion and Summary

This report evaluated four different analytical methods to estimate the AGV fleet size required for the given system layout. Method 1 relied primarily on total travel demand and daily vehicle availability; Method 2 expanded this by introducing blocking and idle-time considerations;

Method 3 accounted for flow imbalances and the resulting empty vehicle movements; and Method 4 incorporated directional travel and random variations in trip assignments.

Applying these approaches to the system produced fleet size estimates ranging from **4 to 7 AGVs**, reflecting the assumptions embedded in each method. While Methods 2 and 3 yielded the lowest requirement due to balanced flows and moderate inefficiency assumptions, Method 4 captured the highest uncertainty and therefore recommended the largest fleet.

Considering the directional nature of travel paths, the potential for variability in traffic patterns, and the importance of maintaining dependable system performance, the analysis concludes that **7 AGVs** would provide the most robust and operationally reliable fleet size for the studied facility.

5. Appendices

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- **Tab-1: DATA**
  Contain the basic input data used in the AGV fleet size estimation, including the From–To material flow matrix, the pickup-to-delivery distance matrix, and the delivery-to-pickup distance matrix. Also list all operational parameters such as daily availability, efficiency, AGV speed, battery charging time, pickup time, and delivery time.

- **Tab-2: Method 1**
  Compute the required number of AGVs by assuming that empty travel distances are equal to loaded travel distances. Use the From–To material flow matrix and the pickup-to-delivery distance matrix to construct the total transportation matrix. Calculate the total transportation distance by summing all matrix elements, convert this distance into travel time using the AGV speed, add pickup and delivery service times based on the total number of trips, and determine the required number of AGVs using the effective daily operating time.

- **Tab-3: Method 2**
  Estimate the required number of AGVs using average transportation measures. Calculate the mean distance per trip and mean trip time based on the total transportation distance and AGV speed. Incorporate pickup and delivery times to obtain the mean time

per trip after accounting for other factors, and determine the required number of AGVs using the effective daily operating time.

- **Tab-4: Method 3**

  Estimate the required number of AGVs by incorporating flow imbalance effects to account for additional empty vehicle travel. Use the From–To material flow matrix and the pickup-to-delivery distance matrix to calculate the total loaded transportation distance. Estimate empty travel distances based on inflow–outflow differences at each workcenter and compute the corresponding empty vehicle transfer distances. Combine loaded and estimated empty distances to obtain the total transportation distance, convert this distance into travel time using the AGV speed, add pickup and delivery service times, and determine the required number of AGVs using the effective daily operating time.

- **Tab-5: Method 4**

  Explicitly account for empty vehicle movements by using reverse (delivery-to-pickup) distances. Construct the number of empty runs matrix based on the From–To material flow structure. Calculate the distance of empty runs by multiplying the number of empty runs with the corresponding delivery-to-pickup distances. Combine the total loaded transportation distance and the total empty travel distance to obtain the overall transportation distance. Convert this distance into travel time using the AGV speed, add pickup and delivery service times based on the total number of trips, and determine the required number of AGVs using the effective daily operating time.