Selection of Automated Guided Vehicles for Industrial Application Using Weighted Sum Method

Divya Sabnis, Megha Patil, and Sagar Wankhede

Abstract For material handling and transportation in various industrial settings automated guided vehicles (AGVs) have emerged as a cutting-edge solution. The diverse requirements of different industries the selection of the most suitable AGV for a specific application is a crucial task. To assist decision makers this study is helpful in their decision-making process. The proposed approach utilizes a multi-criteria decision-making technique, Weighted Sum Method (WSM) that enables the evaluation and comparison of AGVs using multiple criteria. The proposed methodology involves defining relevant criteria such as controllability, accuracy, range, reliability, flexibility, and cost. Accuracy of model predicted by exploring data on the performance and characteristics of various AGVs are collected from reliable sources. The gathered data are then normalized and assigned appropriate weights by domain experts to reflect the relative importance of each criterion. The weighted scores for each criterion are combined using the WSM to obtain an overall score for each AGV model under consideration. For specific material handling applications, the AGV model with the highest overall score predicted as the most suitable model. The proposed model revels that the WSM offers a systematic and efficient approach to AGV selection, empowering decision-makers to make choices grounded in quantifiable criteria rather than intuition or incomplete information. The proposed AGV selection methodology utilizing the Weighted Sum Method presents a structured decision-making process, which is suitable for industrial applications.

Keywords Material handling · AGV · MCDM · WSM · WASPAS

D. Sabnis · M. Patil · S. Wankhede (✉)
School of Mechatronics Engineering, Symbiosis Skills and Professional University, Pune 412101, India
e-mail: svw8890@gmail.com

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1 Introduction

The essential element in contemporary manufacturing systems is automated guided vehicles (AGVs), playing a great importance in facilitating material handling processes. The automated guided vehicles are highly autonomous and efficient, self-driving, and battery operated typically controlled by on board computers. The primary function of AGV is specifically facilitating horizontal movements of goods and transport materials within a facility. The AGVs are firstly introduced in 1955 [1] till now it is continuously growing, expanding in different applications. Nowadays for optimization of material flow and handling in industries, AGVs are playing very essential role for preparation of "fleet size" in manufacturing industries specifically in workstations and storehouses. In industries for material transportation throughout facility, specific task, and responsibilities assigned to AGV. AGV found in very good at doing different applications in manufacturing plants, distribution centers, trans-shipment hubs, warehouses, and even external transportation areas. The ability of AGVs is to do many different things and the quality of being able to change at any situation in logistics and material handling processes. Due to effective use of AGVs in industry manual intervention is reduced and operational efficiency and safety reduced. For efficiently transporting goods from one location to other by avoiding obstacles following navigated paths AGVs works effectively and efficiently. The positive effect of AGVs implementation in manufacturing industries can experience increased productivity, reduced operational costs, and improved overall workflow. A reliable and flexible solution for material transportation in supply chain management is effective use of AGVs. In advanced AGV new features are incorporated like artificial intelligence, advanced sensors, and communications systems. The modern manufacturing and logistic ecosystems improve their performance by making AGVs as integral part in their system.

In the Flexible Manufacturing Systems (FMS) the automated guided vehicle plays pivotal role due its high flexibility. In a constantly evolving manufacturing environment advanced AGVs efficiently handle material transportation in manufacturing plant. Scholars like Tompkins and White [2] have demonstrated the important role of material handling systems in Flexible Manufacturing Systems (FMS). In industry for achieving operational efficiency goals and cost reduction, material handling operations are critically handled as material handling consumes 13–30% total production costs. Consequently, since the 1980s, numerous researchers have been actively seeking new approaches to optimize material handling systems (MHS) within FMS settings. In a Flexible Manufacturing System, multiple cells are responsible for producing different parts, each with specific requirements and processing needs. Having an efficient MHS becomes paramount in such a setup, as seamless and timely transportation of materials between workstations and even among cells directly impacts cost reduction goals. Given the highly competitive nature of the current market conditions, cost reduction is one of the most important objectives for manufacturing businesses to maintain their competitiveness and profitability. By employing AGVs in the material handling process, manufacturers can achieve several benefits. The ability to modify the guide paths of AGVs easily allows for swift reconfiguration of material transportation routes, adapting to changes in production needs without significant disruptions. This inherent flexibility ensures a smooth and uninterrupted workflow in an FMS environment. Furthermore, AGVs contribute to reducing production costs by optimizing material flow, minimizing waiting times, and enhancing overall operational efficiency. As AGVs can autonomously navigate through the facility, they eliminate the need for manual material transportation, reducing labor costs, and potential errors. The streamlined material handling process translates to faster production cycles, allowing manufacturers to meet market demands more effectively. Within an AGV system, several key elements play critical roles, contributing to its efficient, and seamless operation. These elements can be classified into three primary components: the vehicles, the transportation network, and the physical interface that connects the production/storage system with the control system.

The transportation network functions as the fundamental framework of the AGV system, interconnecting all stationary installations like machines and workstations within the central area of the facility. These stations establish crucial pickup and delivery points (P/D points), serving as interfaces that connect the production system with the AGV transportation system. These P/D points act as the key exchange locations where materials are loaded onto or unloaded from the AGVs. AGVs, as the core mobile units of the system, travel between the P/D points, efficiently transporting materials and goods from one location to another. The movement of AGVs can follow either fixed paths, predefined by guide wires or floor markings, or free paths, where they navigate autonomously without the need for physical guidance. AGVs operating without guide paths are referred to as free-ranging AGVs [3]. This distinction in path-following mechanisms allows for flexibility in configuring AGV systems to match the specific requirements of different industrial environments. For accurate and safe navigation throughout the facility guide paths are allotted to AGVs. In critical in busy production environments guide path ensures precise movement and minimizing the chances of deviation and collisions. On the other hand, free-ranging AGVs operate without the constraints of fixed paths. Free-ranging AGVs leverage advanced technologies, such as laser sensors, cameras, or LIDAR, to autonomously navigate through the space. So free-ranging AGVSs are flexible enough to adapt to changes in the environment, making them ideal for environments where the layout may be subject to frequent adjustments or in situations where guide paths are impractical to implement. An AGV system's design is considered for tactical and operational aspects. Tactical issues include points like pickup/delivery locations, fleet size, and flow path architecture. Operational issues include routing and dispatching considerations. Several researchers have addressed these challenges in the past. For instance, Hsueh [4], King and Wilson [5], Ganesharajah and Sriskandarajah [6], Johnson and Brandeau [7], Manda and Palekar [8], and Bordelon Hoff and Sarker [9] have demonstrated operational issues related to AGV dispatching, routing, and scheduling. King and Wilson specifically investigated the design, routing, and scheduling of AGVs, focusing on vehicle requirements, flow paths, and AGV types. Ganesharajah and Sriskandarajah investigated the complexities associated with scheduling, dispatching, and routing of AGVs in various flow route topologies. Johnson and Brandeau demonstrated stochastic models for automated material handling systems design and control, while Manda and Palekar explored their experimentation into MHS design and control problems. Additionally, Hoff and Sarker examined dispatching standards and the creation of guidance paths for AGVs. More recently, Qiu et al. [10] conducted a literature review on design and operational issues related to Flexible Manufacturing Systems (FMS), as well as tactical challenges concerning fleet size and flow path design. Moreover, some researchers, like [2, 11], have integrated modern technologies such as Mechatronics to enhance AGV systems. They utilized various electrical devices, including chipsets, boards, RFIDs, sensors, and other advanced components to increase system throughput and prevent deadlocks and collisions. Overall, the AGV system design has been shaped by insights gained from previous research on tactical and operational considerations, as well as the integration of cutting-edge technologies to optimize its performance. Their approach has the highest quality currently attained, but they failed to account for the expense of creating such a fully automated system. In this context, the Weighted Sum Method (WSM) emerges as an effective and reliable multi-criteria decision-making technique. The WSM allows decision-makers to comprehensively assess and rank AGV models based on a combination of multiple criteria, each assigned a specific weight reflecting its relative importance. By utilizing the WSM/MCDM, the AGV selection process becomes more objective, systematic, and transparent, enabling stakeholders to make informed choices backed by quantitative analysis rather than relying solely on subjective judgments [12–15]. This research aims to propose a structured methodology for selecting AGVs in industrial applications using the Weighted Sum Model. By integrating key criteria and applying appropriate weighting, the proposed model will assist decision-makers in comparing AGV models and identifying the one that best meets the specific requirements of their material handling operations. The research endeavors to validate the effectiveness and practicality of the WSM approach through a real-world case study, highlighting the advantages of employing a data-driven decision-making process in AGV selection.

2 Weighted Sum Method

A multi-criteria decision-making method called the Weighted Sum Method is used to assess and contrast several choices based on a variety of factors. It is commonly used in various fields such as engineering, business, project management, and operations research when there are multiple factors or attributes to consider in decision-making.

The method involves the following steps:

(i) **Identify Criteria**: List the pertinent standards by which the alternatives will be judged. These standards ought to be quantifiable and cover the essential elements of the decision-making process.
(ii) **Assign Weights**: Give each criterion a weight based on how important or important it is to the decision-maker. All weights added together should equal 1 (or 100%).
(iii) **Normalize Criteria**: If the criteria are on different scales, it is necessary to normalize them to bring them to a common scale, usually between 0 and 1, for better comparison.
(iv) **Evaluate Alternatives**: Evaluate each alternative with respect to each criterion and assign scores to them based on their performance in each criterion.
(v) **Calculate Weighted Scores**: Multiply the scores of each alternative by the corresponding weight of the criterion and then sum up these weighted scores for each alternative. This yields a single value representing the overall performance of the alternative considering all criteria.
(vi) **Rank Alternatives**: Based on their combined weighted scores, order the alternatives. The option with the greatest weighted score is regarded as the best or preferred option.
(vii) **Make Decision**: The alternative with the highest rank (or highest weighted score) is the one that best suits the decision-maker's objectives and preferences.

2.1 WSM Formulations

Step 1: Design of a weighted decision matrix

Let's say there are *m* choices and *n* criteria in an MCDM situation, $D = x_{ij}$ be a decision matrix, where $x_{ij} \in \mathbb{R}$ [refer Table 1].

$$D_{ij} = \begin{bmatrix} X_{11} & X_{12} & \dots & X_{1n} \\ X_{21} & X_{22} & \dots & X_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ X_{m1} & X_{m2} & \dots & X_{mn} \end{bmatrix} \quad (1)$$

It is possible to express the weight vector as

$$w_j = \left[w_1 \dots w_n \right], \quad \sum_{j=1}^{n} \left(w_1 \dots w_n \right) = 1. \quad (2)$$

Table 1 Choice matrix for selection of AGV

AGV alternative	Controllability	Accuracy	Range	Reliability	Flexibility	Cost
V1	0.895	0.495	0.495	0.895	0.295	0.695
V2	0.115	0.895	0.895	0.495	0.495	0.895
V3	0.115	0.115	0.115	0.695	0.895	0.895
V4	0.295	0.895	0.495	0.495	0.895	0.115
V5	0.895	0.495	0.695	0.295	0.495	0.115
V6	0.495	0.495	0.115	0.695	0.695	0.895
V7	0.115	0.295	0.115	0.895	0.895	0.895
V8	0.115	0.495	0.495	0.495	0.695	0.695
The weights are calculated using analytical hierarchy approach (AHP)						
Criteria weights	**0.346**	**0.168**	**0.073**	**0.063**	**0.293**	**0.0584**

Step 2: Normalization of decision matrix

$$n_{ij} = \begin{cases} \frac{x_{ij}}{\max .x_{ij}} & |j \in B \\ \frac{\min .x_{ij}}{x_{ij}} & |j \in B \end{cases} \quad (3)$$

where n_{ij} is the normalized value of the ith alternative for the jth criterion. $\max .x_{ij}$ and $\min .x_{ij}$ are the maximum and minimum value of x_{ij} in the jth column for benefit (B) and cost criterion (C), respectively.

Table 2 Normalized decision matrix

AGV alternative	Controllability	Accuracy	Range	Reliability	Flexibility	Cost
V1	1	0.5530726	0.553073	1	0.329609	0.165468
V2	0.128492	1	1	0.553073	0.553073	0.128492
V3	0.128492	0.1284916	0.128492	0.776536	1	0.128492
V4	0.329609	1	0.553073	0.553073	1	1
V5	1	0.5530726	0.776536	0.329609	0.553073	1
V6	0.553073	0.5530726	0.128492	0.776536	0.776536	0.128492
V7	0.128492	0.3296089	0.128492	1	1	0.128492
V8	0.128492	0.5530726	0.553073	0.553073	0.776536	0.165468

Table 3 Weighted normalized decision matrix

AGV alternative	Controllability	Accuracy	Range	Reliability	Flexibility	Cost
V1	0.346	0.092916	0.036135	0.056385	0.086435	0.040588
V2	0.044458	0.168	0.065335	0.031185	0.145035	0.052268
V3	0.044458	0.021587	0.008395	0.043785	0.262235	0.052268
V4	0.114045	0.168	0.036135	0.031185	0.262235	0.006716
V5	0.346	0.092916	0.050735	0.018585	0.145035	0.006716
V6	0.191363	0.092916	0.008395	0.043785	0.203635	0.052268
V7	0.044458	0.055374	0.008395	0.056385	0.262235	0.052268
V8	0.044458	0.092916	0.036135	0.031185	0.203635	0.040588

Step 3: Weighted normalization of decision matrix

$$W_{n_{ij}} = w_j n_{ij} \tag{4}$$

Step 4: Ranking of alternatives

$$S_i^{\text{WSM}} = \sum_{j=1}^{n} w_j n_{ij} \tag{5}$$

where S_i^{WSM} the ranking score of the ith alternative, w_j is the weight of the criterion. The alternatives are then ranked in descending order with highest S_i^{WSM} being ranked highest.

3 Results and Discussion

After calculating the preference scores for each AGV, we rank them based on their overall performance. The AGV with the highest weighted score is considered the most suitable choice for the industrial application and compared ranking of AGV alternative with WASPAS [refer Table 4].

Based on the Weighted Sum Method, the most suitable AGV stands out with ranking as V5 > V1 > V4 > V6 > V2 > V7 > V8 > V3 for the industrial application, with the highest overall preference score. It offers a good combination of controllability, accuracy, range, reliability, flexibility, and cost.

Table 4 Rank of AGV alternative using weighted aggregated sum product assessment (WASPAS) and WSM

AGV alternative	Preference score	WSM	WASPAS
V1	0.658459201	2	2
V2	0.506281101	5	5
V3	0.432727693	8	8
V4	0.618315693	3	3
V5	0.659987201	1	1
V6	0.59236233	4	4
V7	0.479115402	6	6
V8	0.448917302	7	7

4 Conclusion

The Weighted Sum Method has served as a valuable tool for AGV selection in the industrial application, leading us to make an informed and rational decision that aligns with the desired criteria and objectives. A5 has been identified as the most favorable choice, ensuring efficient and reliable material handling operations while considering the various constraints and preferences relevant to the industrial setting.

The Weighted Sum Method allows decision-makers to objectively assess and prioritize AGVs based on various criteria relevant to the industrial application, leading to an optimal choice that aligns with the specific requirements and preferences of the organization.

Conflict of Interest Authors do not have any conflict of interest.

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