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# Investigating grand marshalling operations alternatives for guiding aircraft to their parking positions

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## Abstract

In congested airports, where multiple aircraft operations coincide, ground marshalling becomes even more vital to prevent accidents, delays, and operational inefficiencies. Aircraft marshalling is crucial because of the intricacies and inherent risks associated with manoeuvring large aircraft on the ground, as airports are usually bustling, congested environments with restricted sight, particularly in proximity to terminal gates, hangars, and taxiways. The study successfully applied the CRITIC Weight-VIKOR technique to choose a prominent alternative for marshalling operations at airport. The weights of such criteria as the Operational Efficiency (OE), Safety Enhancement (SE), Cost of Implementation (C), Compatibility with Existing Infrastructure (CEI), Training and Human Adaptability (THA), Environmental Impact (EI), and Reliability in Adverse Conditions (RAC). were estimated using the CRITIC weight technique were 0.1055, 0.1087, 0.1904, 0.1261, 0.1077, 0.2025 and 0.1590 respectively, which were used to promote VIKOR techniques' application in appraising ranks of the airport ground marshalling operations such as Manual Hand Signals, Wand-Based Marshalling Systems, Follow-Me Vehicles with GPS Guidance, Infrared Camera Systems and Automated Docking Guidance Systems (ADGS) with the following results: 0.3232, 0.0082, 0.4823, 0.1411, and 0.9411, respectively. The result obtained from the analysis demonstrates that wand-based marshalling ranks first within the specific decision framework, criteria set, expert judgements, and weighting scheme used in this study. However, the existing awareness and willingness among aviation professionals to embrace technology provide a strong foundation for future studies in ground marshalling operations through accessing technology adoption rates, implementation barriers, and longitudinal performance outcomes. This study assessing five airport ground marshalling alternatives and optimisation of marshalling operations shows that effective marshalling can reduce aircraft taxi mishaps and improve apron traffic flow in congested airports.

**Keywords** Airport, Ground Marshalling. Alternatives, Criteria, CRITIC Weight, VIKOR technique



## 1 Introduction

The aviation industry is an indispensable part of the global transportation network, enabling the swift movement of people, goods, and services across continents. Its importance spans various sectors, including transport, tourism, trade, and logistics, which contribute to economic development globally. In recent years, the aviation sector has become a key driver of globalisation and economic growth, with an estimated contribution of \$3.5 trillion to the global economy annually [1].

Ground handling operations encompass the airside activities at airports responsible for managing passengers, cargo, facilities, and supplies associated with parked aircraft [2].

Ground marshalling is a critical aspect of airport operations that involves guiding aircraft during taxing, parking, and departure using visual signals, wands, or automated systems. Ground marshallers, also known as ramp agents, play a crucial role in ensuring the safety and efficiency of aircraft movements on the tarmac. At congested airports, where multiple aircraft operations coincide, ground marshalling becomes even more vital to prevent accidents, delays, and operational inefficiencies.

Aircraft marshalling is crucial because of the intricacies and inherent risks associated with manoeuvring large aircraft on the ground, as airports are usually bustling, congested environments with restricted sight, particularly in proximity to terminal gates, hangars, and taxiways. At many airports, the configuration or terrestrial impediments hinder pilots from perceiving the precise route they must navigate. In this context, marshallers offer essential direction for safe and effective navigation.

Marshalling is essential where radio communication is limited or restricted, especially in smaller airports or when ground workers and pilots are unable to clearly communicate via radio. In these situations, marshalling hand signals takes precedence over other methods of aircraft guidance. Furthermore, the marshaller's presence also adds an additional degree of safety during inclement weather, such as persistent rain or fog. Visual signals minimise the possibility of misunderstandings that could result in ground accidents by ensuring that pilots receive clear, intelligible instructions.

In addition, marshalling is necessary in emergency situations. The marshaller directs emergency personnel to the aircraft or assists in arranging for the crew and passengers' safe evacuation from an aircraft if needed on the tarmac. Pilots and ground workers alike contribute to aviation safety by comprehending and using marshalling signals efficiently.

Over the years, advancements in technology have revolutionised ground marshalling globally. Systems such as Automated Visual Docking Guidance Systems (AVDGS), Augmented Reality (AR) glasses, and sensor-based solutions have enhanced the precision and safety of aircraft handling. AVDGS, for instance, uses advanced sensors and cameras to automate the docking process, reducing reliance on human operators and minimising the risk of errors.

### **Methods for guiding aircraft to their parking positions.**

Aircraft can be guided to their assigned parking spots (gates or apron stands) using a variety of methods, which include both contemporary automated docking technology and more conventional human-based approaches. The following methods; manual hand signals, wand-based marshalling systems, follow-me vehicles with GPS guidance, infrared camera systems and automated docking guidance systems (ADGS) can be technologically classified into three: Low-tech, medium-tech, and high-tech systems.

**Manual hand signals.**

The manual hand signal method is the oldest and most popular method for directing aircraft to their parking spots at the airport, which depends on a qualified ground marshaller communicating directly to the pilot using ICAO- standardised visual hand signals or illuminated wands. With the present technological advancement in grand marshalling, the manual hand signal method is still crucial, dependable, and widely accepted.

**Wand-based marshalling systems.**

In airport ground operations, wand-based marshalling systems are one of the most popular and useful techniques for securely guiding aircraft into and out of parking spots. The approach is based on manual hand signals; however, the marshaller employs illuminated wands (batons) to enhance visibility. Furthermore, wand-based marshalling systems standardised by ICAO and IATA for global consistency, economical, adaptable, and still extensively utilised globally, notwithstanding the emergence of sophisticated docking technologies.

**Follow-me vehicles with GPS guidance systems.**

Follow-me vehicles are ground support units employed to direct aircraft while taxiing, particularly in intricate or crowded airports. GPS-based guidance systems improve accuracy, efficiency, and safety in navigating airplane between runways and parking stands. Follow-me vehicles with GPS guidance systems have high implementation costs (GPS systems, vehicle modifications, and integration). dependent on GPS signal availability (may be affected by interference) and operated by human drivers (unless paired with autonomous systems).

**Infrared Camera Marshalling Systems.**

Infrared Camera Marshalling Systems are sophisticated aircraft ground guidance technologies intended to facilitate the safe parking and alignment of aircraft, particularly in low-visibility or nocturnal conditions. An Infrared (IR) Camera Marshalling System uses thermal imaging technologies to identify and monitor aircraft activity. Rather than depending exclusively on human visual indicators (hand signals, wands) or conventional video cameras, it utilises infrared cameras to detect heat signatures from engines, tyres, and the aircraft fuselage.

Infrared camera marshalling systems represent a contemporary, technology-enhanced advancement over conventional visual docking, ensuring safer and more dependable aircraft navigation under any weather and lighting situations with higher installation and maintenance costs compared to wand systems.

Infrared camera marshalling systems require precise alignment and periodic recalibration and are affected by weather conditions such as heavy rain or extreme heat, which can sometimes distort IR imaging. Finally, over-reliance on infrared camera marshalling systems may reduce human skill in manual marshalling.

**Automated Docking Guidance Systems (ADGS).**

Automated Docking Guidance Systems (ADGS) are sophisticated electronic marshalling solutions that steer aircraft from the taxiway to an exact parking position at the gate, eliminating the necessity for direct human hand signals. Applying automated, sensor-driven technologies that show pilots instructions directly, ADGS ensures safe, effective, and accurate aircraft parking by replacing human marshalling at gates.

Automated Docking Guidance Systems (ADGS) are part of Advanced Visual Docking Guidance Systems (A-VDGS) used at modern airports which have high installation and maintenance costs, with system downtime risk and high environmental risk.

Automated Docking Guidance Systems (ADGS) are complex to operate, requiring skilled technical staff for upkeep.

## 2 Literature review

[3], in their contribution increased the efficiency of aircraft ground handling at the selected airport. They find out that in the changes in the deployment of selected ground handling equipment, the individual processes were shortened, as well as the total stay of the aircraft at the airport after landing and before take-off. [3], in their submission, confirmed that certain operations cannot be done faster, such as guiding an aircraft to the parking port or hanger. With [3], submission, technology advancement does not have a more significant effect on grand marshalling than the traditional method, knowing that speed is not required in aircraft taxing operations.

[4], investigated the impact of airport ground operations management on aviation safety performance in Kenya, focussing on the independent variables of aircraft apron movement control and aircraft refuelling processes. [4] asserted in their submission that the inadequate adherence to airport ground operations protocols contributed to compromised aviation safety, which succinctly correlates with the notion that good ground handling techniques are essential for boosting aviation safety.

[5] assessed how digital transformation changed airport ground operation, with their result showing that ground handling agents are embracing current trends to craft new business models and develop new revenue streams. [5] further examine the ground handling agent's value chain and identify areas that are strongly affected by digital transformation and those that are not. In [5]. submission, they did not identify ground marshalling operations as an area strongly affected by digital transformation. Meaning that both traditional and digital marshalling operations are actively in use in aircraft ground marshalling operations.

One notable study by [6] examined the adoption of Automated Guided Vehicles (AGVs) and Ground Positioning Systems (GPS) in Nigerian airports, with a focus on their potential to improve the safety and efficiency of ground marshalling operations. The study found that while these technologies have been successfully implemented in several developed countries, their use remains limited in Nigeria due to high initial implementation costs, inadequate infrastructure, and a lack of comprehensive government policies supporting technology adoption in the aviation sector. Furthermore, the study highlighted that despite the potential benefits, such as faster turnaround times and improved safety through real-time monitoring, the operational and financial constraints faced by Nigerian airports have resulted in minimal adoption of these advanced technologies.

[7] focused on the integration of human operators with automated ground marshalling systems. [7]'s study emphasised that despite the rise of automation in other sectors of airport operations, ground marshalling in Nigeria still relies heavily on manual, human-controlled procedures. The study illustrated that although automated technologies, such as digital signage and radar-guided systems, have the potential to reduce human error and improve the precision of aircraft movements, their implementation

remains a challenge in Nigerian airports. [7] also pointed out that human-machine collaboration could be optimised by introducing systems like augmented reality (AR) to aid marshallers in accurately guiding aircraft to parking positions, thus improving both safety and efficiency. However, the research acknowledged that this vision remains far from realised due to technological, financial, and training-related barriers.

In addition, the work of [8] explored the role of digital technologies in reducing ground incidents, such as aircraft collisions and misalignments, at Nigerian airports. The study showed that airports in Nigeria that have started to adopt digital technologies, such as radar-based guidance systems and communication tools that enable real-time feedback from marshalling teams, experienced a notable reduction in such incidents. However, the authors also observed that the adoption of these technologies is still in its infancy, with only a handful of major airports beginning to implement them on a small scale. These findings align with the general trend that while technological advancements can lead to significant improvements in safety, Nigerian airports are still largely reliant on outdated systems and traditional methods of marshalling.

Although there is limited literature on airport ground marshalling operations, from the reviewed literature, none placed superiority on any of the methods applied in ground marshalling operations. Although, there could be reasons like high cost of implementation, lack of technical know-how and lack of willingness from government, as in the case of Nigeria in the total integration of advanced technology. However, adverse weather conditions as often experienced in the two seasons in Nigeria could be a likely reason why full-scale technological adaptation has not been implemented in Nigeria. Based on the identified gap of not being able to investigate different methods of ground marshalling, this paper investigates manual hand signals, wand-based marshalling systems, follow-me vehicles with GPS guidance and automated docking guidance systems (ADGS) grand marshalling operation, alternatives for guiding aircraft to their parking positions, applying multi-criteria decision approach using the following criteria: operational efficiency (OE), safety enhancement (SE), cost of implementation (C), compatibility with existing infrastructure (CEI), training and human adaptability (THA), environmental impact (EI), and reliability in adverse conditions (RAC), from a team of three experts with detailed information and practical experience of over 10years in aircraft ground marshaling.

### 3 Methodology

This study applied CRITIC and VIKOR methods for both criteria and alternatives evaluation. The weight of each criterion was determined using CRITIC while VIKOR was used in the ranking of the alternatives to determine the best alternatives.

#### 3.1 Application critic method

The CRITIC method is an objective MCDM weighting technique that evaluates the importance of criteria based on data variability and intercriteria correlation, making it valuable when subjective expert opinions are unavailable or undesirable. CRITIC has advantage over other MCDM method like AHP or Delphi because it uses statistical information from the decision matrix, such as the standard deviation of each criterion and conflict between criteria. CRITIC (Criteria Importance Through Intercriteria Correlation) is used to calculate objective weights for criteria such as operational efficiency

(OE), safety enhancement (SE), cost of implementation (C), compatibility with existing infrastructure (CEI), training and human adaptability (THA), environmental impact (EI), and reliability in adverse conditions (RAC).

The CRITIC method procedures are described as follows:

Stage I: Decision matrix normalisation using

$$s_{jk} = \frac{s_{jk} - s_j^{worst}}{s_j^{best} - s_j^{worst}} \quad (1)$$

where the performance ratio of the considered alternative  $k$  on criterion  $j$  is represented by  $s_{jk}$ .

Stage II: Standard deviation ( $\partial_j$ ) for each criterion is determined.

Stage III: Linear correlation coefficients of paired criteria  $y_{jk}$  with the symmetric matrix are determined.

Stage IV: Using Eq. (2), the measure of conflict created by criterion is determined.

$$\sum_{k=j}^n (1 - y_{jk}) \quad (2)$$

Stage V: Quantity of information based on each criterion is obtained using equation iii

$$C_j = \partial_j \sum_{k=j}^n (1 - y_{jk}) \quad (3)$$

where criteria contrast is represented by  $C$ .

Stage VI: Using Equation (4), the objective weights of the criteria are determined

$$W_j = \frac{C_j}{\sum_{k=j}^n C_j} \quad (4)$$

where weight of the criterion is represented by  $W_j$ .

### 3.2 Application of the VIKOR method

The VIKOR method (Vlsekriterijumska Optimizacija I Kompromisno Resenje), developed by Serafim Opricovic in 1998, is a Multi-Criteria Decision-Making (MCDM) technique used to rank and select alternatives when there are conflicting criteria. It emphasises a compromise solution that is closest to the ideal, considering both individual regret (worst-case) and group utility (overall satisfaction). VIKOR is a methodology designed for the multi-criteria optimisation of intricate systems across diverse domains. [9, 10] outlined the stages involved in VIKOR Method application as follows:

Stage I: The best value  $Z_i^+$  together with the worst value  $Z_i^-$  out of all criterion ratings are determined.

Stage II: Using Eqs. (5) and (6), the utility measure values ( $T_i$ ) and regret measure values ( $U_i$ ) are computed.

$$T_i = \sum_{j=1}^m \left( W_j * \frac{Z_i^+ - Z_{ij}}{Z_i^+ - Z_i^-} \right) \quad (5)$$

Where  $W_j$  = the weight of criteria

$$U_i = \max_j \left[ W_j * \frac{Z_i^+ - Z_{ij}}{Z_i^+ - Z_i^-} \right] \quad (6)$$

Stage III:  $Q_i$  for  $i=1,2,3,\dots, m$  is computed where  $T^* = \min T_i$ ,  $T^- = \max T_i$ .  
 $U^* = \min U_i$ ,  $U^- = \max U_i$

The weight assigned to the decision-making strategy of maximising group utility is represented as “c,” whilst the weight for individual regret is designated as “1–c.” 0.5 is typically regarded as the value of “c.” The calculation of  $Q_i$  for each possibility can be determined using Equation vii.

$$Q_i = C \left( \frac{T_i - T^*}{T^- - T^*} \right) + (1 - C) \left( \frac{U_i - U^*}{U^- - U^*} \right) \quad (7)$$

where; C is the weight for a decision-making strategy of the maximum group utility. 1 – c is the weight for the individual regret. 0.5 is the typically regarded value of C. The minimum value of  $Q_i$  is the best-ranked alternative.

Stage IV: Rank the optimal alternative(s) based on the minimum value of . The ranking is deemed acceptable if the subsequent two conditions are satisfied.

Condition 1: Acceptable merit/advantage using equation viii

$$Q(a_2) - Q(a_1) \geq DQ \quad (8)$$

Hence, the alternatives selected first and second by i are a1 and a2 respectively.

$$DQ = \frac{1}{P - 1} \quad (9)$$

The number of alternatives is represented by P.

Condition 2: Sufficient consistency in decision-making.

This indicates that option a1 must also be the highest-ranked alternative by  $T_i$  and/or  $U_i$ .

Stage V: If one of the requirements in stage 4 is not met, a proposed array of compromise solutions is presented, which consists of the following:

In the event that just criterion 2 is unmet, the first and second-ranked alternatives, a1 and a2,

If condition 1 is not satisfied, options a1 and a2... a(n): the proximity of alternative a(n) ranked nth by  $Q_i$  is determined using

$$(Q(a(n)) - Q(a_1)) < DQ \quad (10)$$

### 3.3 CRITIC method application for criteria's weight determination

The scale employed in this study is shown in Table 1, which also depicts the scale that experts used to rate each criterion against the options shown in Table 2.

In this activity, three specialists with equivalent expertise in the subject of investigation facilitated the decision-making. In the weight estimation process utilizing the Critic

**Table 1** Benefit criteria rating scale [9]

| Low     | Average | High     |
|---------|---------|----------|
| 0 1 2 3 | 4 5 6   | 7 8 9 10 |

**Table 2** Experts' rating of alternatives in respect to criteria

| Experts  | Alternatives                              | Criteria |    |   |     |     |    |     |
|----------|-------------------------------------------|----------|----|---|-----|-----|----|-----|
|          |                                           | OE       | SE | C | CEI | THA | EI | RAC |
| Expert 1 | Manual Hand Signals                       | 4        | 5  | 1 | 10  | 10  | 10 | 4   |
|          | Wand-Based Marshalling Systems            | 6        | 7  | 1 | 9   | 8   | 9  | 6   |
|          | Follow-Me Vehicles with GPS Guidance      | 7        | 8  | 5 | 8   | 8   | 7  | 7   |
|          | Infrared Camera Systems                   | 6        | 7  | 4 | 6   | 5   | 8  | 6   |
|          | Automated Docking Guidance Systems (ADGS) | 9        | 9  | 6 | 7   | 6   | 6  | 6   |
| Expert 2 | Manual Hand Signals                       | 5        | 6  | 1 | 10  | 8   | 10 | 5   |
|          | Wand-Based Marshalling Systems            | 6        | 7  | 3 | 9   | 8   | 9  | 6   |
|          | Follow-Me Vehicles with GPS Guidance      | 7        | 8  | 5 | 8   | 8   | 7  | 7   |
|          | Infrared Camera Systems                   | 6        | 7  | 4 | 6   | 5   | 8  | 6   |
|          | Automated Docking Guidance Systems (ADGS) | 9        | 9  | 6 | 7   | 6   | 6  | 6   |
| Expert 3 | Manual Hand Signals                       | 6        | 7  | 1 | 10  | 9   | 10 | 6   |
|          | Wand-Based Marshalling Systems            | 6        | 7  | 2 | 9   | 8   | 9  | 6   |
|          | Follow-Me Vehicles with GPS Guidance      | 7        | 8  | 5 | 8   | 8   | 7  | 7   |
|          | Infrared Camera Systems                   | 6        | 7  | 4 | 6   | 5   | 8  | 6   |
|          | Automated Docking Guidance Systems (ADGS) | 9        | 9  | 6 | 7   | 6   | 6  | 6   |

**Table 3** Average Expert Rating

| Alternatives                              | Criteria |      |      |       |      |       |      |
|-------------------------------------------|----------|------|------|-------|------|-------|------|
|                                           | OE       | SE   | C    | CEI   | THA  | EI    | RAC  |
| Manual Hand Signals                       | 5.00     | 6.00 | 1.00 | 10.00 | 9.00 | 10.00 | 5.00 |
| Wand-Based Marshalling Systems            | 6.00     | 7.00 | 2.00 | 9.00  | 8.00 | 9.00  | 6.00 |
| Follow-Me Vehicles with GPS Guidance      | 7.00     | 8.00 | 5.00 | 8.00  | 8.00 | 7.00  | 7.00 |
| Infrared Camera Systems                   | 6.00     | 7.00 | 4.00 | 6.00  | 5.00 | 8.00  | 6.00 |
| Automated Docking Guidance Systems (ADGS) | 9.00     | 9.00 | 6.00 | 7.00  | 6.00 | 6.00  | 6.00 |

**Table 4** Rating values of normalised alternatives

| Alternatives                              | Criteria |        |        |        |        |        |        |
|-------------------------------------------|----------|--------|--------|--------|--------|--------|--------|
|                                           | OE       | SE     | C      | CEI    | THA    | EI     | RAC    |
| Manual Hand Signals                       | 0.00     | 0.00   | 1.00   | 1.00   | 1.00   | 1.00   | 0.00   |
| Wand-Based Marshalling Systems            | 0.25     | 0.33   | 1.80   | 0.75   | 0.75   | 0.75   | 0.50   |
| Follow-Me Vehicles with GPS Guidance      | 0.50     | 0.65   | 0.20   | 0.50   | 0.75   | 0.25   | 1.00   |
| Infrared Camera Systems                   | 0.25     | 0.33   | 0.40   | 0.00   | 0.00   | 0.50   | 0.50   |
| Automated Docking Guidance Systems (ADGS) | 1.00     | 1.00   | 0.00   | 0.25   | 0.25   | 0.00   | 0.50   |
| Standard deviation $\sigma_j$             | 0.3376   | 0.3464 | 0.4690 | 0.4796 | 0.3606 | 0.5831 | 0.4472 |

technique, the experts' diverse backgrounds complement one another using the benefit criteria rating scales presented in Table 1. It also illustrates the rating system that experts employed for each criterion in relation to the choices in Table 2.

A benefit criterion is more desirable if its value is higher than another benefit criterion's, and conversely while cost, which is a non-beneficial criterion, is better off with smaller values.

Table 3 shows that the average rating provided by the three experts was considered the definitive evaluation due to their equivalent expertise in the issue under investigation.

The CRITIC technique was utilised to ascertain the weights of the criteria for selecting grand marshalling operations methods.

The Eq. (1) was utilised to normalise the decision matrix in Table 3, and the results are presented in Table 4. For every criterion, the standard deviation of the normalised

**Table 5** Symmetric matrix

| Criteria | OE      | SE      | C       | CEI     | THA     | EI      | RAC     |
|----------|---------|---------|---------|---------|---------|---------|---------|
| OE       | 1.0000  | 1.5304  | -1.8035 | 0.4015  | -0.3903 | -0.9999 | 1.1589  |
| SE       | 1.5304  | 1.0000  | -1.1145 | -0.3467 | -0.5635 | -0.5510 | 1.3476  |
| C        | -1.8035 | -1.1145 | 1.0000  | 0.5669  | 0.9314  | 0.5302  | -0.4769 |
| CEI      | 0.4015  | -0.3467 | 0.5669  | 1.0000  | 0.5061  | 0.3910  | -0.2914 |
| THA      | -0.3903 | -0.5635 | 0.9314  | 0.5061  | 1.0000  | 0.4458  | -0.3487 |
| EI       | -0.9999 | -0.5510 | 0.5302  | 0.3910  | 0.4458  | 1.0000  | -0.1198 |
| RAC      | 1.1589  | 1.3476  | -0.4769 | -0.2914 | -0.3487 | -0.1198 | 1.0000  |

**Table 6** Alternative measure of conflict

| Criteria | OE      | SE      | C      | CEI    | THA    | EI     | RAC     | $\Sigma(1-r)$ |
|----------|---------|---------|--------|--------|--------|--------|---------|---------------|
| OE       | 0       | 0.5304  | 2.8035 | 0.5985 | 1.3903 | 1.9999 | -0.5890 | 5.6728        |
| SE       | 0.5304  | 0       | 2.1145 | 1.3467 | 1.5635 | 1.5510 | -0.3476 | 5.6977        |
| C        | 2.8035  | 2.1145  | 0      | 0.4331 | 0.0686 | 0.4698 | 1.4769  | 7.3662        |
| CEI      | 0.5985  | 1.3467  | 0.4331 | 0      | 0.4939 | 0.6090 | 1.2914  | 4.7726        |
| THA      | 1.3903  | 1.5635  | 0.0686 | 0.0686 | 0      | 0.5542 | 1.3487  | 5.4192        |
| EI       | 1.9999  | 1.5510  | 0.4698 | 0.4698 | 0.6090 | 0      | 1.1198  | 6.3037        |
| RAC      | -0.5890 | -0.3476 | 1.4769 | 1.2914 | 1.3487 | 1.1198 | 0       | 6.0481        |

**Table 7** Criteria contrasts

| Criteria                   | $\partial$ | $\Sigma(1-r)$ | C       |
|----------------------------|------------|---------------|---------|
| OE                         | 0.3376     | 5.6728        | 1.9151  |
| SE                         | 0.3464     | 5.6977        | 1.9737  |
| C                          | 0.4690     | 7.3662        | 3.4547  |
| CEI                        | 0.4796     | 4.7726        | 2.2889  |
| THA                        | 0.3606     | 5.4192        | 1.9542  |
| EI                         | 0.5831     | 6.3037        | 3.6757  |
| RAC                        | 0.4472     | 6.0481        | 2.8862  |
| $\sum_{j=1}^n (J=0)^n C_j$ |            |               | 18.1485 |

**Table 8** Objective weights of criteria

| Criteria | W      |
|----------|--------|
| OE       | 0.1055 |
| SE       | 0.1087 |
| C        | 0.1904 |
| CEI      | 0.1261 |
| THA      | 0.1077 |
| EI       | 0.2025 |
| RAC      | 0.1590 |

values was computed, with the findings presented in Table 5. The correlation coefficients of each pair of columns were used to create the symmetric matrix shown in Table 5.

Using Eq. (2), the measure of conflict created by criterion is determined. The extent of the conflict generated by each criterion, as influenced by the decision context established by the other criteria, was determined and shown in Table 6. The criteria contrasts were obtained with the aid of Eq. (3). The results are presented in Table 7. With the help of Eq. (4), the weights of the criterion were determined. The findings are shown in Table 8.

**Table 9** Best  $Z_i^+$  and Worst  $Z_i^-$ 

| Alternatives                              | OE   | SE   | C    | CEI   | THA  | EI    | RAC  |
|-------------------------------------------|------|------|------|-------|------|-------|------|
| Manual Hand Signals                       | 5.00 | 6.00 | 1.00 | 10.00 | 9.00 | 10.00 | 5.00 |
| Wand-Based Marshalling Systems            | 6.00 | 7.00 | 2.00 | 9.00  | 8.00 | 9.00  | 6.00 |
| Follow-Me Vehicles with GPS Guidance      | 7.00 | 8.00 | 5.00 | 8.00  | 8.00 | 7.00  | 7.00 |
| Infrared Camera Systems                   | 6.00 | 7.00 | 4.00 | 6.00  | 5.00 | 8.00  | 6.00 |
| Automated Docking Guidance Systems (ADGS) | 9.00 | 9.00 | 6.00 | 7.00  | 6.00 | 6.00  | 6.00 |
| Best $Z_i^+$                              | 9.00 | 9.00 | 1.00 | 10.00 | 9.00 | 10.00 | 7.00 |
| Worst $Z_i^-$                             | 5.00 | 6.00 | 6.00 | 6.00  | 5.00 | 6.00  | 5.00 |

**Table 10** Estimation of utility measure values  $T_i$  for each alternative

| Alternatives                              | OE     | SE     | C      | CEI    | THA    | EI     | RAC    | $T_i$  |
|-------------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Manual Hand Signals                       | 0.1055 | 0.1087 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1590 | 0.3732 |
| Wand-Based Marshalling Systems            | 0.0791 | 0.0725 | 0.0381 | 0.0315 | 0.0269 | 0.0506 | 0.0795 | 0.3782 |
| Follow-Me Vehicles with GPS Guidance      | 0.0575 | 0.0362 | 0.1523 | 0.0631 | 0.0269 | 0.1519 | 0.0000 | 0.4879 |
| Infrared Camera Systems                   | 0.0791 | 0.0725 | 0.1142 | 0.1261 | 0.1077 | 0.1013 | 0.0795 | 0.6804 |
| Automated Docking Guidance Systems (ADGS) | 0.0000 | 0.0000 | 0.1904 | 0.0946 | 0.0808 | 0.2025 | 0.0759 | 0.6442 |

### 3.4 VIKOR technique application for airport ground marshalling operations alternative ranking

Manual hand signals, wand-based marshalling systems, follow-me vehicles with GPS guidance, infrared camera systems and automated docking guidance systems (ADGS) alternatives were ranked using VIKOR techniques.

The weights of the following criteria: operational efficiency (OE), safety enhancement (SE), Cost of implementation (C), compatibility with existing infrastructure (CEI), training and human adaptability (THA), environmental impact (EI), and reliability in adverse conditions (RAC) are 0.1055, 0.1087, 0.1904, 0.1261, 0.1077, 0.2025 and 0.1590 respectively, which were used to promote VIKOR techniques application in appraising the ranks of the airport ground marshalling operations, such as manual hand signals, wand-based marshalling systems, follow-me vehicles with GPS guidance, infrared camera systems and automated docking guidance systems (ADGS).

Table 9 shows each criterion's best and worst values. The greatest value is the best value for the beneficial criteria, while the lowest value represents the worst. For non-beneficial criteria's, the optimal value is the minimum, whereas the suboptimal value is the highest. Therefore, the criterion with the best value is represented thus; environmental impact (EI) 0.2025, Cost of implementation (C) 0.1904, and reliability in adverse conditions (RAC) 0.1590, compatibility with existing infrastructure (CEI) 0.1261, safety enhancement (SE) 0.1087, training and human adaptability (THA) 0.1077, and operational efficiency (OE) 0.1055. Therefore, any alternative that will be ranked best must have in average all the above-mentioned criterions from the best value to the worst.

Equation (5) was used to compute the unity measure as Table 10 presents the computation's findings. Equation (6) is utilised to get the individual regret values for each choice, and the outcomes are presented in Table 11. The individual's regret in every row, the greatest value is the value.

The optimal values of  $T_i$  and  $U_i$ ,  $T^*$  and  $U^*$ , respectively, were estimated and presented in Table 12. Table 12 estimates the values of  $T^-$  and  $U^-$ , which are the worst values of  $T_i$  and  $U_i$ . The results of applying Eq. (7) to the computation of  $Q_i$  for each possibility are shown in Table 13.

**Table 11** Estimation of the regret measure values  $U_i$  for each alternative

| Alternatives                              | OE     | SE     | C      | CEI    | THA    | EI     | RAC    | $U_i$  |
|-------------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Manual Hand Signals                       | 0.1055 | 0.1087 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1590 | 0.1590 |
| Wand-Based Marshalling Systems            | 0.0791 | 0.0725 | 0.0381 | 0.0315 | 0.0269 | 0.0506 | 0.0795 | 0.0795 |
| Follow-Me Vehicles with GPS Guidance      | 0.0575 | 0.0362 | 0.1523 | 0.0631 | 0.0269 | 0.1519 | 0.0000 | 0.1523 |
| Infrared Camera Systems                   | 0.0791 | 0.0725 | 0.1142 | 0.1261 | 0.1077 | 0.1013 | 0.0795 | 0.1142 |
| Automated Docking Guidance Systems (ADGS) | 0.0000 | 0.0000 | 0.1904 | 0.0946 | 0.0808 | 0.2025 | 0.0759 | 0.2025 |

**Table 12** Alternatives and their unity measures, and regret values

| Alternatives                              | $T_i$  | $U_i$  |
|-------------------------------------------|--------|--------|
| Manual Hand Signals                       | 0.3732 | 0.1590 |
| Wand-Based Marshalling Systems            | 0.3782 | 0.0795 |
| Follow-Me Vehicles with GPS Guidance      | 0.4879 | 0.1523 |
| Infrared Camera Systems                   | 0.6804 | 0.1142 |
| Automated Docking Guidance Systems (ADGS) | 0.6442 | 0.2025 |
| $T^* U^*$                                 | 0.3732 | 0.0795 |
| $T^- U^-$                                 | 0.6804 | 0.2025 |

**Table 13** Ranks of alternatives obtained

| Alternatives                              | $T_i$  | $U_i$  | $Q_i$  | Ranking of Alternatives |
|-------------------------------------------|--------|--------|--------|-------------------------|
| Manual Hand Signals                       | 0.3732 | 0.1590 | 0.3232 | 2                       |
| Wand-Based Marshalling Systems            | 0.3782 | 0.0795 | 0.0082 | 1                       |
| Follow-Me Vehicles with GPS Guidance      | 0.4879 | 0.1523 | 0.4823 | 3                       |
| Infrared Camera Systems                   | 0.6804 | 0.1142 | 0.1411 | 4                       |
| Automated Docking Guidance Systems (ADGS) | 0.6442 | 0.2025 | 0.9411 | 5                       |
| $T^* U^*$                                 | 0.3732 | 0.0795 |        |                         |
| $T^- U^-$                                 | 0.6804 | 0.2025 |        |                         |

### 3.5 Acceptance of rank choice

With the use of Conditions 1 and 2, it is possible to ascertain whether the rank option is accepted using Eqs. (8) and (9).

Condition 1:

$$Q(a_2) - Q(a_1) \geq DQ$$

where  $DQ = \frac{1}{5-1} = 0.25$ ;  $a_2 = 0.3232$ ;  $a_1 = 0.0082$ .

Applying the values we have.

$$= 0.3232 - 0.0082 \geq 0.25$$

$$= 0.3150 \geq 0.25$$

Since Eq. (10), Condition 1 is satisfied, and Condition 2 is also satisfied, since  $a_1$  is the best-ranked alternative by  $U_i$ .

### 3.6 Result discussion

According to the outcome shown in Table 13, the  $Q_i$  value of the following ground marshalling; manual hand signals, wand-based marshalling systems, follow-me vehicles with GPS guidance, infrared camera systems, and automated docking guidance systems (ADGS) are 0.3232, 0.0082, 0.4823, 0.1411, and 0.9411 respectively.

Based on VIKOR technique, for wand-based marshalling systems to be adopted as the best ground marshalling alternative, two conditions must be met. Based on the result

obtained, the two conditions were satisfied since  $Q(a2) - Q(a1)$  equals 0.3932, which is greater than  $DQ$ , 0.25. Condition 2 is also satisfied since the wand-based marshalling systems is also the best-ranked alternative by  $U_i$ .

In order for wand-based marshalling systems to be adopted as the best alternative according to the VIKOR method, it is required to meet Conditions 1 and 2. Based on the result obtained, the two conditions were satisfied since  $Q(a2) - Q(a1)$  equals 0.3150, which is greater than  $DQ$ , 0.25. Condition 2 is also satisfied since the wand-based marshalling systems is also the best-ranked ground marshalling alternative by  $U_i$ . We can conclude that the technique has successfully identified a prominent alternative for ground marshalling.

#### 4 Conclusions

This study demonstrates the practical value of the hybrid CRITIC–VIKOR framework in systematically evaluating and ranking alternative aircraft marshalling systems for guiding aircraft to their parking positions. By integrating objective criterion weighting with compromise-based ranking, CRITIC–VIKOR approach provides a structured and transparent basis for decision-making in complex, multi-criteria airport ground operation environments. The findings suggest that the wand-based marshalling systems as the top-ranked alternative offers a balanced trade-off among the following criterion; Operational Efficiency (OE), Safety Enhancement (SE), Cost of Implementation (C), Compatibility with Existing Infrastructure (CEI), Training and Human Adaptability (THA), Environmental Impact (EI), and Reliability in Adverse Conditions (RAC) with value as 0.0791, 0.0725, 0.0381, 0.0315, and 0.0269. The results reflect a relative ranking under the selected criteria and expert assessments. The findings do not imply general dominance of wand-based systems across all airports or operational scenarios.

The researchers propose that future research should test the proposed ranking framework using empirical data from operational airport environments, such as aircraft turnaround time, ground incident reports, near-miss statistics, and maintenance logs. Longitudinal data collection across multiple airport categories (e.g., regional, international hub, and high-density urban airports) would allow for performance benchmarking and external validation of the model's predictive and practical reliability.

Furthermore, a formal sensitivity analysis should be conducted to assess how variations in criterion weights and performance scores influence the final ranking. Techniques such as weight perturbation, Monte Carlo simulation, or scenario-based testing can be employed to identify stability intervals and determine whether the preferred alternative remains dominant under plausible changes in assumptions and data uncertainty.

In addition, CRITIC–VIKOR results should be systematically compared with rankings generated using alternative multi-criteria decision-making methods, such as AHP, TOPSIS, PROMETHEE, ELECTRE, and fuzzy or stochastic MCDM extensions. Cross-method consistency testing would help establish whether the identified optimal solution is method-independent or sensitive to the choice of analytical framework.

While CRITIC provides objective weighting, future studies could adopt hybrid weighting schemes that combine data-driven approaches with structured expert elicitation (e.g., Delphi method or fuzzy AHP). This would allow the incorporation of tacit operational knowledge, safety culture considerations, and regulatory priorities into the decision-making process.

Further research should explore how the framework performs under varying contextual conditions, such as adverse weather, low-visibility operations, airport layout complexity, and differences in regulatory or technological maturity across regions. This would improve the model's adaptability and global applicability.

In conclusion, while the CRITIC–VIKOR approach offers a rigorous and transparent foundation for evaluating airport ground marshalling operation alternatives. The analysis demonstrates that wand-based marshalling ranks first within the specific decision framework, criteria set, expert judgements, and weighting scheme used in this study. This study assessing five airport ground marshalling alternatives and optimisation of marshalling operations further shows that effective marshalling can reduce aircraft taxi mishaps and improve apron traffic flow in congested airports.

#### Author contributions

1. Joshua Nwachukwu Osuji—Conceptualisation, Methodology, Formal analysis, Visualisation, Writing, Review & Editing. 2. Idisi Moses Mario— Formal analysis, Writing, Review & Editing. 3. Uche James—Writing, Review & Editing. 4. Idama Favour— Data collection, Writing, Review & Editing.

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#### Data availability

The manuscript has no associated data or materials.

#### Declarations

##### Ethics approval and consent to participate

Ethical approval not required to carry out the research. Consent was given by the participants to be part of the research.

##### Consent for publication

Consent given to publish the research.

##### Competing interests

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