



# An integrated fuzzy MCDM model for prioritizing strategies for successful implementation and operation of the bus rapid transit system

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## Abstract

The selection and prioritization of suitable strategies to address the challenges to the successful operation and implementation of the bus rapid transit (BRT) system is a common problem faced by practitioners and decision-makers. Recent research has widely discussed the issue, but such assessments have remained limited in the city of Dar es Salaam, Tanzania context, where there are mobility difficulties. The present study addresses this research gap and identifies the most critical challenges to BRT implementation and operation, and recommends the most appropriate strategy for overcoming them. Seven strategies are defined. To prioritize these strategies, five criteria are determined. An integrated multi-criteria decision-making model is introduced. Improved Fuzzy Step-Wise Weight Assessment Ratio Analysis based on the Bonferroni operator was used to determine the importance of the criteria. Measurement of alternatives and ranking according to compromise solution was applied to assess and rank the strategies. The results indicate that “frequent flooding at the Jangwani bridge bus terminal” and “long waiting time at bus stops” are the most critical challenges while the fourth alternative “strengthening the operation and management” is the appropriate strategy to be implemented for successful operation and implementation of the BRT system. After that, a five-phase sensitivity analysis is performed to observe the robustness of the proposed approach. The results indicate the flexibility and applicability of the proposed approach can address real-life problems. The proposed methodology in this work can be instrumental in assisting mass transit operators with the successful implementation and operation of the BRT system.

**Keywords** Dar es Salaam · BRT · MARCOS · IMF SWARA · Operation · Implementation

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# 1 Introduction

Rapid urbanization, a trait of developing nations, particularly those in Africa, has created several transportation problems, including congestion (Adarkwa & Poku-Boansi, 2011), safety concerns (Obeng-Atuah et al., 2017), inaccurate public transportation systems (Poku-Boansi, 2011), imperfect and deficient pedestrian facilities (Amoako et al., 2014), misconduct amidst public transportation providers in terms of not adhering to traffic laws (Agyemang, 2015), rising vehicle ownership (Adarkwa & Poku-Boansi, 2011), unexpected services (Poku-Boansi & Marsden, 2018), and increasing travel demand, particularly in major cities (Poku-Boansi, 2021).

In response to these problems, most governments in developing nations have started reforming their transportation systems with assistance from multilateral institutions like the World Bank and the African Development Bank (ADB). In this context, bus rapid transit (BRT) has emerged as the preeminent economical and effective mass transportation technology that can be installed quickly (Hidalgo & Graftieaux, 2008). BRT systems are already in operation in 45 countries worldwide, with approximately 5542 km of lanes being used (Global BRT Data, 2016).

BRT systems are part of the solution to the continuing global urban expansion impacts in most nations, but notably the metropolitan areas in the emerging world. Before the establishment of BRT, the delivery of public transportation service was frequently marked by the hegemony of irregular operators who run mini-buses that were privately controlled but were hugely coordinated at the route level via alliances. Notwithstanding concerns with safety, accuracy, and congestion, the vast majority of people traveling rely on these services to move around. According to research on the deployment of many BRT projects globally (Kumar et al., 2011), BRT systems have particular implementation issues that, if not handled appropriately early, might result in less-than-acceptable outcomes.

The implementation of BRT systems frequently necessitates a transition from a disorganized public transportation sector to a system that is administered and regulated. The activities of many entities involved in designing, budgeting, implementing, and operating different components of the public transportation system must also be coordinated. Additionally, there is frequently the requirement to perform innovative features that no organization has before undertaken.

In Africa, only three of the 54 nations currently have BRT systems: Nigeria, South Africa, and Tanzania (Agyemang, 2015; Ka'bange et al., 2014; Kumar et al., 2012; McLachlan, 2010; Mobereola, 2009; Rizzo, 2015; Ugo, 2014; Wood, 2015). Many other BRT systems in Africa are still operational, and more are expected in large cities across the continent, particularly Addis Ababa (Ethiopia) and Kigali (Rwanda). The Dar es Salaam bus rapid transit (DART), also referred to as Mwendokasi, is a bus-based transportation system that was put into place in Dar es Salaam to enhance the city's public transportation services by offering lanes specifically designated for boarding stations and bus services with a quick passenger processing system (Chengula & Kombe, 2017).

Dar es Salaam BRT system in Tanzania is the third BRT system in Sub-Saharan Africa, following those in Nigeria and South Africa. A review of the literature yielded no studies that highlighted the prioritization of strategies for the successful implementation and operation of the BRT system in this region of the world. It would be particularly fascinating to learn about the most crucial challenges to BRT implementation and operation, as well as the most effective strategy for overcoming them. Previous research looked into several aspects of the BRT system in Tanzania at various phases of the project. One of the studies examined

the operational implications and difficulties DART operations experienced. Interviews with DART stakeholders were conducted as part of a survey to achieve the study's goal (Matata et al., 2017). Another study on DART used a Bayesian hierarchical modeling approach and a Bayesian hypothesis test to compare the operational performance of BRT against two other modes of transportation (Andrew et al., 2022). The results of their study showed that several factors such as delay and time of day significantly influenced travel time variability along the study routes. There was another study based on interviews and questionnaires that evaluated the effectiveness of DART (Chengula & Kombe, 2017). Besides, Tengecha and Mwendapole (2021) used a semi-structured interview method to collect data related to the DART phase implementation and development. They found that management issues and frequent floods in the main station are among the challenges of the project.

The implementation and operation of DART are one of the topics covered, as shown in the literature review (Andrew et al., 2022; Chengula & Kombe, 2017; Matata et al., 2017; Tengecha & Mwendapole, 2021). But up till now, there have been critical gaps as follows:

- No previous research has used the MCDM method for the identification of the most critical challenges to BRT implementation and operation and recommends the most appropriate strategy for overcoming them. Hence, the results of this limited research were unable to offer mass transit operators any new information regarding the successful implementation and operation of the BRT system.
- No previous work has combined the IMF SWARA based on the Bonferroni operator and MARCOS methods into a single methodological framework.
- This is the first study of this kind that proposes a thorough methodological framework for the prioritization of strategies for the successful implementation and operation of the bus rapid transit system in Tanzania.

There are numerous strategies available, and BRT operators need to choose the suitable one. Recommending a strategy for successful BRT implementation and operation based on specific criteria can lead to poor decisions. As a result, various criteria should be considered, and an appropriate MCDM tool should be used. When determining which strategy is the most appropriate, MCDM approaches can be quite helpful (Ayyildiz, 2022; Ayyildiz & Taskin, 2022; Ayyildiz & Taskin Gumus, 2021; Bouraima et al., 2022a, 2022b, 2022c). MCDM techniques are used in a variety of fields and are critical in determining the best option from several choices (Bouraima et al., 2022a, 2022b, 2022c; Gündoğdu, 2022; Stević et al., 2022). These decision-making models are carried out utilizing proper mathematical methodologies. MCDM approaches are helpful means for assisting policymakers who are involved in the evaluation process (Bouraima et al., 2022a, 2022b, 2022c).

In this study, we used the improved fuzzy SWARA (IMF SWARA) to assess the weights of the criteria. This method was proposed by Vrtagić et al. (2021) to overcome the drawbacks of the previously developed fuzzy SWARA method. In comparison to fuzzy SWARA, the application of the IMF SWARA has three advantages: (i) two or more criteria can have equal values; (ii) giving the value (0,0,0), equal values are obtained and not values twice as large, and (iii) less important criteria have greater values and can play a considerable role in the decision-making procedure. We also used the MARCOS method proposed by Stević et al. (2020) to classify the alternatives. A distinctive attribute of the MARCOS method is its provision of a robust decision through the integration of the three points: (i) definition of references points (ideal and anti-ideal values); (ii) determination of the relationships between the references points and alternatives; (iii) definition of the utility degree of alternatives concerning the ideal and anti-ideal solutions. It is also important to highlight that the Bonferroni operator is applied to define the initial matrix and aggregated the opinions of experts.

**Table 1** List of abbreviations

AHP	Analytical Hierarchy Process
ARAS	Additive Ratio Assessment
CODAS	COmbinative DIstance-based ASsessment
COPRAS	Complex PROportional Assessment
CRADIS	Compromise ranking of alternatives from distance to ideal solution
DEMATEL	Decision-making trial and evaluation laboratory
EDAS	Evaluation based on distance from average solution
FRBS	Fuzzy rule-based system
GAHP	Group analytic hierarchy process
GRA	Grey relational analysis
MABAC	Multi-attributive border approximation area comparison
MAIRCA	Multi attributive ideal-real comparative analysis
PROMETHEE	Preference ranking organization method for enrichment of evaluations
SAW	Simple additive weighting
SWARA	Stepwise weight assessment ratio analysis
TOPSIS	Technique for order preference by similarity to the ideal solution
VIKOR-	VIskriterijumska optimizacija i KOmpromisno Resenje
WASPAS	Weighted aggregated sum product assessment

After the introduction in Sect. 1, the rest of the paper is structured as follows. Section 2 provides an overview of the literature review. Section 3 presents the definition of criteria and alternatives. Section 4 provides the creation of the methodology that is described and explained in detail. Section 5 presented a case study with a detailed calculation given for each approach of the proposed methodology. Section 6 demonstrated the stability of the model through a five-phase sensitivity analysis. The discussion, managerial and practical implications, and conclusions are given in Sects. 7 and 8, respectively.

## 2 Literature review

A list of abbreviations used in this section is provided, followed by a review of previous research on the BRT system investigation, and finally a presentation of the use of MCDM methods in the BRT system.

### 2.1 Abbreviations

Table 1 indicates the list of abbreviations used in this section.

### 2.2 Research on BRT system investigation

BRT systems have dedicated bus lanes, quick fare collecting, modern buses, well-designed terminals, cutting-edge transportation system technologies, and adaptable service schedules. BRT has recently been developed in various nations to address urban transportation demands

(Deng et al., 2013). With minimal time spent on construction and low investment and operational costs, it has been successful in alleviating traffic congestion. Most BRT lanes are built on existing highways, making them more cost-effective than rail-based systems for mass transportation (Abdelghany et al., 2007). Along with the implementation and operation of BRT systems, several research contributions have been undertaken to fully appreciate their impacts.

Acton et al. (2022) used a quasi-experimental technique and hedonic spatial error models with propensity score matching to assess and compare the before-and-after effects of 11 BRT systems on nearby property values in ten metropolitan regions throughout the United States. Lopes et al. (2022) evaluated the interest and refusal factors for the installation of BRT stations situated on the highway's centerline between the opposing traffic lanes. Asimeng (2021) analyzed the strategy used to determine the causes of the projected BRT's failure and concludes the Ghanaian experience. The findings highlighted the difficulties the implementing agency faced, which led to a switch from BRT to a regular bus. According to the information gathered from a questionnaire-based survey, Al-Shaar et al. (2022) created mode choice models to investigate how much knowledge of a new public transportation option in Lebanon would influence mode choice. This study demonstrated the importance of taking into account people's perceptions of new modes of transportation as well as their level of familiarity with older ones when conducting feasibility assessments for any transportation projects in developing nations. Asimeng and Heinrichs (2021) identified the reasons why paratransit operators resist and show low interest in BRT even in situations where public institutions have opted not to replace them but rather invite them to participate in the reforms.

Klopp et al. (2019) examined how BRT developments affect the future of the predominant minibus systems and the creation of urban governance. Otunola et al. (2019) provided a detailed account of the African continent's first BRT system, which opened in 2008 in Lagos, highlighting key factors behind its efficient and effective reforms as well as important principles for other cities looking to improve their public transportation systems. Scordia and Munoz-Raskin (2019) offered insight into the debate over whether there are structural operational indicator disparities between South African cities and their Latin American counterparts for BRT systems. Krüger et al. (2021) studied the BRT as a crucial infrastructure component in Dar es Salaam and investigated its impact on citizens' lifestyles, concentrating on the impact of service disturbances on daily activities and diverse stakeholders' perspectives on the BRT's functionality. Venter et al. (2018) conducted an empirical investigation of the equality consequences of operational BRT systems in the Global South. According to findings from Africa, Asia, and Latin America, BRT offers significant benefits to low-income people in terms of travel time and cost reductions, access enhancement, and safety and health benefits.

Kapadia et al. (2022) conducted a critical analysis of numerous elements influencing the implementation of BRTS services around the world and their application in India. They also addressed how the implementation of a new transportation system influences environmental factors, in addition to the numerous social and physical repercussions. Khan et al. (2022) assessed the first BRT project in Karachi for potential cost savings through perfect coordination of the BRT. Their results indicated that by installing a two-way side-oriented or curb-side-oriented BRT infrastructure without compromising existing capacity, the cost of this stretch could have been reduced. Cruz-Daraviña et al. (2021) investigated the full impact of BRT system adoption on urban freight using Cali (Colombia) as a case study to understand the source and magnitude of these impacts. According to the findings from Cali, the immediately surrounding BRT corridors produce over 62% of urban freight traffic. McGreevy (2021) assessed the appropriateness of four common public transportation systems using data

from a literature review as well as statistical and physical evaluations. Their findings suggested that a “Curitiba-styled” BRT system is the best option for the location due to several socioeconomic benefits. Chang et al. (2022) concentrated on evaluating the spatial synergy between the integrated urban rail transit system and urban form by defining the evaluation criteria based on reviews of relevant literature and developing a novel multi-criteria large-scale group assessment (MCLSGA) in which basic uncertain linguistic information (BULI), an extended form of fuzzy linguistic approach, is used to model and process the subjective assessment information elicited by experiments.

### 2.3 BRT transportation system studies with application of MCDM

The public transportation system has so far employed MCDM to address a wide range of issues, including optimization, management, prioritization, performance, sustainability, and service quality (Aydin et al., 2022; Deveci et al., 2019, 2022; Gokasar et al., 2022a, 2022b; Gokasar et al., 2022a, 2022b). Mavi et al. (2018) evaluated the development scenarios of a BRT system in Tehran using integrated SWARA and COPRAS methodologies in a grey environment. Their analyses revealed that adding buses to the BRT line is the greatest option for increasing the performance of Tehran’s BRT line 1. Erdoğan and Kaya (2020) suggested an integrated systematic approach that includes FRBS, fuzzy MCDM, stochastic MCDM, mathematical modeling, information theory, and heuristic approaches to mitigate risks associated with BRT system failures. The proposed systematic approach was applied to the Istanbul BRT system, and several measures were recommended to produce a more effective maintenance plan. Keyvan Ekbatani and Cats (2015) proposed an MCDM modeling framework including lexicographic, SAW method, TOPSIS method, and concordance analysis for the appraisal of multi-modal urban public transportation services namely regular bus, BRT, and rail rapid transit. Their study’s findings are useful in guiding planning decisions and selecting efforts to improve public transportation. Lambas et al. (2018) applied an MCDM technique to compare and determine a global score of public transport systems between light rail transit and the BRT system in Spain and Italy, respectively. Erdogan and Kaya (2019) employed a hybrid mechanism including interval type-2 fuzzy AHP, stochastic TOPSIS, and Delphi methods to determine the severity of failures in the BRT system in Istanbul (Turkey). Liu et al. (2020) established an extenics-based model using the AHP and entropy methods to formulate the dependence function for measuring the correlation between bus and system performance. Salavati et al. (2020) proposed objective framework-based AHP-TOPSIS methods to compare four public transport modes namely BRT, regular bus, light rapid transit, and metro. Manzolli et al. (2021) presented a study based on MCDA using the PROMETHEE method to compare electric buses with the more conventional rapid transit options under four scenarios to account for different perspectives. The results indicate the benefits of each option concerning the considered scenario. Nassereddine and Eskandari (2017) proposed an integrated MCDM technique based on the Delphi method, GAHP, and PROMETHEE to assess the satisfaction levels of passengers from public transportation systems in Tehran. Kurniawan et al. (2021) applied the fuzzy AHP-DEMATEL techniques to address the passengers’ decision parameters on using the BRT system in Indonesia. Deveci (2018) proposed an interval type-2 fuzzy TOPSIS and GRA-based VIKOR method for the evaluation of customer satisfaction in all the transportation modes in Istanbul. Dadashpour and Rostami (2018) applied the AHP and PROMETHEE II to identify and classify the best fuel for the BRT system to prevent air pollution emissions. Table 2 summarizes an application of MCDM on the BRT system.

**Table 2** Summary of MCDM application on the BRT systems

Authors	Country/continent	Main-criteria	Sub-criteria	Alternatives	Number of experts	Topic
Mavi et al. (2018)	Iran	4	17	4	20	BRT performance assessment
Erdogan and Kaya (2020)	Turkey	–	15	5	3	Risk assessment of public transport
Keyvan Ekbatabi and Cats (2015)	Iran	–	17	3	154	Public transport system appraisal
Lambas et al. (2018)	Spain, Italy	–	30	2	–	Comparative analysis of transit systems
Erdogan and Kaya (2019)	Turkey	5	17	–	10	Failure assessment in BRT system
Liu et al. (2020)	China	2	18	5	20	Bus transit performance assessment
Salavati et al. (2020)	Iran	3	20	4	13	Public transport mode choice
Manzollli et al. (2021)	Europe	3	14	4	–	Rapid transit system evaluation
Nassereddine and Eskandari (2017)	Iran	6	–	5	15	Public transportation system evaluation
Kurniawan et al. (2021)	Indonesia	4	21	–	3	BRT system performance assessment
Deveci (2018)	Turkey	8	–	3	6	Customer satisfaction assessment in the public transportation system
Dadashpour and Rostami (2018)	Iran	8	25	4	3	Alternative fuels assessment for the BRT system

The use of MCDM on BRT systems is one of the subjects discussed, as can be seen from the literature review. However, there is no methodological framework for prioritizing strategies for the successful implementation and operation of the bus rapid transit system. Therefore, using IMF-SWARA-BO-MARCOS methodology, this study suggests a framework for precisely identifying the most critical challenges to BRT implementation and operation, as well as prescribing the most efficient strategy for resolving them. The main contributions and novelty of this study are as follows: (i) the authors collected primary data through IMF SWARA and MARCOS questionnaires from a decision-making panel consisting of experienced professionals from the Dar Rapid Transit Agency; (ii) the authors fill the literature gap on the implementation and operation of the bus rapid transit system in Tanzania. In an extensive search, no study has addressed this topic, identified the most critical challenges to BRT implementation and operation, as well as prescribed the most efficient strategy for resolving them. Therefore, this paper assesses the challenges to BRT implementation and operation in Tanzania. Scientists could replicate the model findings and practical and managerial implications to comprehend the successful implementation and operation of the BRT system in management science. The research's findings can be used as a benchmark for additional investigation by academicians' who study mass transit systems; (iii) this study takes advantage of MCDM methods, which are critical in determining the best option from several choices. The authors further use the IMF-SWARA to determine the weights of challenges (criteria) to BRT implementation and operation. Then, the appropriate strategy is suggested to overcome the challenges after being ranked using the MARCOS method; (iv) giving experts experimental data and utilizing an exceptional MCDM feature to assist them in all steps of the procedure can be recognized as one more contribution. By examining the IMF-SWARA-BO-MARCOS model, the method is an appropriate technique that can be used to solve issues while criteria cannot be illustrated in numerical expressions, especially in the BRT implementation and operation plan and its examination; (v) the findings would be practical for Tanzania's government to overcome the challenges (criteria) to BRT implementation and operation through the choice of appropriate strategies; and (vi) the demonstrated methodology can be extended to other BRT projects across the African continent.

### 3 Problem definition

Because public transportation is considered a key infrastructure and hence an efficient way to make sustainable urban lifestyles and life worlds, discovering solutions to escalating traffic and congestion issues has become an increasingly important matter in recent decades. As a result, a plan to deploy a BRT system in Dar es Salaam appeared in 2002. However, the new transportation system has presented several challenges related to the implementation and operation procedure (Chengula & Kombe, 2017; Ka'bange et al., 2014). Based on these observations, a framework is developed to analyze current challenges using reviewed literature, reports, official documents, and expert opinions. While everyone faces these challenges, solutions should be considered to ensure the BRT's successful implementation and operation. In this study, experts are required to examine adopting efforts to prevent the BRT system's implementation and operation from failing. There are seven distinct alternatives to avoid its ineffective installation and operation.



### 3.1 Definition of alternatives

There are certain alternatives for experts to consider to effectively apply optimization techniques for the successful implementation and operation of a BRT system.

*S1 Introducing a stable automated fare collection (AFC) system* It is critical to implement the AFC system to have a safe and dependable payment system. The AFC system is a collection of items used to automate the ticketing system in the public transportation network (Omoruyi et al., 2018). This safe system includes a ticket-checking machine, an automatic gate machine, and a ticket vending machine, all of which are powered by chip-equipped contactless smart cards. The AFC system improves the accuracy and safety of fare collection.

*S2 Enhance consistency in bus schedules* Due to some structural issues, the BRT system has not yet been able to perform at its full capacity. Due to a lack of operating buses, most bus stops experience long wait periods and crowded buses (Krüger et al., 2021). Thus, there is a need to consistently enhance bus schedules.

*S3 Hire skilled operators* Many buses break down because they don't get checked and repaired frequently. Unskilled operators are to blame for this. Consequently, there is a need to hire skilled operators (Asimeng, 2021).

*S4 Strengthen the operation and management* Despite widespread support among Dar es Salaam people, various problems force the DART system to operate in suboptimal settings. Firstly, the system is typically congested during peak morning and evening hours. Second, intelligent transport system technologies are not fully integrated. Furthermore, the traveler information system is only available on onboard platforms and is not available to passengers waiting for the bus. Based on these observations, there is a need to strengthen the operation and management (Matata et al., 2017).

*S5 Schedule many buses during pick hours* More buses should be provided by BRT management to avoid overcrowding in bus stations or terminals, particularly during peak hours (Tengecha & Mwendapole, 2021). Numerous buses on shorter routes ending nearby should be emphasized.

*S6 Encouraging regular bus checkups and repairs* It is highly encouraged to frequently check and repair buses to minimize unnecessary bus failures (Tengecha & Mwendapole, 2021).

*S7 A feasibility study* Enough research must be conducted before the construction of bus terminals; this will decrease or eliminate various management issues, such as those witnessed at the Jangwani bridge bus terminal (Tengecha & Mwendapole, 2021).

### 3.2 Definition of criteria

Five challenges have been identified from the literature review and opinions of experts.

*C1 Frequent flooding at Jangwani BRT terminal* According to current data, the Jangwani lowlands have been flooded practically every rainy season for several years (Ka'bange et al., 2014). In such circumstances, the provision of BRT transport services has ceased, resulting in the immobility of people and other operations that rely only on BRT services for transportation in and out of the city (Krüger et al., 2021).

*C2 E-ticketing problem* The e-ticketing system is an essential component of the Intelligent Transportation System (ITS), which will allow commuters to plan their routes and substantially minimize the amount of time they spend waiting for buses at bus stops. It also aids in the capture of crucial data in transportation operations, which aids in the planning

and regulation of transportation services in the city. However, it has been recently noticed a shortage of e-tickets (Chengula & Kombe, 2017; Munishi et al., 2021).

*C3 Long waiting time at bus stops* The limited number of BRT buses is a challenge that leads to long waiting times and overcrowded BRT stations, especially at peak times (Chengula & Kombe, 2017; Krüger et al., 2021).

*C4 Lack of expert operation and management* Because of the lack of experts and the re-assignment of roles and responsibilities, operational processes have been significantly delayed. Every day, the high number of passengers, the low number of buses running in the system, and the ensuing overcrowding and delays pose significant issues (Krüger et al., 2021).

*C5 Inconsistency bus schedules* The lack of operational schedules is among the managerial issues that impede the successful operation and implementation of the BRT system (Tengecha & Mwendapole, 2021).

## 4 Methodology

In the research, an integrated IMF SWARA-MARCOS methodology is presented to assess the weight of criteria and to prioritize the strategies for the successful implementation and operationalization of BRT based on the weighted criteria. Figure 1 indicates the integrated methodology. The mathematical calculations of IMF SWARA are first examined. Next, the Bonferroni operator is used for the aggregation of experts' opinions and the determination of the initial matrix. The MARCOS method is finally shown as the ranking means.

### 4.1 IMF SWARA method

The improved fuzzy SWARA is introduced by Vrtačić et al. (2021). After that, many researchers have applied it to many fields such as the assessment of logistics village (Zolfani et al., 2021), healthcare system evaluation (Vojinović et al., 2022), construction machinery selection (Matić et al., 2022), the impact of vehicles on the safety of traffic (Damjanović et al., 2022), transportation of dangerous goods (Vojinović et al., 2021), sustainability of the economic system (Starčević et al., 2022), and production optimization (Dordević et al., 2022). The improved fuzzy SWARA comprises five subsequent steps as follows:

*Step 1* Examination and classification of criteria in descending order of critical importance.

*Step 2* Obtention of the significant importance of the criterion ( $C_j$ ) in contrast with the precedent one ( $C_{j-1}$ ), based on the initially acquired classification and linguistic scales from Table 3.

*Step 3* Computation of fuzzy coefficient  $\bar{k}_j$

$$\bar{k}_j = \begin{cases} \bar{1} & j = 1 \\ \frac{\bar{1}}{s_j} & j > 1 \end{cases} \quad (1)$$

*Step 4:* Determination of the weights  $\bar{q}_j$

$$\bar{q}_j = \begin{cases} \bar{1} & j = 1 \\ \frac{\bar{q}_{j-1}}{\bar{k}_j} & j > 1 \end{cases} \quad (2)$$

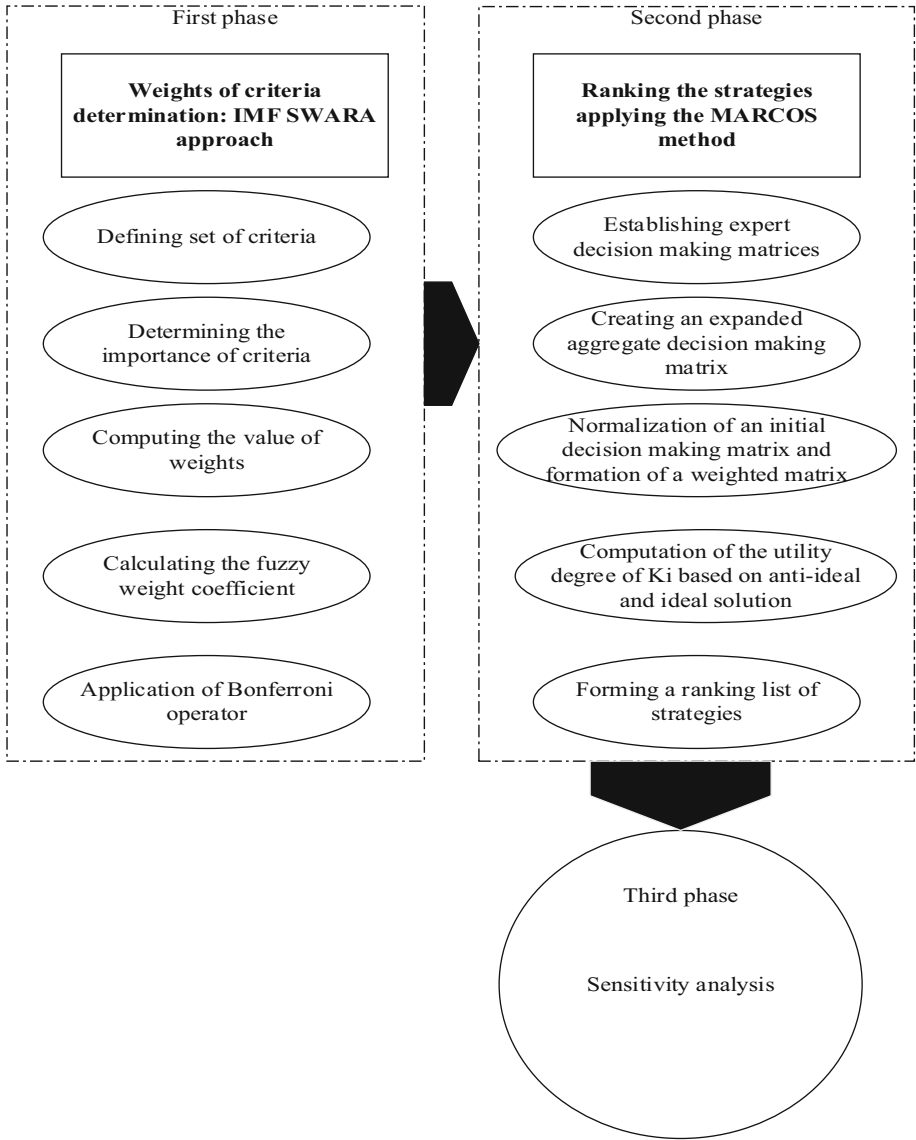


Fig. 1 Research flow diagram of the IMF SWARA MARCOS model

Step 5 Definition of the fuzzy weight coefficients

$$\bar{w}_j = \frac{\bar{q}_j}{\sum_{j=1}^m \bar{q}_j} \tag{3}$$

where  $w_j$ —the analogue fuzzy weight of the criteria  $j$ ;  $m$ —the number of criteria.

**Table 3** Linguistic terms of the improved IMF SWARA method

Linguistic terms	Scale
Absolutely less	1.000, 1.000, 1.000
Dominantly less	0.500, 0.667, 1.000
Much less	0.400, 0.500, 0.667
Really less	0.333, 0.400, 0.500
Less	0.286, 0.333, 0.400
Moderately less	0.250, 0.286, 0.333
Weakly less	0.222, 0.250, 0.286
Equally	0.000, 0.000, 0.000

## 4.2 Bonferroni operator

The Bonferroni operator (Bonferroni, 1950) is applied to aggregate the experts' opinions and to determine the initial decision-making matrix.

$$a_{ij} = \left( \frac{1}{e(e-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^e a_i^{mp} \otimes a_j^{mq} \right)^{\frac{1}{p+q}} \quad (4)$$

where  $e$  represents the number of experts who take part in the survey, while  $p, q \geq 0$  is a set of non-negative numbers.

## 4.3 MARCOS method

Stević et al. (2020) have recently proposed the MARCOS method, which principle consists of finding a solution based on the interconnection between reference values and alternatives. The MARCOS approach is utilized in a variety of applications, including, the assessment of software projects (Puška et al., 2020), the performance of COVID-19 of insurances enterprises (Ecer & Pamucar, 2021), railway performance assessment (Bouraima et al., 2021), assessment of sustainable transportation based on fuel vehicles (Pamucar et al., 2021), dam construction safety (Celik & Gul, 2021), sustainable production under circular economy environment (Stević et al., 2021), service quality of airlines industry (Bakir & Atalik, 2021), evaluation of drones based-city logistics (Kovač et al., 2021), sustainable performance variables (Badi et al., 2022), supplier selection (Badi & Pamucar, 2020), sustainable city logistics (Saha et al., 2022), truck mixer selection (Ivanović et al., 2022), regional aircraft selection (Bakir et al., 2021), selection of organ transplantation networks (Salimian et al., 2022), hydrogen gas grid development (Iordache et al., 2022), hazardous healthcare waste (Simic et al., 2022), reach stacker selection (Vesković et al., 2022). Seven steps have characterized the methods as bellows.

*Step 1* Establishment of the original matrix.

Step 2 Creation of an expanded initial matrix through the definition of the ideal (AI) and anti-ideal (AAI) solutions in Eqs. (6) and (7) based on the type of criterion.

$$X = \begin{matrix} & C_1 C_2 \dots C_n \\ \begin{matrix} AAI \\ A_1 \\ A_2 \\ \dots \\ A_m \\ AI \end{matrix} & \begin{bmatrix} x_{aa1} & x_{aa2} & \dots & x_{aan} \\ x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \\ x_{ai1} & x_{ai2} & \dots & x_{ain} \end{bmatrix} \end{matrix} \tag{5}$$

$$AAI = \min_i x_{ij} \text{ if } j \in B \text{ and } \max_i x_{ij} \text{ if } j \in C \tag{6}$$

$$AI = \max_i x_{ij} \text{ if } j \in B \text{ and } \min_i x_{ij} \text{ if } j \in C \tag{7}$$

where B is an advantageous criteria category; C is a non-advantageous criteria category.

Step 3 Normalization of the expanded original matrix (X). Equations (8) and (9) are employed to normalize the matrix  $N = [n_{ij}]_{m \times n}$ :

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \text{ if } j \in C \tag{8}$$

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \text{ if } j \in B \tag{9}$$

where  $x_{ij}$  and  $x_{ai}$ —matrix X components.

Step 4 Weighted matrix  $V = [v_{ij}]_{m \times n}$  computation via Eq. (10).

$$v_{ij} = n_{ij} \times w_j \tag{10}$$

Step 5 Utility degree of alternatives  $K_i$  calculation via Eqs. (11) and (12)

$$K_i^- = \frac{S_i}{S_{aai}} \tag{11}$$

$$K_i^+ = \frac{S_i}{S_{ai}} \tag{12}$$

where  $S_i$  ( $i = 1, 2, \dots, m$ )—the sum of the components of V via Eq. (13)

$$S_i = \sum_{j=1}^n v_{ij} \tag{13}$$

Step 6 Calculation of the utility function of alternatives f ( $K_i$ ) through Eq. (14).

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1-f(K_i^+)}{f(K_i^+)} + \frac{1-f(K_i^-)}{f(K_i^-)}}; \tag{14}$$

where  $f(K_i^-)$  and  $f(K_i^+)$  are the anti-ideal and ideal solutions computed through Eqs. (15) and (16).

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} \tag{15}$$

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} \tag{16}$$

Step 7 Ranking of alternatives.

## 5 Case study

This section presents a real case example of prioritizing strategies for the successful implementation and operation of the BRT system in Tanzania. Based on the reviewed literature, reports, official documents, and expert opinions, five potential challenges have been identified by the authors. A detailed explanation of these five criteria along with the alternatives is provided in Sect. 3. Based on the hierarchical framework in Fig. 2, the data collection was obtained from three different experts using the linguistic scale as explained by Stević et al. (2020), so all criteria are transformed into beneficial in the calculation process. The three respondents have been working at the Dar Rapid Transit Agency for over five years.

### 5.1 Determining the criteria weights using the improved fuzzy SWARA

Table 4 indicates the coefficient criteria weights based on the IMF SWARA method. As revealed in Table 4, the experts admitted that the frequent flooding at the Jangwani bridge bus terminal is the most critical challenge with a 0.270 value followed by a long waiting time at the bus stop (0.187), lack of expert operation and management, and lack of operational schedules with 0.184 value each one, and E-ticketing problem (0.173). Experts have given frequent flooding considerable attention in Fig. 3. Our results follow a previous study by Krüger et al. (2021), where flooding caused directly by periods of intense rainfall presents a significant challenge for the BRT. After the frequent flooding in Fig. 3, the second challenge

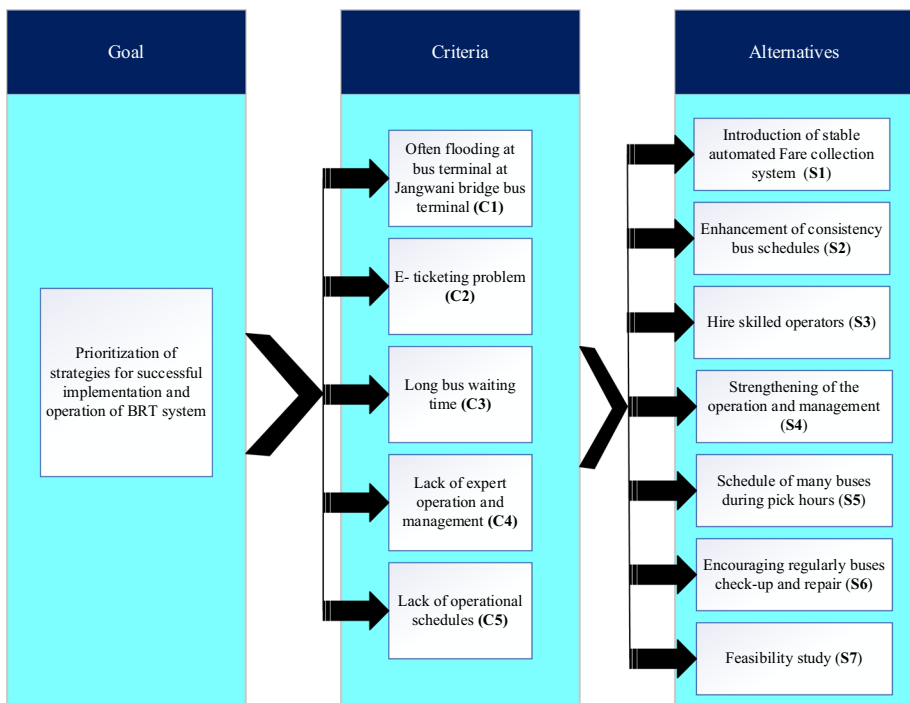


Fig. 2 Framework of prioritizing the strategies to overcome challenges in BRT implementation and operations

**Table 4** Assessment of criteria through the IMF SWARA approach

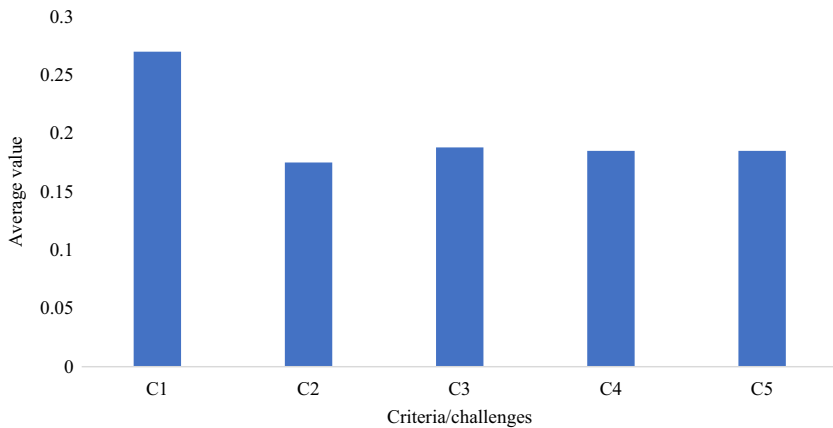
E1	$S_j$		$k_j$		$q_j$		$w_j$		Crisp value		
C1			1.000	1.000	1.000	1.000	1.000	0.263	0.273	0.286	0.273
C2	1/4	2/7	1/3	1.286	1.333	0.750	0.778	0.800	0.212	0.229	0.212
C3	0.000	0.000	1.000	1.000	1.000	0.750	0.778	0.800	0.197	0.229	0.212
C5	1/3	2/5	1/2	1.333	1.400	0.500	0.556	0.600	0.132	0.171	0.152
C4	0.000	0.000	1.000	1.000	1.000	0.500	0.556	0.600	0.132	0.171	0.152
			SUM			3.500	3.667	3.800			1.001

E2	$S_j$		$k_j$		$q_j$		$w_j$		Crisp value		
C1			1.000	1.000	1.000	1.000	1.000	0.252	0.260	0.270	0.260
C4	2/7	1/3	2/5	1.286	1.333	0.714	0.750	0.778	0.180	0.210	0.195
C5	0.000	0.000	1.000	1.000	1.000	0.714	0.750	0.778	0.180	0.210	0.195
C3	0.000	0.000	1.000	1.000	1.000	0.714	0.750	0.778	0.180	0.210	0.195
C2	2/9	1/4	2/7	1.222	1.250	0.556	0.600	0.636	0.140	0.172	0.156
			SUM			3.698	3.850	3.970			1.001

E3	$S_j$		$k_j$		$q_j$		$w_j$		Crisp value		
C1			1.000	1.000	1.000	1.000	1.000	0.266	0.276	0.290	0.276
C5	2/7	1/3	2/5	1.286	1.333	0.714	0.750	0.778	0.190	0.226	0.207
C4	0.000	0.000	1.000	1.000	1.000	0.714	0.750	0.778	0.190	0.226	0.207
C2	2/7	1/3	2/5	1.286	1.333	0.510	0.563	0.605	0.135	0.175	0.155
C3	0.000	0.000	1.000	1.000	1.000	0.510	0.563	0.605	0.135	0.175	0.155
			SUM			3.449	3.625	3.765			1.001



**Fig. 3** Results of the challenging factors for all three experts and their final values

is long waiting times. Our findings are similar to the results of Munishi et al. (2021), who discovered that long waiting times are one of the factors that severely limit the reliability of BRT.

## 5.2 Evaluation of strategies based on the MARCOS method

In this section, an MCDM model consisting of seven alternatives and five criteria is created and the application of the MARCOS method to obtain the ranks of alternatives is initiated. In the first step of MARCOS, a group decision-making procedure consisting of three experts represents the initial matrix. The opinions of experts are aggregated using the Bonferroni operator and an initial matrix of decision-making is obtained. Using Eqs. (6) and (7), an extended initial decision-making matrix is obtained, as indicated in Table 5. Applying Eq. (8), the normalized values for criteria are acquired, e.g.:  $n_{ij} = \frac{x_{ij}}{x_{ai}}$  if  $j \in B \leftrightarrow n_{14} = \frac{3.651}{7.000} = 0.522$ ,  $n_{44} = \frac{6.298}{7.000} = 0.900$  and a complete normalized matrix, shown in Table 6 is obtained.

**Table 5** Extension of the initial matrix

Criteria	C1	C2	C3	C4	C5
Anti-ideal	1.000	2.309	3.651	4.655	4.967
S1	1.000	7.000	3.651	5.323	4.967
S2	1.291	3.651	7.000	5.657	6.658
S3	1.915	6.658	4.655	7.000	6.325
S4	3.651	6.658	6.325	6.298	7.000
S5	1.291	2.646	7.000	5.657	6.325
S6	1.633	2.309	5.972	5.657	5.323
S7	7.000	5.323	5.323	4.655	5.000
Ideal	7.000	7.000	7.000	7.000	7.000



**Table 6** Normalization of the matrix

Criteria	C1	C2	C3	C4	C5
Anti-ideal	0.143	0.330	0.522	0.665	0.710
S1	0.143	1.000	0.522	0.760	0.710
S2	0.184	0.522	1.000	0.808	0.951
S3	0.274	0.951	0.665	1.000	0.904
S4	0.522	0.951	0.904	0.900	1.000
S5	0.184	0.378	1.000	0.808	0.904
S6	0.233	0.330	0.853	0.808	0.760
S7	1.000	0.760	0.760	0.665	0.714
Ideal	1.000	1.000	1.000	1.000	1.000

**Table 7** Weight-normalized matrix

Criteria	C1	C2	C3	C4	C5
Anti-ideal	0.039	0.057	0.097	0.122	0.130
S1	0.039	0.173	0.097	0.140	0.130
S2	0.050	0.090	0.187	0.148	0.175
S3	0.074	0.165	0.124	0.184	0.166
S4	0.141	0.165	0.169	0.165	0.184
S5	0.050	0.066	0.187	0.148	0.166
S6	0.063	0.057	0.159	0.148	0.140
S7	0.270	0.132	0.142	0.122	0.131
Ideal	0.270	0.173	0.187	0.184	0.184

The next step is weighting the normalized matrix using Eq. (10). For instance,  $v_{11} = n_{11} \times w_{11} = 0.143 \times 0.270 = 0.039$ . The weighted normalized is shown in Table 7.

By applying Eq. (13), all the values (by rows) for alternatives are summarized as follows:

$$S_{AAI} = 0.039 + 0.057 + 0.097 + 0.122 + 0.130 = 0.445$$

Correspondingly, the values for the remaining alternatives are obtained.

By applying Eq. (11), the utility degrees of the anti-ideal solution are calculated.

An example of the calculation is:

$$K_1^- = \frac{0.580}{0.446} = 1.300$$

While using Eq. (12), the utility degrees about the ideal solution are obtained, e.g.  $K_1^+ = \frac{0.580}{0.998} = 0.581$ .

**Table 8** MARCOS method outcomes

	$S_i$	$K_{i-}$	$K_{i+}$	$f_{K-}$	$f_{K+}$	$f_{K_i}$	Rank
AAI	0.445						
S1	0.580	1.300	0.581	0.309	0.691	0.510	6
S2	0.650	1.459	0.652	0.309	0.691	0.573	4
S3	0.713	1.599	0.714	0.309	0.691	0.628	3
S4	0.824	1.848	0.826	0.309	0.691	0.725	1
S5	0.617	1.383	0.618	0.309	0.691	0.543	5
S6	0.568	1.274	0.569	0.309	0.691	0.500	7
S7	0.797	1.789	0.799	0.309	0.691	0.702	2
AI	0.998						

The utility function in terms of the anti-ideal solution is obtained using Eq. (15) as follows:

$$f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} = \frac{0.581}{1.300 + 0.581} = 0.309$$

While the utility function in terms of the ideal solution is obtained using Eq. (16) as follows:

$$f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} = \frac{1.300}{1.300 + 0.581} = 0.691$$

Finally, the utility function of alternative S1 is obtained by applying Eq. (14).

$$\begin{aligned} f(K_1) &= \frac{K_1^+ + K_1^-}{1 + \frac{1-f(K_1^+)}{f(K_1^+)} + \frac{1-f(K_1^-)}{f(K_1^-)}} = \frac{1.300 + 0.581}{1 + \frac{1-0.691}{0.691} + \frac{1-0.309}{0.309}} \\ &= \frac{1.881}{1 + 0.447 + 2.236} = \frac{1.881}{3.683} = 0.510 \end{aligned}$$

The final results are obtained identically as elucidated in Table 8.

Through the application of the MARCOS method, the best alternative is strengthening the operation and management (S4) with a 0.725  $K_i$  value, whereas encouraging regular bus checkups and repair (S6) with a 0.500  $K_i$  value was seen to be the worst alternative. Other alternative classifications can be written as  $S7 > S3 > S2 > S5 > S1$ .

## 6 Sensitivity analysis

In this section, a sensitivity analysis comprising five phases is carried out as follows.

### 6.1 Assessing the impacts of various weight values on rankings results

The impact of changing the four most significant criteria weights is evaluated using forty scenarios in which the first four important criteria, namely C1, C3, C4, and C5, were reduced

using Eq. (17), while C5 yielded the same results as C4 due to equal values. In each of the ten scenarios, the four criteria were changed. In every scenario, the value of the criterion decreased between 5 and 95%, whereas the values of the other criterion were all uniformly perfect by applying Eq. (17). After defining 40 sets (Table 9) with the new values of the criteria, the calculation has been performed.

$$\overline{W}_{n\beta} = (1 - \overline{W}_{n\alpha}) \frac{\overline{W}_{n=\beta}}{(1 - \overline{W}_n)} \quad (17)$$

where  $\overline{W}_{n\beta}$ —new value of criterion for the 40 scenarios.  $\overline{W}_{n\alpha}$ —the reduced value of the important criteria by scenarios groups.  $\overline{W}_n$ —initial value of criterion which reduced value.

Figure 4 shows the comparison of original results with all 40 established scenarios in which there were no significant changes in terms of ranking of strategies for successful implementation and operation of the BRT system. As can be seen in Fig. 4, S4 (best alternative) has remained in the same ranking position for 34 scenarios, and the second-best option (S7) has remained in the same ranking position for 28 scenarios. Alternatives S1 and S2 have remained in the same ranking positions for 24 and 32 scenarios, respectively. Alternatives S3 and S5 remained in the same ranking position except for eight scenarios, while S7 remained in the same ranking position except for 12 scenarios.

## 6.2 Effects of the rank reversal issue on the ranking

The effects of adding or removing an alternative to assess the consistency of the model are proposed by Matic et al. (2022). It is used to assess the sensitivity of the developed framework to the rank reversal issue. Six distinct situations were established by eliminating the poorest choice and then studying the variations in the classification outcomes. Figure 5 shows that the rank reversal procedure of the original matrix had no effect on the results, and the suggested model's ranking results showed that alternatives were rated as  $S4 > S7 > S3 > S2 > S5 > S1 > S6$  in all of the scenarios.

In each scenario, the worst alternative is eliminated one by one until the best alternative is obtained. Table 10 shows the obtained results, which revealed that S4 is the best option in all cases. As a result, these findings attest to the effectiveness of the proposed model, which is both stable and consistent.

## 6.3 Comparison with other MCDM approaches (ranks)

In the third stage, the proposed model is compared with nine other MCDM methods: CODAS (Keshavarz Ghorabae et al., 2016), COPRAS (Zavadskas et al., 1994), CRADIS (Puška et al., 2021), WASPAS (Zavadskas et al., 2012), ARAS (Zavadskas & Turkis, 2010), SAW (Afshari et al., 2010), EDAS (Keshavarz Ghorabae et al., 2015), MABAC (Pamučar & Čirović, 2015; Pamučar et al., 2018), and MAIRCA (Gigović et al., 2016). Figure 6 depicts the comparative analysis results, which include the final rankings.

In Fig. 6, the classification of alternatives differs based on the method used, resulting in the computation of the SCC and WS coefficients for creating the link in this part of the validation of initial values acquired. It should be noted that S4 retains the best place (first one) with CRADIS, WASPAS, SAW, and MABAC, and occupies the second position with CODAS, COPRAS, ARAS, and EDAS. Meanwhile, S6 is in the worst place (last position) with CODAS, COPRAS, CRADIS, ARAS, and SAW, while it took the 6th position with

**Table 9** New criterion weights based on forty scenarios

	W1	W2	W3	W4	W5
S1	0.256	0.177	0.190	0.187	0.187
S2	0.229	0.183	0.197	0.194	0.194
S3	0.202	0.190	0.204	0.201	0.201
S4	0.175	0.196	0.211	0.208	0.208
S5	0.148	0.202	0.218	0.214	0.214
S6	0.121	0.209	0.225	0.221	0.221
S7	0.094	0.215	0.232	0.228	0.228
S8	0.067	0.222	0.239	0.235	0.235
S9	0.040	0.228	0.245	0.241	0.241
S10	0.013	0.234	0.252	0.248	0.248
S11	0.273	0.165	0.189	0.186	0.186
S12	0.278	0.147	0.193	0.190	0.190
S13	0.284	0.130	0.197	0.193	0.193
S14	0.290	0.113	0.200	0.197	0.197
S15	0.295	0.095	0.204	0.201	0.201
S16	0.301	0.078	0.208	0.205	0.205
S17	0.307	0.061	0.212	0.209	0.209
S18	0.312	0.043	0.216	0.213	0.213
S19	0.318	0.026	0.220	0.217	0.217
S20	0.324	0.009	0.224	0.220	0.220
S21	0.273	0.175	0.177	0.186	0.186
S22	0.279	0.179	0.159	0.190	0.190
S23	0.285	0.183	0.140	0.194	0.194
S24	0.292	0.187	0.121	0.199	0.199
S25	0.298	0.191	0.103	0.203	0.203
S26	0.304	0.195	0.084	0.207	0.207
S27	0.310	0.199	0.065	0.211	0.211
S28	0.316	0.203	0.047	0.215	0.215
S29	0.323	0.207	0.028	0.220	0.220
S30	0.329	0.211	0.009	0.224	0.224
S31	0.273	0.175	0.189	0.175	0.186
S32	0.279	0.179	0.193	0.156	0.190
S33	0.285	0.183	0.197	0.138	0.194
S34	0.291	0.187	0.201	0.119	0.198
S35	0.297	0.191	0.206	0.101	0.202
S36	0.303	0.195	0.210	0.083	0.206
S37	0.309	0.199	0.214	0.064	0.211
S38	0.316	0.203	0.218	0.046	0.215
S39	0.322	0.207	0.222	0.028	0.219
S40	0.328	0.211	0.227	0.009	0.223

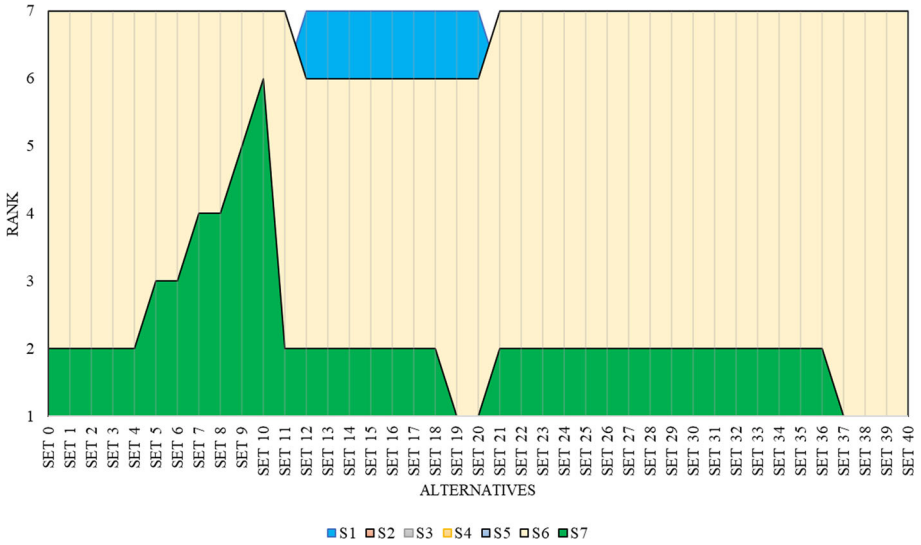


Fig. 4 Comparison of original results with all established scenarios

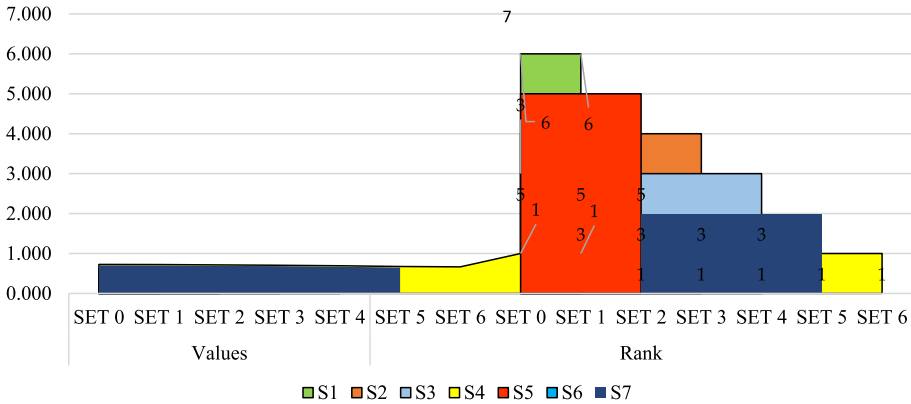
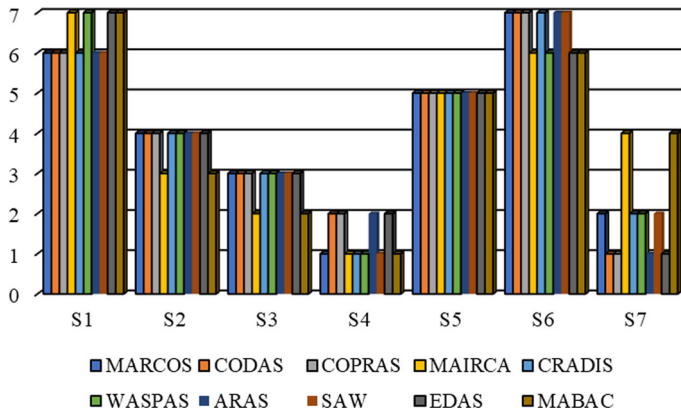


Fig. 5 Reverse rank matrix test results

Table 10 The new classification of the alternatives based on scenarios

Scenario	Ranking
Original	S4 > S7 > S3 > S2 > S5 > S1 > S6
Scenario 1	S4 > S7 > S3 > S2 > S5 > S1
Scenario 2	S4 > S7 > S3 > S2 > S5
Scenario 3	S4 > S7 > S3 > S2
Scenario 4	S4 > S7 > S3
Scenario 5	S4 > S7
Scenario 6	S4



**Fig. 6** Comparison with the other nine MCDM methods

WASPAS, EDAS, and MABAC. When using MABAC, the greatest variation occurs when the position of the seventh alternative (S7) changes from second to fourth rank.

#### 6.4 SCC and WS correlation

Table 11 displays the SCC and WS coefficients in comparison analysis for rank changes. There is a higher interdependence of rankings when nine different methods are used, with SCC and WS coefficients of 0.920 and 0.887, respectively. Also, a complete interdependence exists between the proposed model and those of the IMF SWARA-CRADIS and IMF SWARA-SAW. It has an extremely high interdependence coefficient, except for MAIRCA and MABAC (SCC = 0.850, WS = 0.857), revealing the stability of the results.

#### 6.5 Comparative analysis with criteria method

In the fifth stage, a comparison of the criteria method was assessed, along with two other two popular methods namely fuzzy FUCOM-MARCOS (Badi et al., 2022) and fuzzy PIPRECIA-MARCOS (Bakır et al., 2021). The comparative analysis for the criteria method is shown in Fig. 7. It should be noted that the ranking of the alternatives is constant. In addition, S4 holds the first position while S6 is in last place.

### 7 Discussion, managerial and practical implications

This section highlights the discussion and managerial and practical implications based on the findings of the case application. The study considers the appropriate strategy selection for the successful implementation and operation of the BRT system taking into account a real case where critical challenges to the BRT system are identified. First of all, a criteria assessment is performed for the prioritization of strategies. For this goal, the challenges in implementing and operating the BRT system are defined as criteria, and these criteria are weighted using the IMF SWARA method based on the Bonferroni operator. The MARCOS method is used to rank the strategies. Thus, an integrated IMF SWARA-BO and MARCOS approach is

Table 11 SCC and WS coefficients in comparison analysis for variation in ranking

SCC	MARCOS	CODAS	COPRAS	MAIRCA	CRADIS	WASPAS	ARAS	SAW	EDAS	MABAC	AV
MARCOS	1.000	0.964	0.964	0.857	1.000	0.964	0.964	1.000	0.929	0.857	0.950
CODAS	0.964	1.000	1.000	0.750	0.964	0.929	1.000	0.964	0.964	0.750	0.929
COPRAS	0.964	1.000	1.000	0.750	0.964	0.929	1.000	0.964	0.964	0.750	0.929
MAIRCA	0.857	0.750	0.750	1.000	0.857	0.893	0.750	0.857	0.786	1.000	0.850
CRADIS	1.000	0.964	0.964	0.857	1.000	0.964	0.964	1.000	0.929	0.857	0.950
WASPAS	0.964	0.929	0.929	0.893	0.964	1.000	0.929	0.964	0.964	0.893	0.943
ARAS	0.964	1.000	1.000	0.750	0.964	0.929	1.000	0.964	0.964	0.750	0.929
SAW	1.000	0.964	0.964	0.857	1.000	0.964	0.964	1.000	0.929	0.857	0.950
EDAS	0.929	0.964	0.964	0.786	0.929	0.964	0.964	0.929	1.000	0.786	0.921
MABAC	0.857	0.750	0.750	1.000	0.857	0.893	0.750	0.857	0.786	1.000	0.850
0.920											
WS	MARCOS	CODAS	COPRAS	MAIRCA	CRADIS	WASPAS	ARAS	SAW	EDAS	MABAC	AV
MARCOS	1.000	0.867	0.867	0.843	1.000	0.996	0.867	1.000	0.862	0.843	0.914
CODAS	0.867	1.000	1.000	0.643	0.867	0.862	1.000	0.867	0.996	0.643	0.874
COPRAS	0.867	1.000	1.000	0.643	0.867	0.862	1.000	0.867	0.996	0.643	0.874
MAIRCA	0.873	0.768	0.768	1.000	0.873	0.877	0.768	0.873	0.773	1.000	0.857
CRADIS	1.000	0.867	0.867	0.843	1.000	0.996	0.867	1.000	0.862	0.843	0.914
WASPAS	0.996	0.862	0.862	0.848	0.996	1.000	0.862	0.996	0.867	0.848	0.914
ARAS	0.867	1.000	1.000	0.643	0.867	0.862	1.000	0.867	0.996	0.643	0.874
SAW	1.000	0.867	0.867	0.843	1.000	0.996	0.867	1.000	0.862	0.843	0.914
EDAS	0.862	0.996	0.996	0.648	0.862	0.867	0.996	0.862	1.000	0.648	0.874

Table 11 (continued)

WS	MARCOS	CODAS	COPRAS	MAIRCA	CRADIS	WASPAS	ARAS	SAW	EDAS	MABAC	AV
MABAC	0.873	0.768	0.768	1.000	0.873	0.877	0.768	0.873	0.773	1.000	0.857 0.887



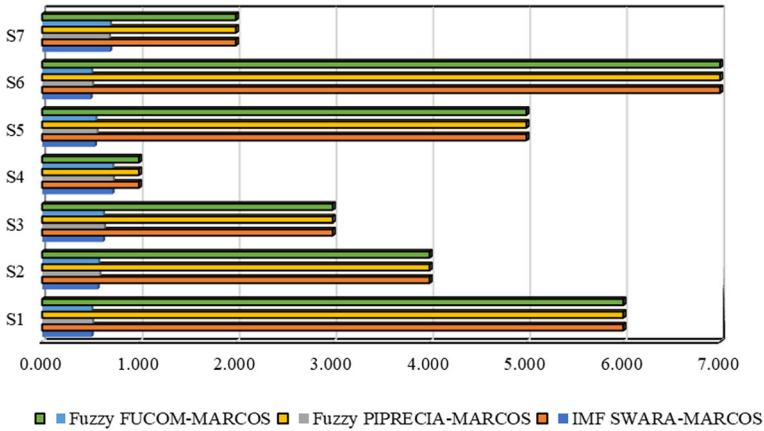


Fig. 7 Comparative analysis for criteria method

proposed to enable the selection of the appropriate strategy for the BRT system problem. The proposed approach provides the assessment of the criteria and alternatives for the BRT system problem based on researched literature, reports, official documents, and expert opinions. In this regard, the challenges to the successful implementation and operation of the BRT system are investigated, and an appropriate strategy is strategically determined. For mass transit operators who aim to eradicate the challenges to a successful implementation and operation of the BRT system and provide effective service delivery to users, it is important to propose an appropriate plan of action. At this point, the proposed integrated approach will be useful in finding the appropriate alternative with the identification of critical challenges for the BRT system. The study indicates that the frequent flooding at the Jangwani bridge bus terminal followed by the long waiting time at bus stops are the most critical factors challenging the implementation and operationalization of BRT. It’s crucial to find a solution to the Jangwani bridge situation. A strategy should be developed to reduce the risk of flooding in the future, by elevating the bridge. However, before the plan is put into action, a few issues still need to be handled. Since floods have been threatening the informal settlements in river basins practically every year for the past ten years (2009–2018), they would need to be displaced. Additionally, community facilities are within the valley, and their continued presence in this place must be assessed. To set up a longer-term solution, practical steps should be made. To take one example, a holistic planning approach is required to routinely eliminate alluvial sediments from the riverbank, which would significantly improve the situation, decrease susceptibility to rainstorm disasters and floods, and allow attention to be directed toward more tough problems. Internal discussions between BRT participants to more effectively distribute responsibilities and “optimize” the operational plan of the system should be seen as a prerequisite for other initiatives to be effective. There is also a need to increase the number of buses to address long wait times at bus stops.

The alternative “S4-strengthening of the operation and management” has been chosen by experts as the appropriate strategy since its implementation will on one hand improve the effectiveness of the BRT system and from another hand assess the appropriate zone to construct and implement bus stops and BRT stations. The respondents are informed of the study’s

findings. The outcomes from ranking the strategies to overcoming the difficulties in implementing and operating the BRT system are equivalent to the expectations and presumptions of all experts.

The prioritization of strategies for the effective implementation and operation of the BRT system has not been studied using MCDM in the literature. Thus, the proposed methodology has numerous theoretical and practical contributions to the literature on BRT systems. The main theoretical and practical implications of the study are as follows:

IMF SWARA based on BO operator is integrated with MARCOS methodology and applied to the prioritization of strategies for successful implementation and operation of the BRT system for the first time in the literature.

Using researched literature, reports, official documents, and expert opinions, the criteria to evaluate the strategies for successful implementation and operation of the BRT system are determined. In this way, a thorough framework for assessing the challenges is brought to the literature. An expert group is established comprising experienced professionals from the Dar Rapid Transit Agency.

Although the proposed strategy prioritization model has not considered the challenges under the socio-economic and environmental aspects, it contributes to the BRT systems literature because it is developed in an extendable and adaptable manner. The proposed strategy prioritization model can be used by other BRT systems in Africa that are still operational, as well as new ones that are expected in major cities across the continent, particularly Addis Ababa (Ethiopia) and Kigali (Rwanda), respectively. Additionally, it might be a tool for learning about the challenges involved in successfully implementing and operating the BRT system.

## 8 Conclusion

This study identifies the challenges to the successful implementation and operation of the BRT system and recommends the most appropriate strategy for overcoming them. It is important for mass transit operators how critical these challenges are in terms of impeding the effectiveness of the BRT system. Within the scope of the study, the problem of determining the challenges, the weights of these challenges, and appropriate strategies are accordingly discussed. To determine the weights of these challenges, the methodology process is discussed in the study. Firstly, all challenges (criteria) that may impede the effectiveness of the BRT system are determined as a result of researched literature, reports, official documents, and expert opinions. After the criteria are determined, experts are asked to assess these criteria. After the assessment procedure using linguistic variables, the weights of the criteria are determined using the IMF SWARA method based on the Bonferroni operator. The alternatives (strategies) are then ranked by weighted challenges using the MARCOS method. In this way, it is stated which strategy should be implemented for the BRT system to have a successful implementation and operation.

The following is a list of the paper's contributions to the field of study and practice: (1) the challenges that impede the successful implementation and operation of the BRT system are pinpointed and ranked; (2) the most critical challenges for the successful implementation and operation of BRT system are determined; (3) A real-life application in Dar-es-Salaam is carried out and presented to indicate the applicability and reliability of the proposed methodology; (4) Seven different strategies are evaluated according to the determined challenges and the appropriate one is recommended to be implemented; (5) The proposed methodology

is intended to be used by mass transit operators for successful implementation and operation of the BRT system.

Although this study has contributed to the implementation and operation of the BRT system literature, still has some research limitations and disadvantages. Only the challenges faced during phase 1 out of the six phases of the implementation and operation of the BRT system are included in the proposed strategy prioritization model to demonstrate our approach. The evaluation of a small number of challenges that fall under the study's scope constitutes the first limitation. A lack of a set of criteria for choosing suitable experts for data collecting is another limitation. The study's sole consideration of experts from the Dar Rapid Transit Agency, without taking academicians into account, is the third limitation. The fourth limitation relates to the application of the MARCOS approach for ranking alternatives, which has the disadvantage of using the single normalization (linear normalization) technique.

Future research may need to consider the other phases of the BRT system as well as the new challenges that may emerge through their execution by using this methodology. Selecting the appropriate experts is critical for researchers, and they need to be more cautious in this regard. As a result, a set of criteria should also be formed for choosing the right experts. Additionally, a greater number of academic experts should be included to improve the consistency of the experts' reviews. Besides, we recommend the use of a possibilistic programming framework under uncertainty (Goli et al., 2022a, 2022b), an accurate algorithm (Goli et al., 2022a, 2022b), and double normalized method (Ivanović et al., 2022) in developing future integrated decision-making models. Future research may also consider the application of the proposed framework in sustainable building material selection, and expertise-based bid evaluation for construction-contractor selection.

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** This article does not contain any studies with animals performed by any of the authors.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

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