LESSONS LEARNED FROM EVALUATING OPTIONS USING MULTI-CRITERIA ANALYSIS IN TWO CORRIDORS WITHIN THE CITY OF JOHANNESBURG

M NKOSI[1]*, M JABLONSKI[1] and NC DUZE[2]**

[1]Planning and Traffic Engineering, SMEC South Africa, 267 Kent Avenue, Ferndale, Johannesburg 2194, South Africa; Tel: 011 369 0703; *Email: Muzi.Nkosi@smec.com; **Tel: 011 369 0653; Email: Mandy.Jablonski@smec.com
[2]Transport System Management, Department of Transport, City of Johannesburg, 75 Helen Joseph Street, Johannesburg; Email: NobuntuD@joburg.org.za

ABSTRACT

The City of Johannesburg has adopted an Integrated Corridor Management (ICM) approach to design selected strategic public transport corridors within the city's Strategic Integrated Public Transport Network. ICM is the use of all corridor elements to attempt to optimise the movement of people whilst improving safety and minimising environmental impact, all at an affordable cost. The ICM solutions developed were corridor specific and varied between targeted infrastructure upgrades, incentive schemes for minibus taxis, revitalisation of the rail network, land-use changes, and road-based public transport interventions. As such, the evaluation of the options required consideration of a wide range of quantitative and qualitative impact categories within an environment of limited available time and budget. Multicriteria Analysis (MCA) is a decision support tool that can simultaneously account for qualitative and quantitative criteria in evaluating strategies and options. MCA has been applied in various projects globally and across multiple sectors, including transport projects, with the aim of reducing the number of options to an optimal preferred option for the stakeholders involved. This paper highlights the challenges and lessons learned from applying an MCA to evaluate ICM options for two separate transport corridors in the City of Johannesburg. These included the challenge of ensuring clarity in questionnaires for participants in the process and the associated interpretation of results emerging from the process.

1. INTRODUCTION

This paper delves into the use of Multi-Criteria Decision-Making (MCDA) in two case studies carried out in the City of Johannesburg. The studies focus on an integrated corridor management approach applied in transportation planning. Integrated corridor management involves coordinating various transport modes to optimise corridor performance. To achieve this, several factors, such as technology, transport modes, institutional arrangements, operations, and infrastructure, consideration must be considered.

The MCDA technique is useful in evaluating different options when different stakeholders have varying priorities. It was also beneficial in comparing options that could not be easily quantified. The options resulting from the permutations of different elements were grouped into categories based on workshops, and a wide range of quantitative and qualitative criteria were developed. MCDA was found to be the most flexible method for evaluating the proposed options based on each criterion, given the limited time and budget available.

The paper aims to contribute to the literature on the use of MCDA in evaluating integrated corridor management approaches, weighting criteria and categories, and lessons learned from its application in developing countries.

The paper is divided into several sections, including an introduction, a review of the literature on MCDA, a description of the study area's background, the methodological approach used, results, lessons learned, and a summary of the main takeaways.

2. LITERATURE REVIEW

Multi-Criteria Decision-Making (MCDM) or Multi-Criteria Decision Analysis (MCDA) is a technique used to evaluate alternative options based on a set of criteria in order to select the highest-ranking options. MCDA is an alternative to quantitative techniques such as financial, cost-effectiveness, and cost-benefit analysis. It enables the consideration of non-monetary variables in the evaluation. Ambrasaite et al. (2011) argued that assessments or methods based only on monetary terms limit the impact that non-monetary criteria or factors might have on the proposed alternatives being evaluated.

The flexibility of MCDA to incorporate non-monetary criteria in the evaluation is important; for example, in the context of the household travel survey of 2019, it was noted that users in Gauteng were dissatisfied with issues such as safety and security, which may not be easily quantifiable or convertible to monetary terms (GDRT, 2019). Furthermore, these criteria might be quantifiable, but due to limited available time and budget, it might not be feasible to do so. The MCDA is flexible when there is a need to incorporate non-monetary criteria in the evaluation technique, especially when the aim is to evaluate conflicting trade-offs between options or alternatives without necessarily requiring an optimal solution.

Siksnelyte et al. (2018) found that there is a growing number of publications focused on the use of Multiple Criteria Analysis (MCA) to support decision-making across various fields. It has been argued that the use of MCA can facilitate sustainable decision-making (Siksnelyte et al., 2018; Thakkar, 2021). In the transportation sector, MCDA has been employed to assess alternative rail route alignments for linking four Eastern European cities within the European Union (Ambrasaite et al., 2011), as well as for transport route selection (Broniewicz & Ogrodnik, 2020; Ambrasaite et al., 2011).

The participation of stakeholders at different stages of MCDA is crucial to ensure that the outcomes of the process are widely acceptable (Ward et al., 2016). However, involving stakeholders in the process can be challenging. Developing criteria for the evaluation of transport interventions have been studied in South Africa (Kane, 2010). Various MCDA methods and techniques have been detailed in the literature for transportation infrastructure project appraisals, including Analytic Hierarchy Process (AHP), TOPSIS, and PROMETHEE (Broniewicz & Ogrodnik, 2020; Thakkar, 2021). It is important to note that the paper does not explain how each method is executed, but a step-by-step procedure for various MCDA methods can be found in Thakkar (2021). The advantages and disadvantages of each method have also been discussed (Velasquez & Heste, 2013), with some arguing that heavy reliance on subjective measures can significantly impact the final outcome (Ambrasaite, et al., 2011). Moreover, different MCDA techniques may lead to inconsistent problem ranking, and the selection of a specific method can result in different outcomes (Thakkar, 2021).

3. METHODOLOGY

There are several key concepts to consider to understand the analysis of MCDA better, as will be discussed. These include categories, options, criteria, and evaluation. Options are the different possible alternatives or courses of action that can be taken to address a particular issue or challenge. Criteria are the measurable components of each option or alternative that helps to determine its effectiveness. Categories refer to the groupings or aggregations of performance measures across various criteria for a particular option. Finally, evaluation refers to the overall assessment process that results in ranking the different options. While this is not an exhaustive explanation, understanding these key concepts can help to clarify the MCDA analysis process.

3.1 Overview

The evaluation process for the corridors is depicted in Figure 1 and involves several steps. Initially, the issues and challenges along the corridor were identified through a status quo assessment. Thereafter, transport options were developed to address these issues based on industry expertise. Criteria for the evaluation of the options were developed and grouped into different categories.

Workshops were conducted to gather input on the weighting of criteria within categories, as well as to understand the significance of each category in the City's context. Concurrently, quantitative criteria were evaluated for each option. The qualitative and quantitative criteria were normalised and standardised, allowing for their combination. Weights were applied to each option's normalised and standardised criteria to compute the MCDA score. After that, the options were ranked based on their respective scores to determine the highest-ranking option.

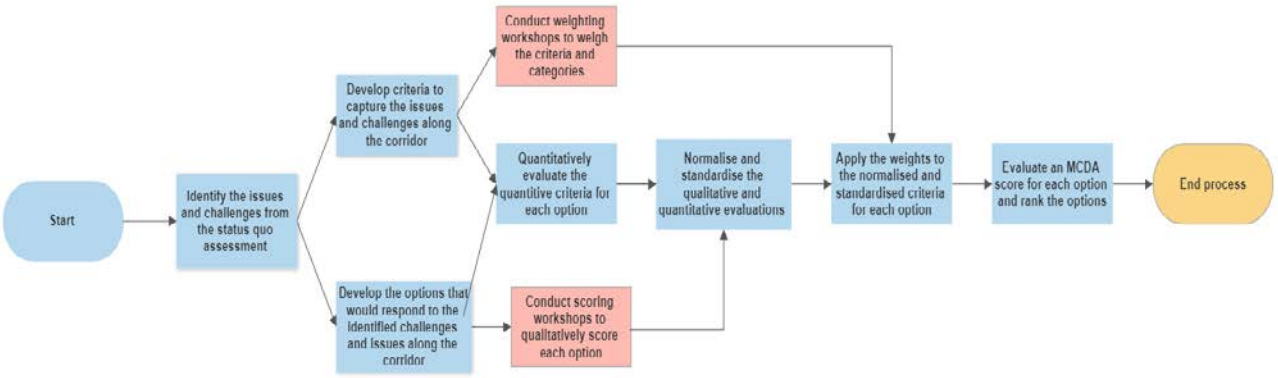


Figure 1: MCDA approach

The categories included economic, social and environmental dimensions in line with the National White Paper on Transport, which sets out as an objective “To invest in infrastructure or transport systems in ways which satisfy social, economic, or strategic investment criteria”. While the discussions will draw on lessons from the two applications of Multi-Criteria Decision Analysis (MCDA) within the southern and northern corridors, details within this section will frequently focus on the approach for the southern corridor (Orange Farm to the Inner-City corridor), which is the more recent of the studies. The southern corridor study incorporates and improves upon the lessons learned in the previous northern corridor study.

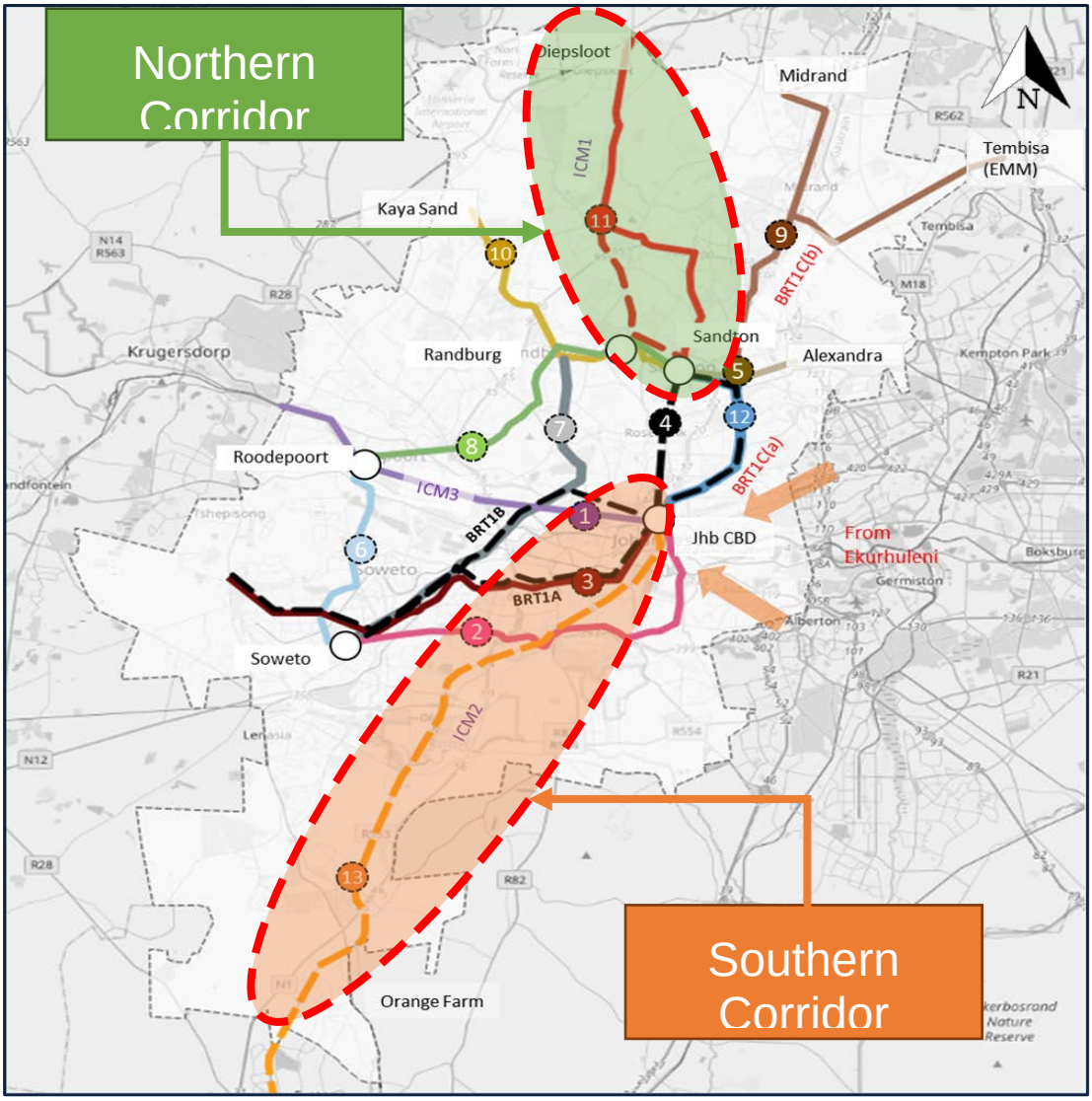
The Analytic Hierarchy Process (AHP) was used as a decision-making technique. The method was selected because it involves breaking down complex problems into smaller, more manageable parts. The method relies on a hierarchical structure of criteria and alternatives to determine the best option based on a set of predefined criteria. When using the AHP method, one important consideration is the potential impact of deviations in the weighting assigned to the various criteria. The weights assigned to each criterion reflect their relative importance in the decision-making process, and even slight variations in the assigned weights can significantly impact the outcome.

3.2 Study Area Overview

The MCDA was applied to two corridors within the City of Johannesburg, and an overview of the two corridors is as shown in Table 1. The locality map of the study areas is shown in Figure 2.

Table 1: Overview of the study area

Studies	Corridor Description	Overview
Northern Corridor	Diepsloot Fourways Randburg Central Business District Sunninghill Sandton Corridors	Diepsloot is a township in the north of Johannesburg, South Africa, home to more than 150,000 people. It was established in the mid-1990s during the transition from apartheid to democracy. Despite being closer to economic hubs such as Fourways and Sandton, the township faces significant transport-related problems. This is because it was built far away from the city centre, resulting in long and expensive commutes for residents. Limited public transport options are available in the area, which are characterised by irregular schedules and high costs, meaning that access to economic opportunities remains restrictive.
Southern Corridor	Orange Farm Inner City Corridor	Orange Farm is a township located about 45 kilometres south of Johannesburg, South Africa. This area is one of the most impoverished in the Gauteng Province and is characterised by poor transport infrastructure and services. The transport-related problems in Orange Farm are primarily attributed to the legacy of apartheid, which saw the development of townships on the periphery of cities, far from economic opportunities and with limited transport links. The transport infrastructure in Orange Farm is inadequate, with limited public transport services, poor road conditions, and a lack of pedestrian walkways and cycling infrastructure. The result is that the residents of Orange Farm face significant challenges in accessing economic opportunities, education, healthcare, and other basic services, with negative impacts on their quality of life and socio-economic well-being. While some of these challenges are best faced by providing services within Orange Farm, effective long-distance transport to the City Centre is critical for the immediate improvement of opportunities for the people within the Southern Corridor.



Source: Adapted City's Strategic Integrated Public Transport Network, 2019

Figure 2: Locality map for the corridor

3.3 Options Overview

Nine options were developed per corridor within the City of Johannesburg based on a status quo analysis of each corridor, as shown in Table 2 and Table 3 for Northern and Southern corridor respectively. Stakeholder Engagement meetings were conducted in both corridors to gather insights from various stakeholders, including local residents (through ward meetings and presentations), local business owners, minibus taxi operators, and other public transport users.

In the northern corridor, the solutions focused on non-motorised transport interventions and shorter-distance, road-based public transport improvements. These improvements aimed to involve existing minibus taxi operators in operational changes. On the other hand, the southern corridor presented a different set of challenges, such as long distances and non-operational rail infrastructure. Consequently, the options for this corridor included the revitalisation of the passenger rail corridor and improving the existing bus systems through the use of electric public transport vehicles.

Table 2: Northern corridor options

Option	High-Level Overview
Option 1: Queue Jump Lanes	This infrastructure-only intervention uses the existing public transport services in the area but provides new queue jump lanes (kerbside) for Public Transport vehicles as well as lay-byes and public transport stops every 500-1000m along the length of the corridor. If this Intervention is selected, queue jump lanes will be provided at critical intersections to allow PT vehicles to jump long queues at intersections. The net result is that the existing service will be improved.
Option 2: Dedicated PT Lanes	This infrastructure-only intervention uses the existing public transport services in the area but provides full-length dedicated lanes (kerbside) for Public Transport vehicles as well as lay-byes and public transport stops every 500-1000m along the length of the corridor.
Option 3: High Occupancy Vehicle (HOV) Lanes	This infrastructure-only intervention uses the existing public transport services in the area but provides full-length dedicated lanes for all vehicles carrying at least two passengers (excluding drivers). This Intervention also includes park-and-ride facilities at key nodes to enable carpooling.
Option 4: Commuter Non-Motorised Transport	This Intervention includes the provision of wide dedicated non-motorised transport lanes to support pedestrians, cyclists, trolley pushers and other modes of NMT. The proposed NMT lanes may need to divert from the primary road to align to the lower gradient. As many trips in CoJ are longer than walking distance, bicycle lanes would need to be provided for longer trips. Associated bike-share, bike rental or bicycle provision programs could be implemented to support this concept.
Option 5: Technology Interventions	This Intervention includes the provision of technological interventions to support the ICM concept along the corridor. The minimum intervention includes a Corridor Management Unit (CMU) to manage operations along the corridor with additional technological interventions, including a Live traffic model; Live synchronisation of traffic lights; Notifications on conditions posted on social media; Variable Message Signage (VMS); Emergency corridor management; PT Vehicle tracking; CCTV.
Option 6: Formal Unscheduled Minibus Taxis	This Intervention involves a subscription service for Minibus Taxis. Each tier of subscription would include additional requirements and an increased subsidy for the minibus taxi owner. Individual routes for Minibus Taxis will be specified according to operating licenses. This allows for different levels of buy-in from the minibus taxi industry as well as activating the potential to formalise the industry.
Option 7: Formal Scheduled MBT (no queue jump lanes)	This Intervention includes the provision of a formal Scheduled MBT service. An operating company would be required to manage this new formal and scheduled service. This service will involve the scheduled operations of Minibus Taxis. This Intervention can act independently with direct services or, alternatively, be used as a feeder service.
Option 8: Formal Scheduled MBT (queue jump lanes)	This Intervention includes the provision of a formal Scheduled MBT service operating on dedicated MBT queue jump lanes. An operating company would be required to manage this new formal and scheduled service. MBTs would form the primary mode of Public Transport service but in a formalised manner under the operational control of the City.
Option 9: Formal PT Services such as a Quality Bus Service (QBS) or BRT-Lite	A new multi-modal integrated Public Transport trunk-feeder service. The service would be totally integrated with the existing Rea Vaya service in terms of branding and payment systems but without full-length BRT median lanes and infrastructure. Vehicle size would be selected based on corridor demand (articulated buses in portions of the corridor with high demand with smaller vehicles where required) with queue-jump lanes (kerbside) provided where possible and significantly beneficial. Stops and stations would be designed at a lower quality than existing Rea Vaya stations but with key basic comforts for users. Options such as Pre-Boarding at stations can be considered in the full feasibility study.

The following were the nine options that were developed for the southern corridor:

Table 3: Southern corridor options

Option	High-level Overview
Option 1: Business-as-usual	Proposes leaving the current infrastructure and services unchanged. This option is intended to serve as a baseline for measuring the direction of change.
Option 2: Pre-covid rail services provided through diesel trains	Proposed the rehabilitation of the rail infrastructure to enable the service to operate using diesel trains. This option also includes the provision of feeder bus services to increase rail patronage.
Option 3: Modernise and revitalise the rail infrastructure.	Proposed the modernisation and revitalisation of the rail infrastructure, as detailed in the envisaged Corporate Plan 2020/22 of PRASA. This option includes the provision of feeder services to enable greater coverage of rail service. Additionally, a bus service would be introduced to parts of the corridor that would not benefit from the modernised rail service.
Option 4: Express bus services	Express services will operate along the primary route of the corridor, while regular services that make stops at every station will be alternated with express services along the alternative route. Furthermore, feeder services will be provided to increase patronage on both primary and secondary routes by connecting to the express service.
Option 5: Dedicated public transport lanes	The proposed introduction of public transport lanes to be utilised by public transport during specific periods of the day. Existing services, such as provincial subsidised bus services and minibus services, would continue to service the corridor.
Option 6: Alternative energy bus services	Introduction of an alternative energy public transport system, such as hydrogen, electric, or CNG. The operational concepts of option 4 (express bus service) would be adopted, and charging infrastructure would be provided at strategic depots/terminals.
Option 7: Electric minibus services	The option proposes the introduction of charging infrastructure at strategic taxi ranks along a specific corridor. The ranks would be retrofitted and upgraded to integrate a solar system into the energy grid. The proposal also includes contracting minibus services to operate on both the main and alternative corridors. The city would provide energy for free to the industry in exchange for establishing fare rates for operators on the route. Incentives would be provided to operators to regulate fare rates, allowing access to the charging system, which would allow infrastructure operators to pass savings onto users.
Option 8: Extended complimentary BRT services	The option proposes the extension of complimentary Bus Rapid Transit (BRT) services to Orange Farm in the south. The proposed service would be supported by introducing feeder services. This option also includes introducing limited stations at selected strategic locations along the corridor. The main routes would be operated by buses, while the feeder service would be operated by either minibuses or buses.
Option 9: Land use option	The option investigates measures to reduce trip lengths compared to other transport-oriented options and solutions. The objective is to explore the comparative impact of minimising the trip length by 5%, 10%, and 15%. The proposed land uses refer to Transit-Oriented Development (TOD) measures and other supporting measures as proposed in the Region G Master Plan, Southern farms, and other relevant proposals.

3.4 MCDA Structure

To assess the northern corridor criteria, the technical team employed independent qualitative scoring. Then Project Steering Committee, which comprised transport planners, town planners, road engineers, and public transport operations managers, weighted the scores. The primary objective was to minimise bias and ensure a fair evaluation of the available options. However, stakeholders who reviewed the results recommended involving a more diverse team in the scoring process in future studies. Consequently, the

evaluation of the southern corridor incorporated both quantitative and qualitative criteria, which the Project Steering Committee and the project team scored to ensure a more comprehensive range of perspectives were considered.

The criteria and the categories of the MCDA that were used to evaluate the various options for the southern corridor are shown in Figure 3.

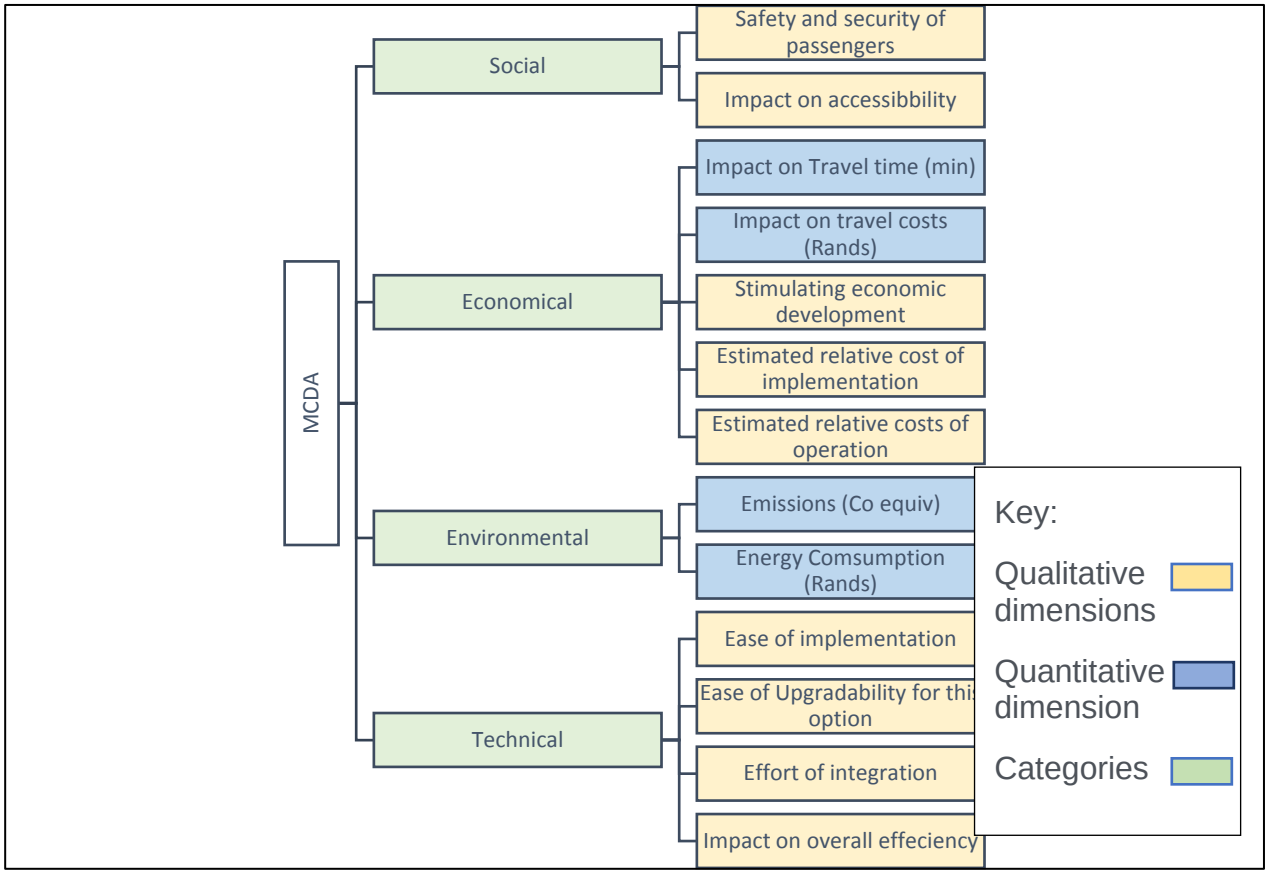


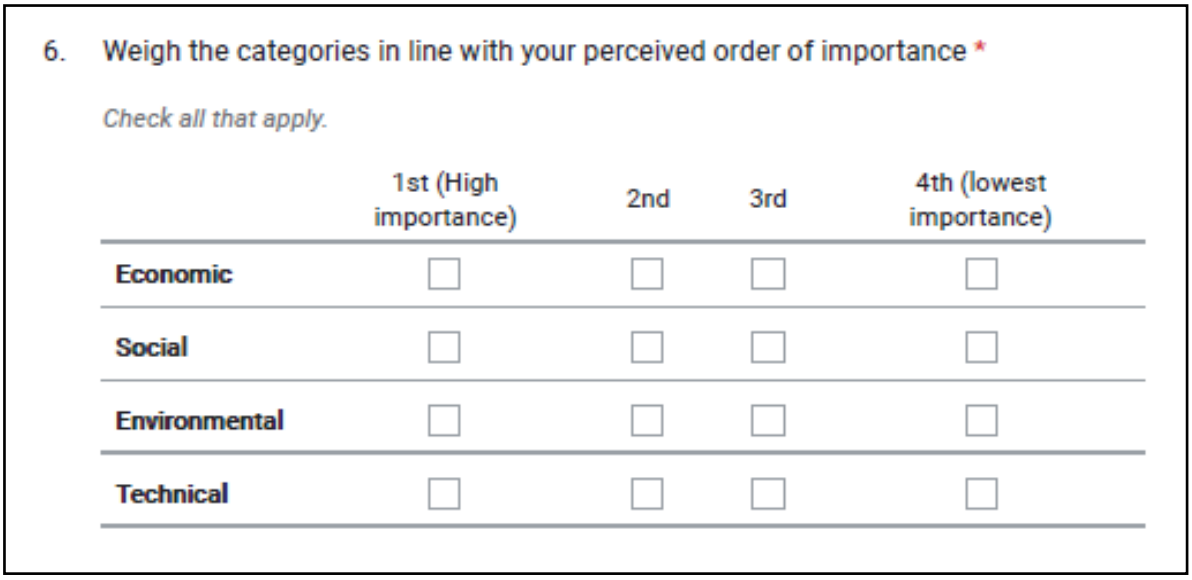
Figure 3: Structure of the MCDA used for the Orange Farm to Inner City corridor

3.5 Workshops

The process for completing the weighting of the criteria questionnaire differed for the northern and southern corridors. For the northern corridor, the weighting of the criteria questionnaire was completed during workshops that included city officials and professionals working with the City, such as the research institutes and other consultants. The questionnaire could be completed using an Excel form or on paper. Initially, a single workshop was planned; however, an additional workshop was required to provide clarity on the definitions of different criteria, and another workshop was required to assist with filling out the forms.

The southern corridor questionnaire was completed by the project team, including professionals involved in the project as well as city officials from various relevant departments. This aimed to better represent the transport users as the City's mandate is to improve services for them. Due to the challenges with the northern corridor workshops and to accommodate the added complexity of scoring criteria for the southern corridor, the questionnaire was developed online using Google Forms. Again, multiple workshops were required to assist with completing the questionnaire.

A sample of the questionnaire is shown in Figure 4.



6. Weigh the categories in line with your perceived order of importance *

Check all that apply.

	1st (High importance)	2nd	3rd	4th (lowest importance)
Economic	☐	☐	☐	☐
Social	☐	☐	☐	☐
Environmental	☐	☐	☐	☐
Technical	☐	☐	☐	☐

Figure 4: Sample of the weighting and scoring questionnaire

For the weighting of categories and criteria for the northern corridors, participants were required to score different categories directly against each other by assigning a percentage to each category and later by assigning a percentage value to each criterion within a category. This resulted in categories and criteria having very small differences in value as participants tended to assign close to equal weighting to different categories or criteria. In order to encourage participants to select a more important category or criteria and to simplify the questionnaire, the southern corridor participants were asked to rank the categories, and then the criteria within each category and percentage weights for these were then assigned using this information.

4. RESULTS

This section provides some of the results of the MCA process for the southern corridor to highlight lessons learned from the process.

In total, there were 21 responses that were received, which was a 100% response rate. Seven (33%) of the respondents were from the external technical team assisting the city in conducting the feasibility study, while fourteen (66%) were internal City Officials.

The weighting exercise was conducted to determine the relative significance of the different categories and criteria in the MCA structure. The overall weighting of the categories is shown in Figure 5 to Figure 8. In summary, the following was noted:

- For the overall category weighting, the working team (Consultants to the city) and city officials emphasised the corridor's economic and social categories.
- For the economic category, the impact of travel costs was emphasised by both teams.
- For the social category, there was no significant difference between categories.
- For the technical category, the city officials emphasised the option’s efficiency, while the working team scenario emphasised the ease of implementation.

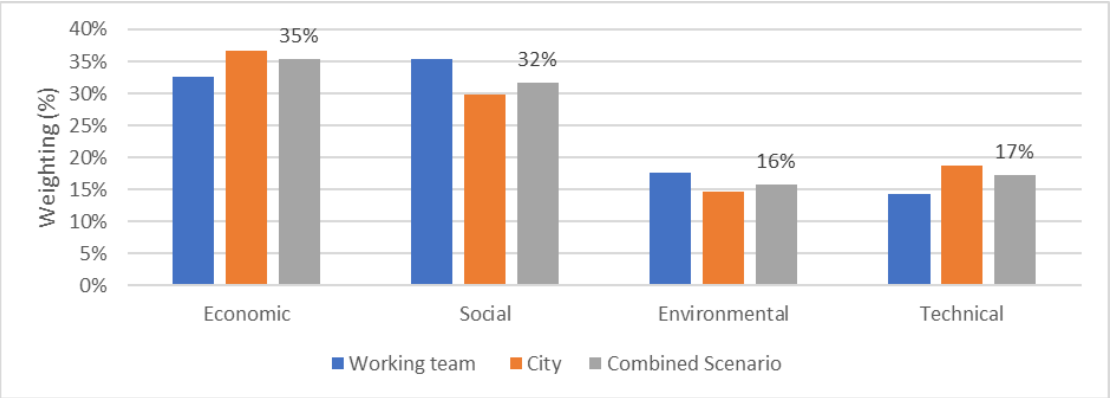


Figure 5: Overall categories weighting

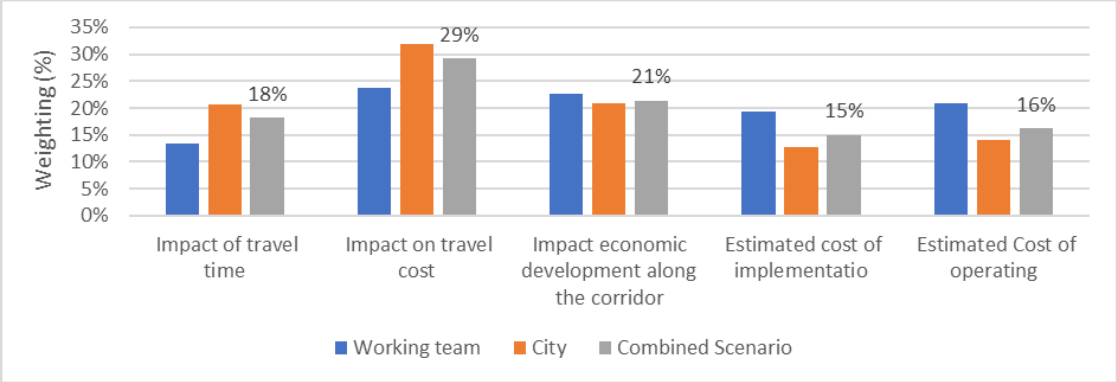


Figure 6: Weighting of the economic category

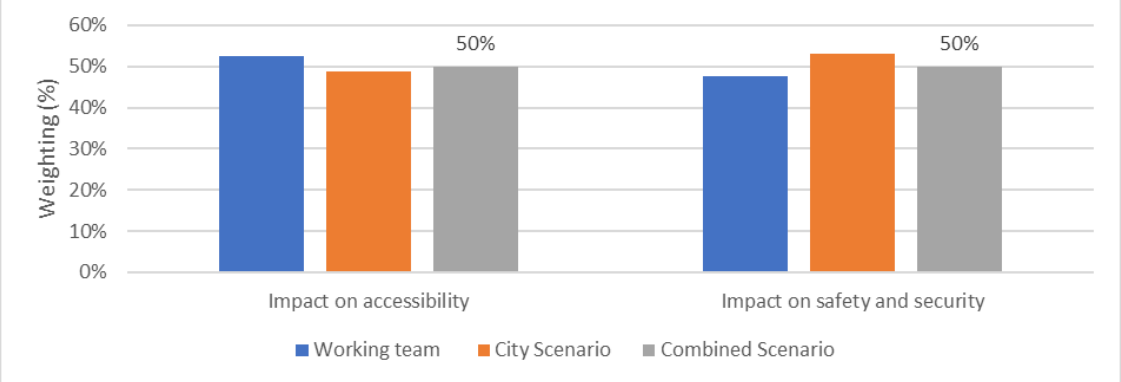


Figure 7: Weighting of the social category

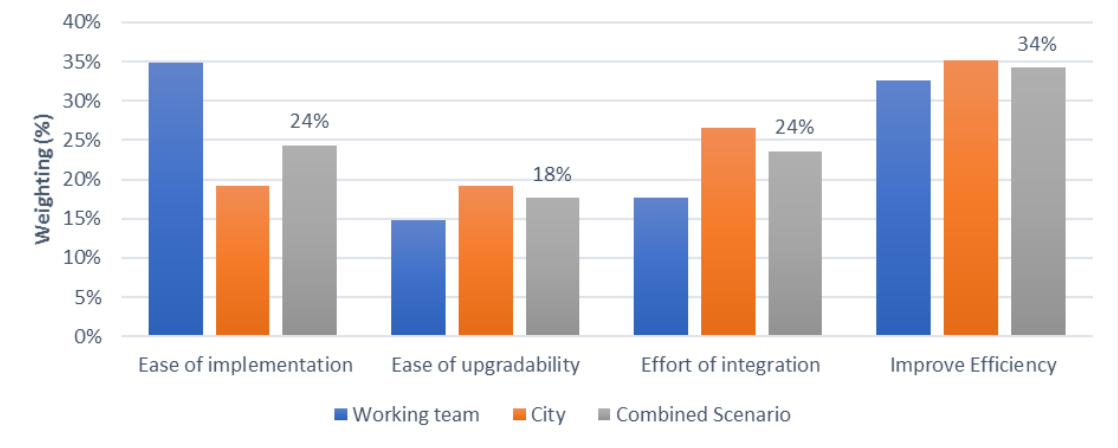


Figure 8: Weighting of the technical category

Upon analysing the preliminary responses and results gathered during the piloting of the questionnaire, it became apparent that the construction of some questions led to the production of counterintuitive responses. Notably, an instance of this was observed in evaluating the "ease of implementation" criterion, which aimed to assess the feasibility of practically implementing a given option by the City.

Instead, respondents appeared to rate the options based solely on the scale of an option rather than the practicality of implementing it. Therefore, adjustments were made to the questions to clarify definitions before the main scoring was conducted, which mostly involved administering the survey to City officials.

The ranking, as evaluated is shown in Table 4. An MCDA score of 1 is the most desirable as it indicates that the options provide an optimal solution, while scores closer to 0 are less desirable and indicate less optimal solutions. The MCDA scores are close to 1 and will be assigned a ranking close to 1. The ranking was based on weighting, qualitative scoring, and quantitative assessment; the options that ranked high in decreasing order of importance include the following:

- Option 9: Land used option.
- Option 3: Modernise and revitalise the rail infrastructure.
- Option 6: Alternative energy bus service.
- Option 8: Extended complimentary BRT services.

It must be noted that Option 3 and Option 9 ranked the same when evaluated to two decimal places. However, when the decimal places were increased, the results are shown in the table.

Table 4: Combine scenario ranking

Option	MCA (rounded to 2 decimal places)	Ranking
Option 1: Business-as-usual	0,61	7
Option 2: Pre-Covid rail services provided through diesel trains	0,57	9
Option 3: Modernise and revitalise the rail infrastructure	0,67	2
Option 4: Express bus services	0,63	5
Option 5: Dedicated public transport lanes	0,58	8
Option 6: Alternative energy bus services	0,63	4
Option 7: Electric minibus services	0,61	6
Option 8: Extended complimentary BRT services	0,66	3
Option 9: Land use option	0,67	1

5. LESSONS LEARNED

This section highlights some of the lessons observed during the administration of the MCA process. The highest number of challenges was experienced during the administration of the questionnaire and associated communication.

Amongst the lessons Learned:

- Incorporating quantitative criteria into a Multi-Criteria Analysis (MCA) that already includes qualitative criteria can enhance the analysis and make the decision-making process more robust and defensible. The addition of quantitative criteria adds objectivity and transparency to the process, ensuring that both quantitative data and subjective evaluations are considered, leading to more defensible outcomes.
- During workshops designed to complete an MCA questionnaire, communication issues and misunderstandings of definitions can arise, particularly when participants come from diverse professional backgrounds. To overcome these challenges, clear definitions of the criteria must be provided, and workshops should be structured to allow open discussion and clarification of any misunderstandings that may arise.
- The structure of a questionnaire can significantly impact the results obtained from it. For instance, asking respondents to assign percentages may not yield nuanced and detailed results, whereas asking respondents to order categories from most to least important can provide more accurate and meaningful results. Therefore, it is essential to carefully consider the structure of a questionnaire to obtain accurate and meaningful results.
- The choice of questionnaire platform may not have a significant impact if participants come from a small group with similar access to technology. However, if there are variations in technology access or familiarity, the choice of platform may become critical.

6. CONCLUSION

The article discusses the application of Multi-Criteria Decision-Making (MCDM) to assess nine Integrated Corridor Management options. In creating criteria, it is vital to consider issues and challenges unique to the study area, using the status quo assessment as a starting point to capture these challenges. The MCDA was employed to evaluate the nine options developed for each corridor to address their specific challenges. The MCDA offered a structured approach for assessing the options against different criteria.

The external consulting team and city officials prioritised the economic and social categories in the weighting of categories while assigning less weight to the environmental and technical categories for the corridor. The authors highlight the importance of piloting a questionnaire, particularly when it is intended for a diverse group of stakeholders, even if stakeholders have similar levels of education and access to technology. The study found that the structure of the questionnaire can influence the results, especially when administered through an online platform with limited opportunities for clarification.

7. REFERENCES

Ambrasaite, I, Barfod, MB & Salling, KB. 2011. MCDA and Risk Analysis in Transport Infrastructure Appraisals: The Rail Baltica Case. Procedia – Social and Behavioral Sciences, 20:944-953.

Barfod, MB. 2018. Supporting Sustainable Transport Appraisals Using Stakeholder Involvement and MCDA. Transport, 33(4):1052-1066.

Broniewicz, E & Ogrodnik, K. 2020. Multi-criteria analysis of transport infrastructure projects. Transportation Research Part D: Transport and Environment, 83(D):1-15.

GDRT. 2019. Gauteng Province Household travel survey Report 2019/20, Johannesburg: Gauteng Province Department Roads and Transport.

Hashemi, H & Abdelghany, KF. 2016. Real-time traffic network state estimation and prediction with decision support capabilities: Application to integrated corridor management. Transportation Research Part C: Emerging Technologies, 73:126-146.

Kane, L. 2010. Sustainable transport indicators for Cape Town, South Africa: Advocacy, negotiation and partnership in transport planning practice. Natural Resources Forum, 34:289-302.

Siksnelyte, I, Zavadskas, EK & Streimikiene, D. 2018. An Overview of Multi-Criteria Decision-Making Methods in Dealing with Sustainable Energy Development Issues. Energies, 11(10):1-20.

Thakkar, JJ. 2021. Multi-Criteria Decision Making. Gateway East, Singapore: Springer Nature Singapore Pte Ltd.

Velasquez, M & Heste, PT. 2013. An Analysis of Multi-Criteria Decision-Making Methods. International Journal of Operations Research, 10(2):56-66.

Ward, JE, Dimitriou, TH & Dean, M. 2016. Theory and Background of Multi-Criteria Analysis (MCA): Toward a Policy-led MCA for megaproject transport. The Journal of Research in Transportation Economics, pp. 48-99.