SUBTERRANEAN TRANSPORTATION NETWORKS IN SOUTH AFRICA: PRE-FEASIBILITY, CHALLENGES AND OPPORTUNITIES

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ABSTRACT

As urban traffic congestion worsens, subterranean transportation networks offer a promising solution for enhancing mobility in South Africa. This paper presents findings from interviews with 107 industry experts assessing the feasibility and challenges of underground excavation. Key cost drivers such as equipment, geological conditions, and water management were identified. Respondents cited issues such as soil and groundwater management, safety and ventilation, and regulatory compliance. A majority (63%) expressed optimism about subterranean networks, highlighting benefits like congestion relief and urban space optimisation, while 37% raised concerns over high costs, integration challenges, and political feasibility. Success hinges on investment, advancing tunnelling technology, and government support. The study concludes subterranean transport is technically feasible, but broader adoption requires pilot projects, awareness campaigns, and long-term planning to overcome financial and regulatory hurdles.

Keywords: Subterranean Transportation, Underground Networks, Tunnel Excavation, Traffic Congestion, Urban Mobility, Mass Rapid Transit.

1. INTRODUCTION

South African cities face severe traffic congestion that hampers mobility and economic productivity. Central business districts are especially affected during peak hours due to high activity concentration and limited road capacity (Van Ryneveld, 2018; Born, 2021). Rapid urbanisation continues to worsen the issue. UN Habitat (2013) projects urban populations to grow by five million monthly over the next four decades.

Minibus taxis dominate public transport in South Africa but remain inefficient, contributing to congestion. Efficient public transit could ease road pressure and improve mobility during peak hours (Stats SA, 2017; Subair et al., 2024; Aftabuzzaman et al., 2010). Globally, countries have implemented subterranean mass rapid transit systems to alleviate urban congestion (Shrestha et al., 2024). Subway networks in London Underground, Tokyo Metro, and New York City Subway demonstrate success. Africa, however, lags behind largely due to high capital investment requirements (Florida, 2018; Ball, 2015).

South Africa's 1970s feasibility study for a 24-kilometre underground railway, initially estimated at R151 million, was ultimately shelved due to funding challenges. Adjusted for inflation, the cost would be approximately R14.6 billion today (Ball, 2015). Most African cities still rely heavily on road-based transit (Mageto et al., 2024). Despite high upfront costs, Mass Rapid Transit (MRT) systems provide significant long-term benefits. They enhance capacity, reduce vehicle use, and encourage compact urban development (Litman, 2004). MRT systems also lower economic losses due to congestion, reduce emissions, and support densification (Chen et al., 2024; Vuchic, 1999). In cities like Singapore, Stockholm, and the London Underground, integration with road pricing has enhanced congestion management (Cervero, 2013). While these international examples serve as illustrative benchmarks, the differing economic, geographic, and governance contexts mean their applicability in South Africa requires careful consideration. Localised strategies and case-specific feasibility remain central to the methodology employed in this study.

Implementing subterranean mass rapid transit (MRT) systems in South Africa involves several complex challenges, particularly in relation to excavation. Excavation methods such as cut and cover and tunnel boring machines (TBMs) are capital-intensive, often comprising 35 to 40 percent of overall project expenditures (Antoniou et al., 2023). These costs are not uniform and depend on a variety of site-specific conditions. For example, in densely built urban areas like Johannesburg or Cape Town, existing underground utilities and limited surface space increase the complexity and cost of excavation. Geological conditions also play a crucial role; areas with hard rock formations or high groundwater tables require advanced dewatering systems and specialized equipment. Furthermore, South Africa’s regulatory landscape mandates strict compliance with environmental and occupational safety standards, which can further extend project timelines and increase costs (Membah & Asa, 2015). These layered challenges underscore the importance of thorough geotechnical investigations, context-sensitive excavation planning, and adaptive construction technologies.

This paper investigates the pre-feasibility of subterranean MRT in South Africa through expert interviews. The perspectives of civil engineers and planners inform practical recommendations tailored to the country’s urban and economic context.

2. STUDY AREA: FOUR MAJOR SOUTH AFRICAN CITIES

This research focused on four South African metropolitan areas with high population densities and peak-hour congestion: Cape Town, Durban, Johannesburg, and Pretoria. These cities were chosen for their substantial urban traffic loads and the potential impact subterranean MRT systems could have on mobility. Their heavy reliance on private vehicles and minibus taxis highlights the need for efficient, sustainable alternatives. Table 1 provides a comparative overview of the population size, geographic area, and public transport systems in Johannesburg, Pretoria, Cape Town, and Durban, highlighting the urban contexts relevant to assessing subterranean MRT feasibility.

Nationwide evaluations identified these four cities as the most suitable study areas based on population and congestion levels. Pretoria ranks as the most congested city, followed by Cape Town, Johannesburg, and Durban (Moyo et al., 2022). Each city presents specific challenges related to urban sprawl, traffic volumes, and limited public transport infrastructure (Gambe et al., 2023).

This diverse metropolitan sample allows the study to examine how subterranean MRT systems might alleviate congestion and support sustainable urban development across different city contexts.

Table 1: Comparative overview of population, area, and public transport systems in four major South African cities

City	Population (millions)	Area (km²)	Public Transport Modes	Notes
Johannesburg	6.3	1,645	Minibus taxis, Gautrain, Rea Vaya BRT, Metrobus	Rea Vaya serves over 45,000 daily commuters; Gautrain connects to Pretoria
Pretoria	2.89	1,644	Minibus taxis, Gautrain, A Re Yeng BRT, Metrorail, Tshwane Bus Services	A Re Yeng BRT and Gautrain provide rapid transit options
Cape Town	4.6	2,461	Minibus taxis, MyCiTi BRT, Metrorail, Golden Arrow Bus Services	MyCiTi BRT offers dedicated lanes; Metrorail network consists of 96 stations
Durban	3.5	2,297	Minibus taxis, GO!Durban BRT (planned), Metrorail, Durban People Mover, Muvo Bus	GO!Durban BRT under development; Metrorail connects city to surrounding areas

(Gumbo & Moyo, 2020)

3. METHODOLOGY

This study employed a qualitative research design to evaluate stakeholder perceptions and identify key factors influencing the adoption of subterranean transportation systems in South Africa. The methodology integrates primary data collection through structured interviews with industry experts and secondary data analysis to comprehensively understand the challenges and opportunities in subterranean excavation.

3.1 Research Design

The research was designed to achieve three primary objectives:

- Identify key challenges and opportunities associated with excavation and construction methods, as explored through the literature review and detailed in Section 4: Key Challenges in Subterranean Excavation.
- Understand industry stakeholders' current perceptions and insights regarding subterranean transit systems, as presented in Section 5: Stakeholder Insights on Subterranean MRT Feasibility.
- Provide actionable recommendations based on stakeholder input, derived from the findings discussed in Section 6.

3.2 Data Collection

3.2.1 Preliminary Information

Secondary data was obtained from literature reviews, government reports, and industry publications. This data provided context on global best practices, historical projects, and technological advancements in tunnel excavation. Insights from these sources informed the development of interview questions and the overall analysis framework.

3.2.2 Primary Data

Primary data was collected through structured interviews with 107 industry professionals, including civil engineers, geotechnical experts, and project planners.

The interviews consisted of eight questions divided into five sections:

- Road and tunnel excavation expenditure costs.
- Challenges in road and tunnel excavation operations.
- Feasibility of subterranean mass transit networks in South Africa.
- Familiarity with emerging technologies for subterranean excavation.
- Overall impressions of current industry practices and potential advancements.

Participants were asked to share their experiences, challenges, and perspectives on excavation practices, safety considerations, environmental impacts, and the feasibility of implementing subterranean transit systems in South Africa.

3.3 Analytical Approach

3.3.1 Qualitative Analysis

Thematic analysis was conducted on qualitative responses from the interviews to identify recurring themes and insights. Key themes included managing geological variability, ensuring regulatory compliance, addressing community concerns, and identifying potential cost-saving measures.

3.4 Ethical Considerations

Ethical approval was obtained before data collection. Participants were informed about the study's objectives and obtained consent before interviews. Data confidentiality and anonymity were maintained throughout the research process. By focusing on the insights and experiences of industry stakeholders, this study provides a detailed understanding of the current state of subterranean transportation planning in South Africa and identifies potential pathways for sustainable development.

4. KEY CHALLENGES IN SUBTERRANEAN EXCAVATION

Subterranean excavation presents numerous challenges, particularly in developing nations like South Africa, where infrastructure limitations and urban planning complexities exacerbate the difficulties. These multidimensional challenges spanning technical, financial, environmental, and social considerations (Melo Zurita, 2020).

4.1 Geological and Soil Variability

The geological diversity across urban centres makes excavation for subterranean transit systems inherently complex. Variations in soil types, groundwater conditions, and rock formations require careful assessment to ensure the stability of excavation sites. Managing groundwater inflow becomes a critical concern in regions with high water tables. Techniques like dewatering are necessary but add to the costs and environmental impact of the project (Al-Arafat et al., 2024).

The unpredictability of geological conditions can lead to delays and cost overruns; however, many of these risks can be mitigated through comprehensive geotechnical investigations and adaptive construction strategies. While certain geological challenges require advanced techniques and careful planning, others can be resolved with well-established engineering methods and site-specific assessments to ensure project safety and feasibility (Paraskevopoulou & Boutsis, 2020).

4.2 Urban Density and Land Use Constraints

High population densities in South African cities present logistical and infrastructural challenges for large-scale excavation projects. Traditional methods such as cut-and-cover can severely disrupt traffic flow and local economic activity, while deep tunnelling using tunnel boring machines (TBMs) minimizes surface impact but demands significant capital investment and technical expertise (Guglielmetti et al., 2008).

South Africa’s urban transport challenges are deeply rooted in historical spatial segregation and ineffective urban planning, leading to sprawl, inadequate infrastructure, and systemic transport poverty (Mthimkulu, 2017; McKay, 2019). Although interventions like Bus Rapid Transit systems and the Gautrain have been introduced, their reach and effectiveness remain limited (McKay, 2019). Addressing these issues requires a holistic, integrated approach that encompasses technical, financial, environmental, and social considerations (Mthimkulu, 2017; Chakwizira, 2013). Sustainable solutions such as underground mass transit systems offer potential but must be supported by inclusive planning processes, stakeholder engagement, and efforts to overcome barriers such as limited technical capacity and access to modern tunnelling technologies (Fourie & Malan, 2021).

4.3 Community Engagement and Public Perception

Public support is essential for the successful implementation of subterranean transit projects. In the South African context, community concerns often include noise, vibrations, and the perceived risk of property damage during construction activities. These concerns can be intensified by historical distrust, poor communication, and lack of visible short-term benefits (Pérez-Brito, 2018; McKay, 2019). Misinformation and low public awareness regarding the long-term advantages of underground transit systems may further hinder acceptance. As emphasised by Wang et al. (2021), effective engagement strategies such as transparent public consultations, targeted educational campaigns, and collaborative planning forums are crucial. Demonstrating tangible outcomes like reduced congestion, improved mobility, and safer, more sustainable urban environments can help build the public trust needed to support such transformative infrastructure initiatives.

4.4 Safety and Technological Adaptation

Safety considerations are paramount during subterranean excavation. Issues like ground stability, ventilation, and fire safety require advanced engineering solutions. TBMs, while technologically sophisticated, are not without limitations. They require precise calibration to adapt to varying geological conditions and are often limited to circular tunnel designs (Brox, 2013).

Emerging technologies offer potential solutions by reducing costs and construction times. However, adapting these innovations to local contexts in developing nations requires significant investment in training and infrastructure (Rinchen et al., 2024).

4.5 Institutional Barriers

The implementation of subterranean systems requires coordinated institutional support and efficient regulatory frameworks (Reilly, 2021). Challenges such as fragmented governance structures and infrastructure prioritisation delays can affect project timelines and continuity. Clear policy direction, streamlined approval processes, and effective inter-agency coordination are essential to reduce administrative barriers and support the successful delivery of complex engineering projects (Schulders, 2022).

The challenges of subterranean excavation are multifaceted, requiring a holistic approach to address technical, financial, environmental, and social barriers (Mthimkulu, 2017). While advanced technologies and innovative financing models offer potential solutions, their successful implementation depends on robust planning, stakeholder engagement, and institutional support (Fourie & Malan, 2021). Developing countries like South Africa must prioritise sustainable and cost-effective strategies to unlock the benefits of subterranean transit systems, paving the way for enhanced urban mobility and economic growth (Marsh, Brent & De Kock, 2020).

5. RESPONDENTS' INSIGHTS ON SUBTERRANEAN MRT FEASIBILITY

This section highlights insights gathered from a survey of 107 respondents, including civil engineers, geotechnical experts, and other industry professionals. Their perspectives provide a comprehensive understanding of the feasibility, challenges, and opportunities of implementing subterranean mass rapid transit (MRT) systems in South Africa.

5.1 Cost Drivers in Excavation

The survey identified key cost drivers for both road and tunnel excavation. Respondents emphasised that the costs associated with equipment, material management, and addressing geological variability represent a significant portion of overall expenses.

5.1.1 Road Excavation Costs

High costs arise from traffic management, material and equipment logistics, and regulatory compliance. Factors such as adverse weather conditions and managing underground utilities also add to project costs.

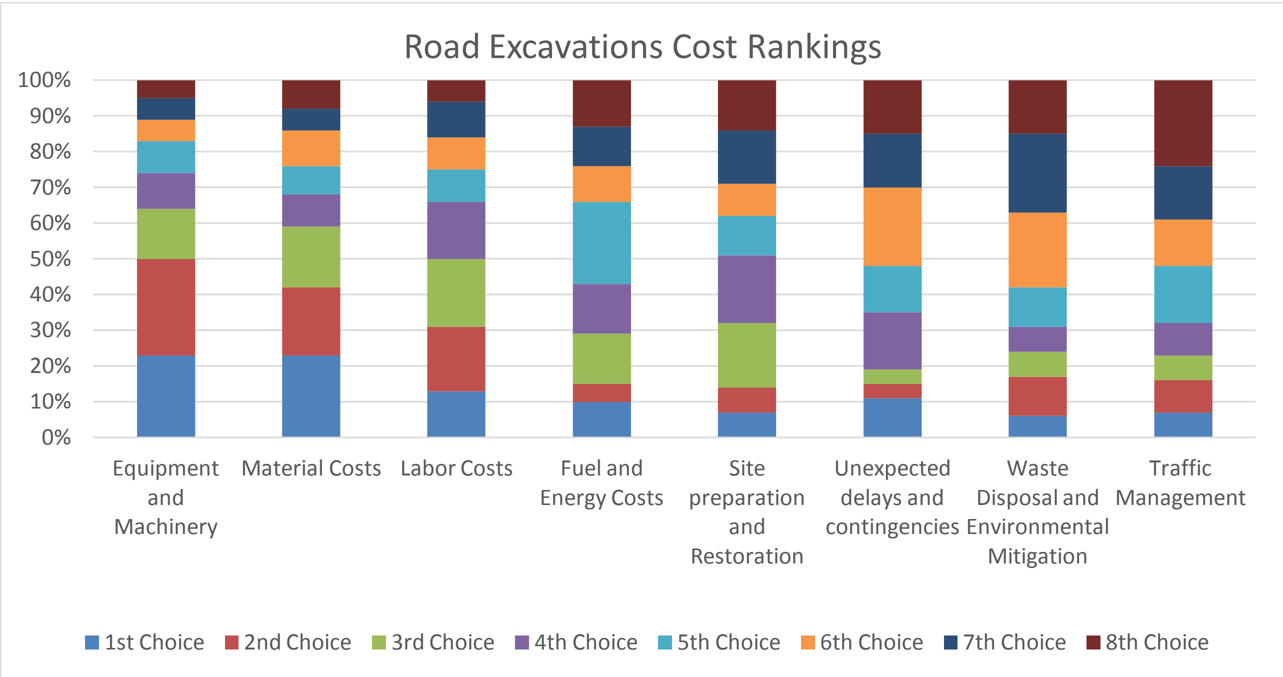

Figure 1: Road excavation cost rankings by stakeholders

Figure 2 presents the respondents' road excavation cost components rankings, highlighting their perceptions of cost distribution. The consensus among respondents indicates that the initial investment in equipment and machinery is considered the most significant expense, followed by material and labour costs. Other cost components, including fuel and energy, site preparation and registration, waste disposal and environmental mitigation, and traffic management, are generally regarded as contributing equally to the overall expenditure, as reflected in the ranked responses.

5.1.2 Tunnel Excavation Costs

Based on the feedback received from the respondents, major cost contributors include specialized equipment like tunnel boring machines (TBMs), safety and ventilation systems, and water management measures. Maintaining structural integrity in varying ground conditions was also noted as a significant expense.

Figure 3 illustrates the respondents' ranked choices for cost components in tunnel (subterranean) excavation, highlighting the relative significance of each factor. The majority of respondents identified specialized equipment and machinery as the most significant cost driver, underscoring the financial burden associated with procuring and maintaining advanced tunnelling technologies. Material and labour costs were ranked as the second most substantial expenses. The remaining cost components, including environmental and regulatory compliance, geotechnical analysis and survey, waste removal and disposal, power supply and energy, and groundwater management, were perceived to contribute relatively equally to the overall costs. This distribution reflects the multifaceted nature of tunnel excavation, where various operational and compliance factors collectively influence project budgets.

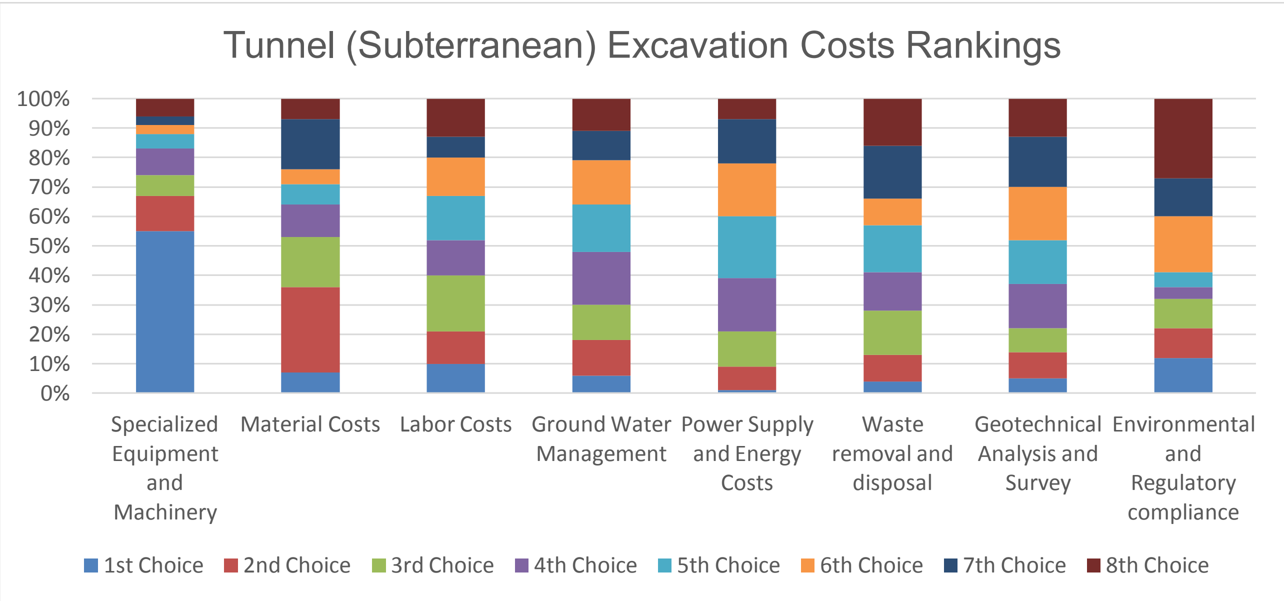

Figure 2: Respondents' ranked choices on subterranean excavation cost rankings

5.2 Challenges in Excavation

Respondents highlighted distinct challenges for road and tunnel excavation projects:

5.2.1 Road Excavation Challenges Included But Are Not Limited to:

- Variability in soil and ground conditions.
- Managing traffic flow and minimising disruptions.

- Adhering to environmental regulations and mitigating erosion and sediment runoff.
- Addressing logistical difficulties in urban environments.
- Contending with underground utilities and water table management.

5.2.2 Tunnel Excavation Challenges:

- Managing unanticipated geological conditions and soil stability.
- Ensuring safety and adequate ventilation during construction.
- Controlling water inflow and dewatering costs.
- Navigating logistical and access restrictions in densely populated urban areas.
- Securing and maintaining specialised equipment while controlling costs.

These challenges emphasise the need for robust planning, advanced technology, and experienced labour in subterranean projects.

5.3 Familiarity With New Technologies

As illustrated in the figure above, the survey highlighted a diverse range of familiarity levels among respondents regarding innovative excavation technologies, such as those developed by The Boring Company. Specifically, 31% of respondents indicated familiarity with these advanced technologies, suggesting a foundational understanding of their potential applications and benefits. Meanwhile, 32% reported limited knowledge, implying some awareness but a lack of in-depth understanding or practical exposure. Notably, 37% of respondents were unaware of such advancements, reflecting a significant knowledge gap within the industry.

This disparity in familiarity underscores the critical need for industry stakeholders to prioritise the exploration and adoption of emerging excavation technologies. Advanced solutions hold the potential to significantly enhance efficiency, reduce costs, and address many of the challenges associated with subterranean excavation, such as environmental compliance, geotechnical complexities, and energy consumption. To bridge this gap, targeted efforts, including professional development programs, technology demonstrations, and knowledge-sharing initiatives, must equip stakeholders with the expertise required to effectively harness these innovations. Expanding awareness and understanding within the industry will improve project outcomes and foster long-term sustainability and innovation in subterranean infrastructure development.

Stakeholder insights highlight both the potential and the challenges of implementing subterranean MRT systems in South Africa. While optimism surrounds their ability to reduce congestion and improve urban living, significant hurdles related to cost, public awareness, and regulatory support must be addressed. By focusing on these critical areas and leveraging advanced technologies, South Africa can make meaningful progress toward a sustainable and efficient underground transportation network.

5.4 Pre-Feasibility of Subterranean Transportation in South Africa

When asked whether subterranean MRT systems could work in South Africa, 63% of respondents expressed optimism, while 37% were sceptical. Respondents identified key factors that need to be addressed for the widespread adoption of subterranean MRT systems in South Africa. Table 2 summarises key perspectives expressed by respondents regarding the feasibility of subterranean MRT systems in South Africa, grouped into supportive views, sceptical concerns, and identified prerequisites for successful implementation.

Table 2: Summary of respondent perspectives on subterranean MRT feasibility, concerns, and implementation prerequisites

Supportive Perspectives	Sceptical Perspectives	Implementation Prerequisites
Congestion Relief: Subterranean networks could alleviate urban congestion and improve mobility.	High Costs: The significant initial and operational expenses.	Investment and Funding: Increased public and private sector investment, potentially through public-private partnerships, is critical.
Environmental Impact: Reduced air pollution and noise.	Economic and Political Feasibility: Competing infrastructure priorities and lack of government support.	Government Policy and Political Will: Clear, stable policies and prioritization of subterranean transit projects
Economic and Social Benefits: Enhanced urban accessibility, reduced travel times, and better land use.	Integration Challenges: Difficulties in merging subterranean systems with existing infrastructure.	Urban Planning Integration: Comprehensive planning to align with existing infrastructure and address urban sprawl.
Geological Feasibility: Certain areas of South Africa have geology suitable for tunnelling.	Public Awareness and Support: Limited understanding of the benefits of such systems.	Public Engagement: Raising awareness and gaining public support through educational campaigns.
		Technological Advancements: Adopting cutting-edge tunnelling technologies to address South Africa's diverse geological conditions.
		Safety and Security: Ensuring safety in construction and long-term system reliability.
		Regulatory Frameworks: Developing precise standards and frameworks for subterranean systems.
		Economic Stability: Strengthening the economy to support long-term investment in infrastructure.
		Economic Stability: Strengthening the economy to support long-term investment in infrastructure.
		Environmental Considerations: Mitigating ecological impact through detailed environmental impact assessments.

6. CONCLUSIONS AND RECOMMENDATIONS

Implementing subterranean mass rapid transit (MRT) systems in South Africa presents both challenges and opportunities. Survey results and supporting analysis offer insights into feasibility, perceptions, and conditions needed for successful implementation.

6.1 Conclusions

Subterranean MRT systems could significantly improve urban mobility in South Africa by addressing traffic congestion, supporting environmental goals, and optimising land use. 63 percent of respondents were optimistic about the feasibility of such systems.

6.1.1 Significant Benefits

Underground transit can reduce travel times, limit environmental impact, and boost economic activity through job creation, improved access, and investment attraction.

6.1.2 Challenges to Implementation

High initial capital costs, logistical complexities, and the need for specialised equipment remain significant barriers to subterranean MRT implementation. Technologies such as those developed by The Boring Company offer potential for faster and more efficient tunnelling, but their adoption in South Africa presents financial and institutional challenges. Historically, South Africa has faced difficulties in adopting and localising advanced infrastructure technologies due to limited funding, procurement complexities, and skill shortages. These constraints must be addressed through targeted investment strategies, local capacity building, and phased implementation models to ensure long-term feasibility. Additionally, public awareness, policy alignment, and integration with existing infrastructure require careful planning and sustained coordination.

6.1.3 Technological and Knowledge Gaps

While advanced tunnelling technologies show promise in reducing costs and construction times, a substantial portion of industry stakeholders remain unfamiliar with these innovations. This highlights the need for knowledge dissemination and capacity building.

6.1.4 Key Cost Drivers

Respondents identified equipment, labour, and materials as major cost contributors, alongside regulatory and environmental compliance requirements.

6.2 Recommendations to Support Implementation

- **Funding**: Establish public-private partnerships, explore tax incentives and concessional loans, and pilot small-scale projects in major urban centres.
- **Policy Support**: Streamline regulatory processes and foster inter-agency collaboration to reduce delays.
- **Technology Adoption**: While TBMs and similar technologies reduce long-term costs, their adoption requires significant upfront investment and training. Financial support and skills development must go hand-in-hand.
- **Urban Planning**: Integrate subterranean MRT into existing urban layouts, addressing urban sprawl and connectivity gaps through coordinated planning.
- **Public Engagement**: Strengthen community trust with transparent communication and public education on the long-term benefits of underground transit.
- **Environmental Readiness**: Conduct detailed geotechnical and environmental studies. Consider sustainable practices such as reusing excavated materials.
- **Economic Feasibility**: A cost-benefit and lifecycle cost study is recommended to assess long-term viability and guide investment decisions.
- **Pilot Projects**: Use demonstration sites to refine technical approaches, assess public reception, and build institutional momentum.

6.3 Final Remarks

While the development of subterranean MRT systems in South Africa presents significant challenges, the potential benefits may outweigh these obstacles if approached through strategic planning and coordinated collaboration. By addressing financial constraints, adopting appropriate technologies, and building sustained public and institutional support, South Africa could harness the transformative potential of underground transit. These efforts have the capacity to reduce urban congestion and contribute to more sustainable and inclusive urban growth. Future research should investigate innovative financing mechanisms, construction technologies, and the broader socio-economic implications of subterranean MRT implementation in the local context.

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