

Decision Support System for Assessment & Selection of Optimum Mass Transit Option

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Abstract

Many cities in the world are aspiring to have a world-class, sustainable public transport system. However, the cost of building new mass transport systems, especially metro projects, is so high it can lead to the postponement of such projects. New mass transit modes such as Bus Rapid Transit (BRT), Trackless Tram (TT) and suspended systems are continuously emerging. Some of the new emerging modes can deliver high capacity that can be equivalent to Light Rail Transit and Metro Systems but with significantly less cost. This research is meant to develop a comprehensive approach for comparing & assessing several aspects of different mass transit modes. Different research tools, including in-depth literature review, content, and case study analysis, multicriteria assessment, benchmarking and efficiency analysis, are used to reach conclusions for optimum mass transit options from different perspectives.

Keywords

Mass Transit, Multicriteria Assessment, Policies, Sustainability

1. Introduction

Cities around the world are aspiring to have world-class, sustainable and efficient public transport systems that are needed to enhance public transport, relieve congestion, and provide accessibility to different society groups—thus contributing to achieving a sustainable urban fabric. Mega projects such as Metros, Light Rail require significant investment and time to be completed. Limited funding, budget and time constraints are hindering the ambitious plans of many cities. This may lead these cities to delay their plans or to select options that are less efficient. Many

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transport authorities in the world are facing the challenge of deciding on the best mass transit option/or options that is suitable and optimum for their conditions.

The dilemma of selecting the suitable mass transit system causes postponement of many public transport projects around the world see [1] and recently [2]. In the meantime, several new mass transit modes have emerged in recent years including Bus Rapid Transit (BRT), Trackless Trams (TT) and Suspended Systems. Such systems are known to be highly efficient, and some of them can provide almost the same capacity as metro lines but with lesser capital and operational costs.

This research is meant to develop a novel assessment approach for mass transit systems. The suggested approach will compare and assess the various aspects of different proposed mass transit systems. It will utilise several research tools including multicriteria assessment, benchmarking, and efficiency analysis to reach conclusions for optimum mass transit options from different perspectives. The developed approach will identify main components and characteristics and will take into consideration several aspects including technical, operational, level of service, financial/economic, safety and environment and some sustainability aspects.

Two main outcomes are expected from this research including a multicriteria assessment tool to compare mass transit systems and a decision support system for planners and decision makers to conclude which mass transit system is more appropriate for a given corridor/network and a given budget. The novelty of the research is justified based on the compilation of the criteria used for the comparison and the assessment of the mass transit modes and packaging these together to develop a decision support tool.

2. Methodology

The hypothesis posed in this research is that TT/BRT can replace LRT/Metro systems and do the same functionalities of providing premium public transport capacity in a sustainable manner particularly with lesser whole life cycle costs and better financial efficiency. The following 2 main objectives are expected to be achieved in this research.

- 1) Develop a structured approach for comparing and assessing options/alternatives of mass transit systems, taking into consideration sustainability and other aspects.

- 2) Demonstrate the applicability of such approach to make conclusions and recommendations.

The research followed a robust methodology to attain its objectives of developing a structured approach for comparing and assessing TT/BRT versus other mass transit systems including metro. The research developed a multicriteria framework for comparing TT/BRT versus LRT/metro systems. Six criteria categories were developed including technical criteria (9 criterion), operational criteria (11 criterion), level of service criteria (5 criterion), financial and economic criteria (8 criterion), safety and environmental criteria (4 criterion), and other criteria (4

criterion) *i.e.* a total of 41 criterion. These Were applied to compare several mass transit systems namely buses, BRT, trackless tram, tram, monorail LRT and metro. Results of the comparison was further used to conduct bar chart and benchmarking analysis and efficiency computation.

The following presents the 8 steps methodology followed in this research:

- 1) Identify mass transit systems to be assessed.
- 2) Conduct literature and best practice reviews on different mass transit systems.
- 3) Identify the main characteristics, components, of the different mass transit systems.
- 4) Identify factors and criteria which impact the selection of mass transit systems.
- 5) Develop a multicriteria comparison among the considered mass transit options.
- 6) Compile data and conduct bar charting, benchmarking, and efficiency analysis,
- 7) Develop a comprehensive transit decision support system tool based on using the wealth of data and information provided by the considered criteria.
- 8) Demonstrate the applicability of the transit decision support system tool.

The outcomes expected from this research is a multicriteria assessment tool to compare mass transit systems as well as a decision support system for planners and decision-makers to conclude which mass transit system is more appropriate for a given corridor/network and a given budget.

3. Main Mass Transit Systems

This study will examine and compare seven mass transit modes namely conventional buses, bus rapid transit, trackless tram, streetcar, light rail transit, monorail, and rail rapid transit, see **Figure 1**.



Figure 1. Considered mass transit modes [3].

Buses operate in mixed traffic, along fixed routes with stations and stops. Their capacity is relatively low, with low investment and high operating costs. There are six bus types, namely minibus, midibus, standard bus, articulated bus, double articulated bus, and double-decker bus.

Bus Rapid Transit (BRT) is an iconic improvement to ordinary buses. It is composed of one or a trail (articulated) of iconic buses operating on segregated lanes along the side of the road network. BRT provides high capacity that can be equivalent to Light Rail Systems at a relatively lower cost. Currently more than

190 cities have BRT systems, see <https://brtdata.org/>.

Trackless Tram (TT) is a high-capacity and rubber-tired system that runs on a dedicated corridor and has signal priority. Vehicles are autonomous and have sensors that allow for smooth ride quality TT are a more stylish version of BRT in terms of appearance and attractiveness.

Streetcars is a street transit mode comprised of one to three cars, electrically powered operating on streets with mixed traffic, but sometimes with separate ROW or limited separation from other traffic through preferential treatment [1].








Light Rail Transit (LRT) is a mass transit mode with a capacity comparable to heavy rail. It primarily operates on rights-of-way in the medians of arterial roads, within short tunnels, or separated at grade through vehicle-free zones in central cities [1]. Its vehicles, one- to four-car transit units (TUs), are electrically powered.

Monorails are suspended from or straddled on a single elevated rail or beam [4]. Vehicles are fully automated and driverless. They gain power from electric motors that transfer force to steel wheels moving along a single rail or rubber tires running along the beam [4].

Rail Rapid Transit, also known as heavy rail and metro, is an electric rail system with a 4 to 10-car operating on exclusive rights-of-way and fully access-controlled stations [4]. ROW is usually within tunnels, grade-separated and at the top of aerial structures. Compared to all other mass transit modes, it scores the highest in capacity, speed, safety, reliability, passenger comfort, and operating efficiency, representing the optimal transit mode for a high-capacity network service or line [1]. However, it also has the highest capital and operation costs.

Table 1 provides a summary of the general operation and performance characteristics of the main mass transit systems.

Table 1. Operation & performance characteristics of main mass transit systems.

Mass Transit Modes		General Characteristics	
Buses		<ul style="list-style-type: none"> Operate in mixed traffic Move along fixed lines with frequent stops 	<ul style="list-style-type: none"> Performance affected by traffic condition Low investment costs High operating costs
Bus Rapid Transit (BRT)		<ul style="list-style-type: none"> Operate on segregated ROW with dedicated lanes and stops Short Headways 	<ul style="list-style-type: none"> Off-board fare collection system Higher investment costs than Buses Strong image
Trackless Tram		<ul style="list-style-type: none"> Runs on a dedicated corridor with signal priority High-capacity 	<ul style="list-style-type: none"> Rubber-tired Quiet operation Autonomous Distinctive appearance
Streetcar		<ul style="list-style-type: none"> Operate with mixed traffic, but sometimes with separate ROW One-to three-car 	<ul style="list-style-type: none"> Electrically powered Excellent riding comfort Operating speed and reliability depend on road condition
Light Rail Transit (LRT)		<ul style="list-style-type: none"> Operates on the medians of arterial roads, within short tunnels, or separated at grade through vehicle-free zones 	<ul style="list-style-type: none"> One – to four- car Comparable capacity to heavy rail Electrically powered
Monorail		<ul style="list-style-type: none"> Operate on exclusive ROW and fully access-controlled stations 4 to 10-car Attain maximum speed from guidance 	<ul style="list-style-type: none"> Fail-safe signal control and electric traction Highest in capacity, speed, safety, reliability passenger comfort and operating efficiency
Rapid Rail Transit		<ul style="list-style-type: none"> Operate on exclusive ROW and fully access controlled stations 4 to 10-car Attain maximum speed from guidance 	<ul style="list-style-type: none"> Fail-safe signal control and electric traction Highest in capacity, speed, safety, reliability passenger comfort and operating efficiency

4. Developing Multicriteria Assessment (MCA) Tool

After exploring the characteristics of the main mass transit options, this section deals with developing a multicriteria assessment tool for comparing mass transit options using more than 40 criteria to enable cities to screen and short list the possible options prior the in-depth quantitative analysis. The developed MCA tool involves five steps as shown in **Figure 2**.

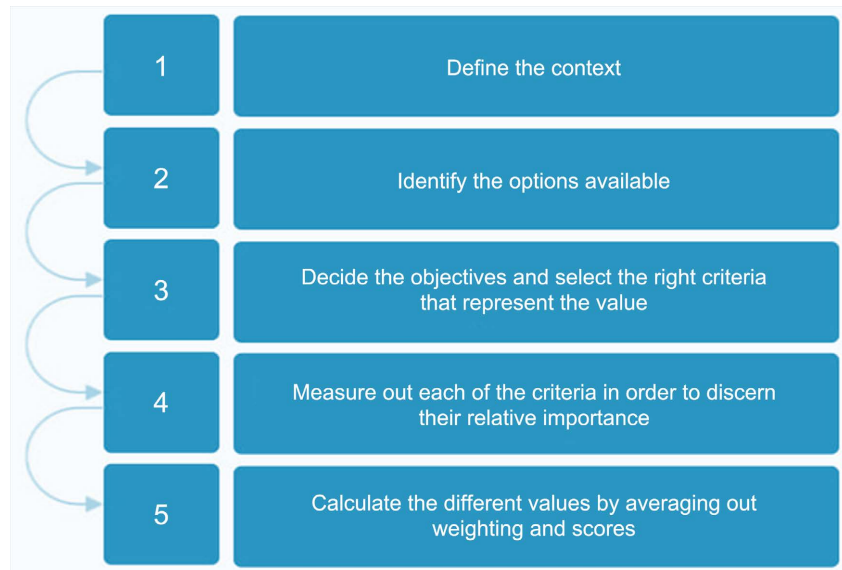


Figure 2. Steps followed in applying the mca tool.

Table 2. Criteria typology.

Technical Assessment (9 Criteria)	Operational Assessment (11 Criteria)	Level of Service (LOS) Assessment (5 Criteria)	Financial/Economic Assessment (8 Criteria)	Safety & Environmental Assessment (4 Criteria)	Other Assessment Criteria (4 Criteria)
ROW Requirement	Doors	Headway	Total Capital Cost	Safety and Security	Ease of Implementation
Guideway	No. of Units	Frequency	Capital Cost Per Passenger	Environmental Impacts (Air)	Time of Implementation
Section Facilities	Turning Radius	Punctuality	Guideway Cost	Environmental Impacts (Noise)	Maturity
Spacing between Stations	Propulsion	Comfort	Stations Cost	Energy Consumption	Iconic Image
Vehicle Dimensions	Type of Control	Convenience/ Disabled access.	Vehicle Cost		
No of Axles	Passenger Holding capacity		Operational Cost Per passenger		
Axle Weight	Line capacity		Maintenance Cost		
Vehicle Weight	Operating Gradient		Fare Structure		
Type of Wheel	Acceleration/Deceleration				
	Operating Speed				
	Max. Technical Speed				

The MCA included 6 categories of criteria namely: technical, operational, Level of Service financial, safety and environment and others, see **Table 2**. This amounted to 41 criteria covering all spectrums of transport sustainability including: economic/

financial, social, environmental, technical, safety and security. These criteria were compiled for each of the 7 modes from a thorough in-depth literature review see [5] to [24]. An assortment of sources was used in this research, including numerous governmental reports and journal articles as well as textbooks. The Appendix 1 includes 6 tables showing the 41 criteria across the 7 considered modes. It is also important to note that the other criteria including ease and time of implementation, as well as maturity and iconic image of the mass transit systems, could be as important to decision makers as the funding and capacity criteria.

5. In Depth Comparison of Mass Transit Modes

After presenting the multicriteria assessment table, this section will analyse the most critical criteria. The analysis will be through bar charts, benchmarking comparisons, and calculating efficiency indicators. It will encompass mass transit system outputs, including speed, comfort, frequency, reliability, maintenance cost, safety, time of implementation, passenger capacity per car, average speed, and implementation time. Notably, it will examine these criteria versus capital cost since it is the most critical input that policy and decision-makers consider in selecting the optimum mass transit option.

5.1. Bar Charting Main Characteristics of Mass Transit Options

Based on the multicriteria values extracted from several sources, this section will show some examples of the bar chart comparison among the various considered mass transit modes. **Figure 3** shows variation in station spacing between mass transit modes. Bus and tram systems have the lowest spacing, indicating that such systems suit local short trips. On the other hand, station spacing for metro and LRT are the highest, revealing their applicability for long central trips. Although metros require fewer stations, they are relatively expensive compared to bus stations.

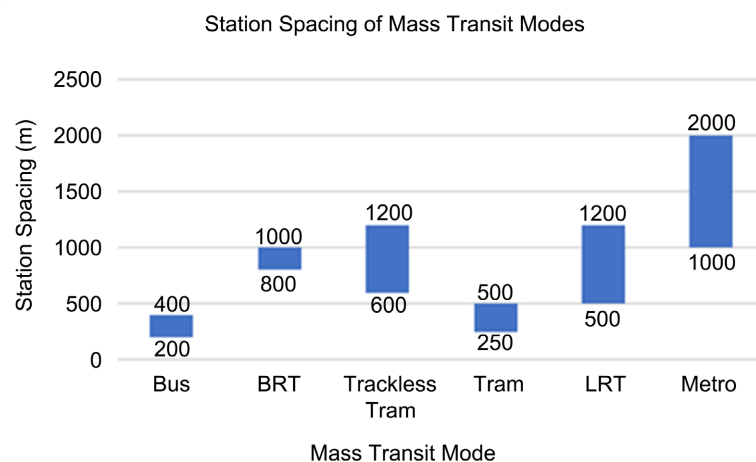


Figure 3. Station spacing of mass transit modes.

Figure 4 below shows the number of axles for most mass transit modes. The typical range of axles for mass transit systems is 2 to 6. However, for tram systems, the range is widened to be from 4 to 10.

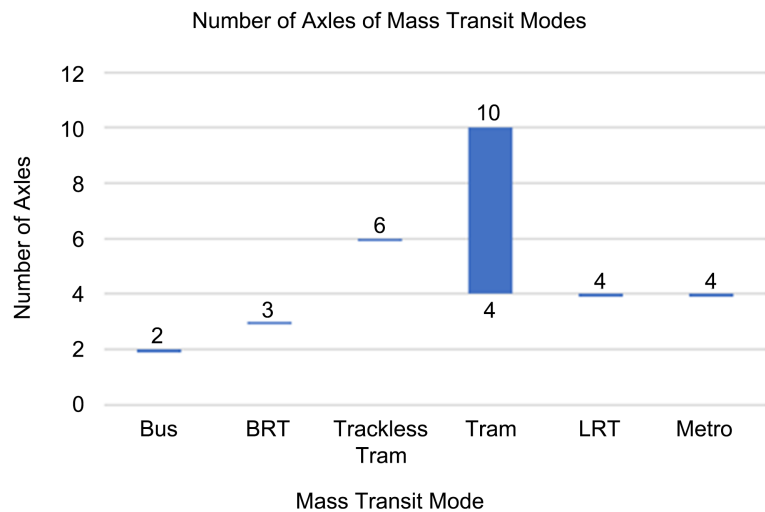


Figure 4. Number of axles of mass transit modes.

Another related component of the mass transit system is the number of units, as depicted in Figure 5. The figure clearly shows that the Metro system has the highest range from 2 to 10 units, demonstrating the potential for mass carrying capacity. This number is followed by the monorail system with units ranging from 3 to 6. The minimum is the bus being one vehicle unit.

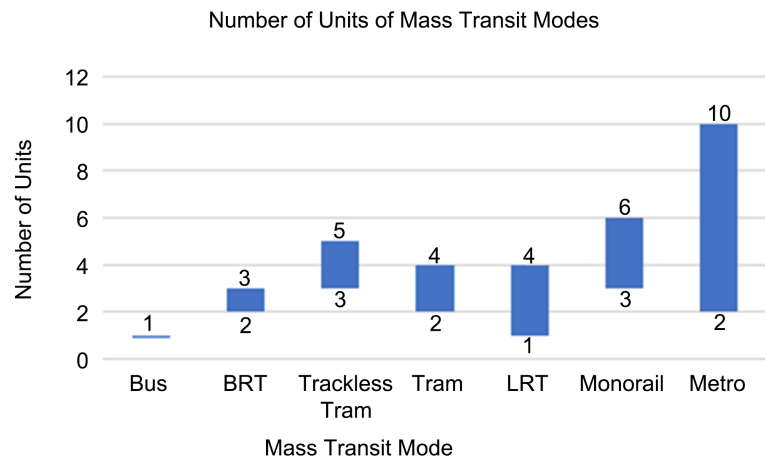


Figure 5. Number of units of mass transit modes.

Apart from vehicle capabilities, the implementation time for mass transit systems varies. Figure 6 suggests that the more sophisticated the system regarding its technical and operational requirements, the longer its implementation time will be. This pattern is also partly due to the distribution of funding and budgeting of

costly systems over longer periods of time. In this way, metro systems can take an average of seven years to get constructed, while the implementation time for all other systems is in the range of one to 3 years. Metros take the longest time because of the challenges also in acquiring the ROW and constructing the associated infrastructure. An interesting finding from the Figure below being the lower implementation time for trackless trams compared to BRT, suggesting they are quicker to implement.

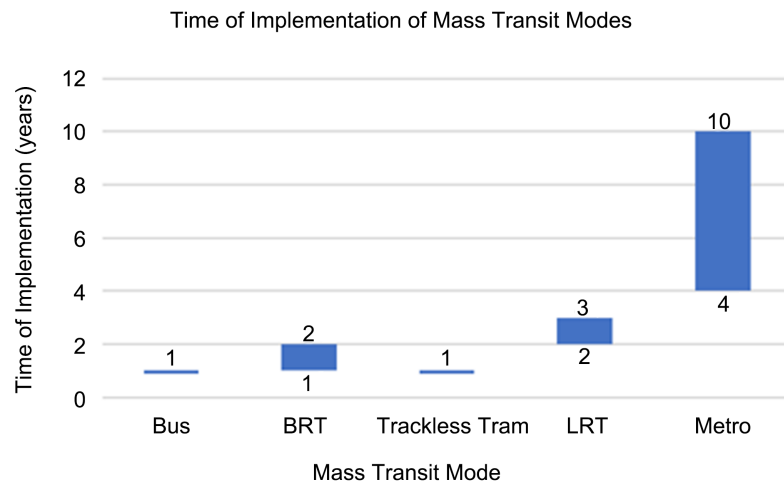


Figure 6. Time of implementation of mass transit modes.

Moreover, the operational cost per passenger is noteworthy for comparison. As seen from **Figure 7**, buses have the highest operation cost per passenger-km at \$0.57 per km, while metros have the lowest at \$0.28 per passenger-km. Trams and LRT are in the middle, with an approximate value of \$0.43 per passenger-km. The trend reveals that with larger transit systems, the operational per passenger-km goes down, due to carrying a higher number of passengers and travelling longer (*i.e.*, Economies of scale). The opposite is true for smaller transit systems.

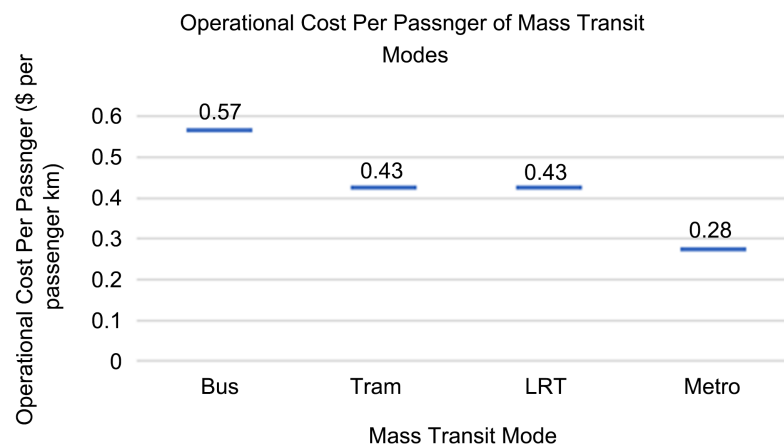


Figure 7. Operational cost per passenger of mass transit modes.

5.2. Efficiency Comparisons of Mass Transit Options

Based on the multicriteria values extracted from several sources, this section will show some examples of efficiency comparisons among the various considered mass transit modes. Such comparisons will be related to the capital cost per km as an input. **Figure 8** compares operating speed versus capital costs. The figure shows that the average operating speed of the 6 considered mass transit systems is around 31 km/hour, with the trackless tram, the monorail, and the metro speeds are above the average, while the bus, BRT, and LRT are below it. A closer inspection reveals that the minimum operating speed is about 16 km/h for the tram. The figure shows that trackless Tram provide the highest operating speed of 50 km/hr. for capital cost of 11 million USD/km.

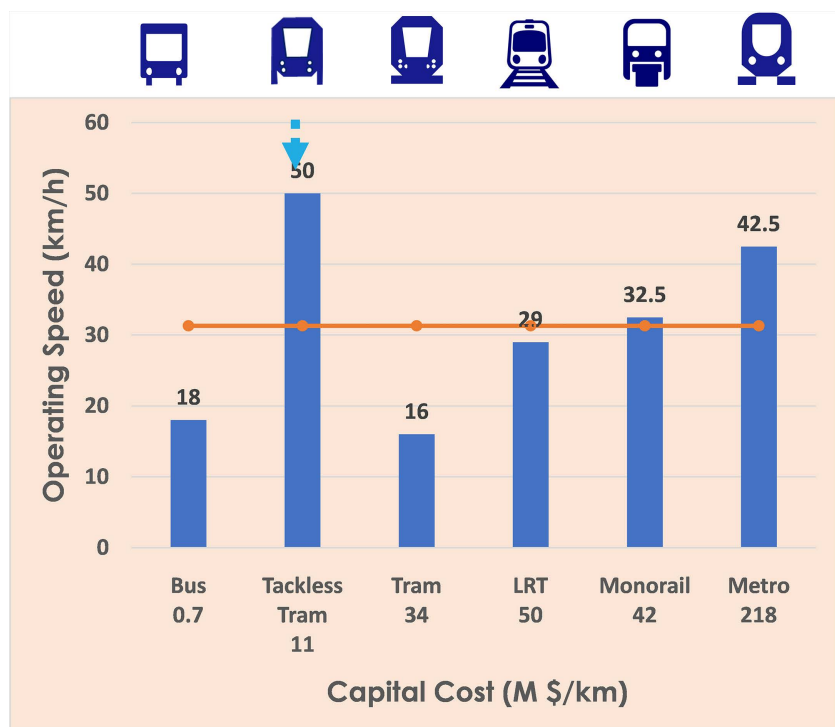


Figure 8. Operating speed of mass transit modes versus capital cost/km.

Figure 9 compares the frequency and capital costs for buses, BRT, trams, LRT, and Metro. The figure shows that these five systems have an average frequency of around 94 TU/h, with the bus and BRT above the average line, while the tram, LRT, and metro below it. A closer inspection reveals that the minimum frequency is about 30 TU/h for the metro, while the maximum is 180 TU/h for the BRT.

Figure 10 compares the carbon dioxide emissions and capital costs for buses, monorails, and Metro. The figure shows that these three systems have an average carbon dioxide emission of around 32.9 g per passenger km, with the bus above the average line, while the monorail and metro below it. The figure demonstrates that buses are the worst in terms of CO₂ emissions, yet they are very cost efficient as their capital cost is less than 1 million USD/km.

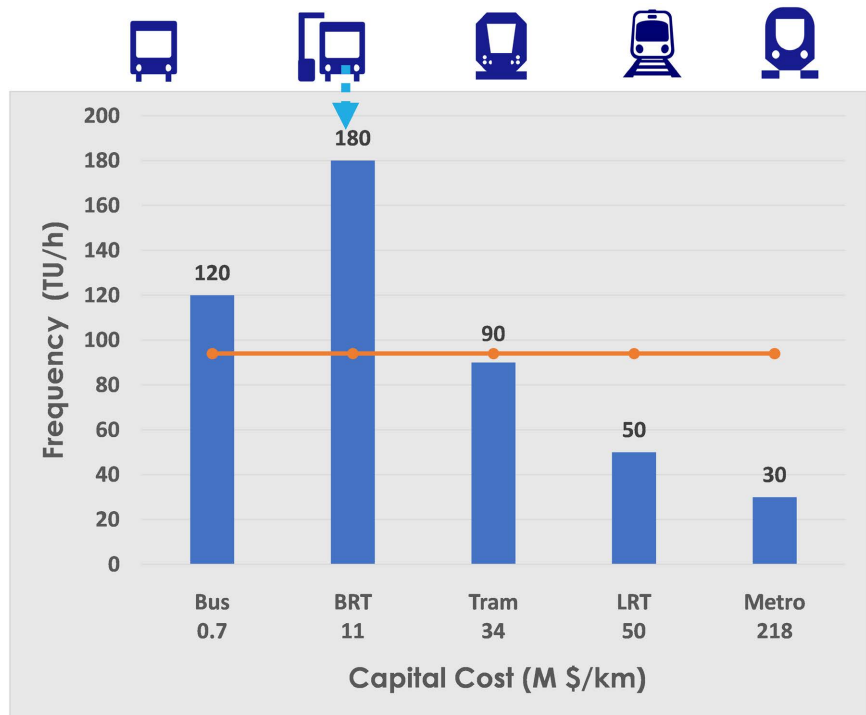


Figure 9. Frequency of mass transit modes versus capital cost/km.

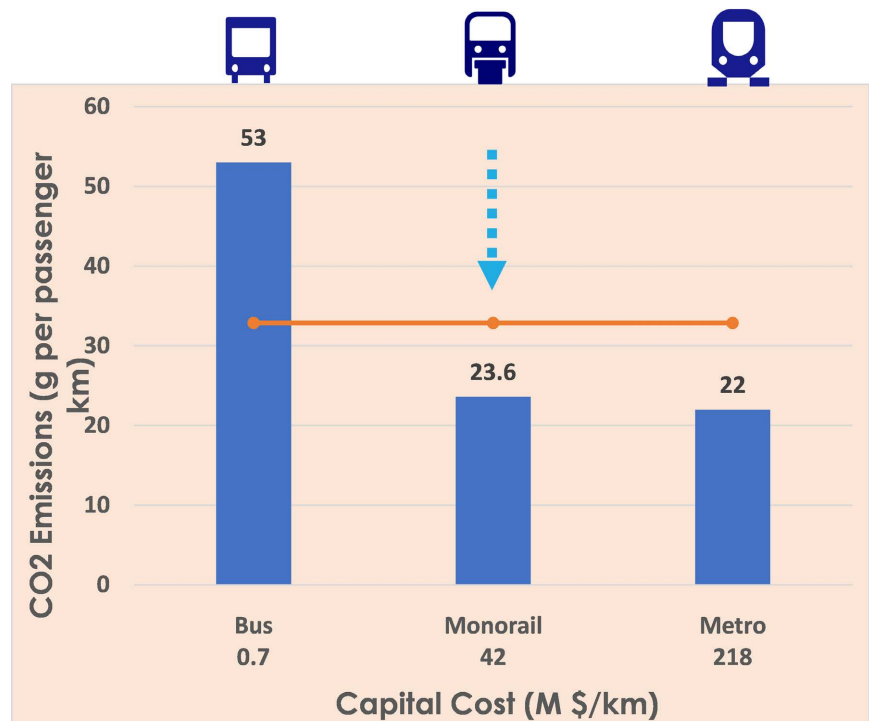


Figure 10. CO₂ emissions of mass transit modes versus capital cost/km.

As for noise levels, Figure 11 shows for the four considered systems the average noise level being around 79.5 dBA, with the bus and metro above the average line, while the LRT and monorail below it. A closer inspection reveals that the minimum

noise level is 75 dBA for LRT and monorail, while the maximum is 84 dBA for both the bus and metro. Thus, in terms of generating noise, the bus system is the worst while the metro system is the best.

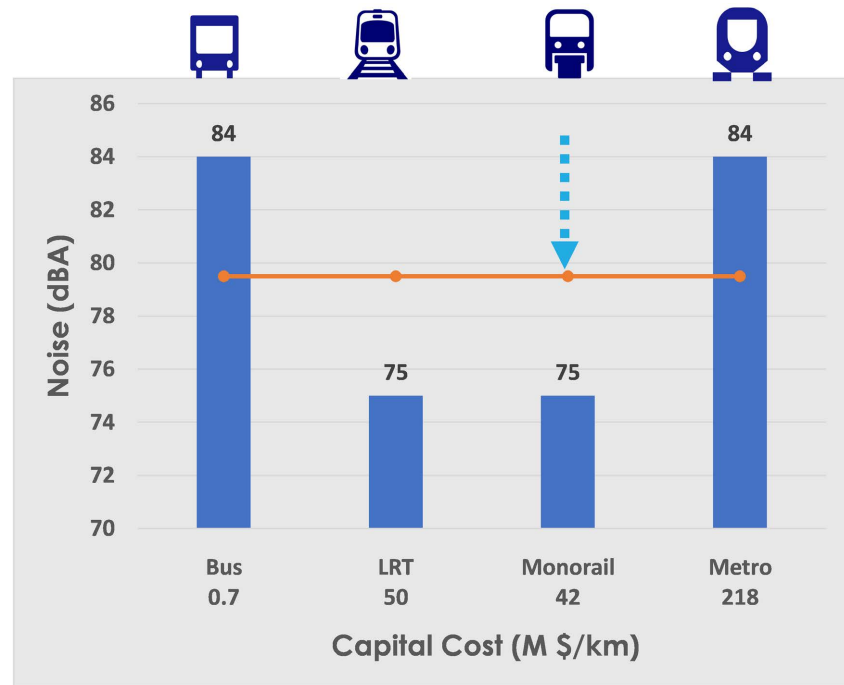


Figure 11. Noise emissions of mass transit modes versus capital cost/km.

6. Demonstration of the Transit Decision Support System Tool

Deciding on the most suitable system that fits each city/corridor is rather a complex process. Usually, Government entities will employ engineering consultancy with high expenses to answer the basic question of “what the suitable system for a specific city/corridor is. While employing such consultancy advice is necessary, having a multicriteria analysis tool for quick decision-making to allow narrowing down options and clarifying the pros and cons of each system is very useful, and therefore this research developed a transit decision support tool that requires only 2 inputs (length of the corridor and number of passengers required to be carried per hour per direction). Such inputs will be used via an analysis platform based on the multicriteria information, comparison, and assessment. Such analysis will generate a number of outputs that can be categorized as operational, financial and economic as well as safety and environmental outputs, see **Figure 12**. It is to be noted that all factors influencing mass transit selection are considered in the multicriteria analysis however as the most 2 important factors for mass transit systems decision are related to funding availability and potentiality for meeting expected demand that is why these 2 factors are considered most relevant in the demonstration of the tool, but definitely other factors can be used from the multicriteria tables in the Appendix 1.

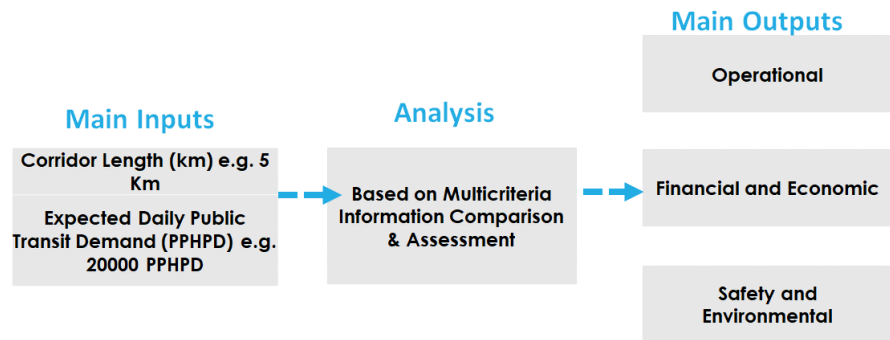


Figure 12. Main components of the transit decision support tool.

To demonstrate the applicability of this tool, a hypothetical case study is suggested where a city considers a number of mass transit options along a corridor of 5 km with an expected daily public transport demand (PPHPD) of 20000 PPHPD. Running the tool will produce the following outputs as shown in Figures 13-15. Figure 13(a) and Figure 13(b) show the financial outputs in terms of unit capital costs for each system transferred into absolute required capital cost for the total length of 5 km. It is obvious that trackless tram can provide the required capacity while requiring capital investments of 11 million USD/km while the metro is the only other mode providing the capacity required with very high capital investments of 218 million USD/km.

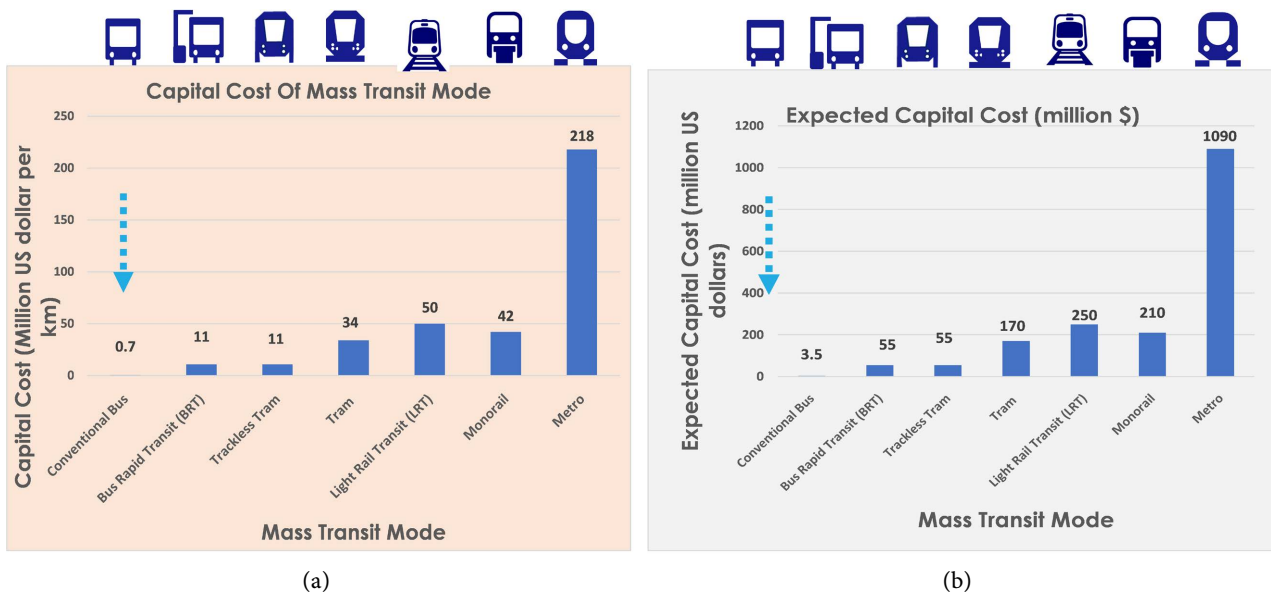


Figure 13. (a): Main financial & economic outputs (unit capital costs); (b): main financial & economic outputs (absolute capital costs).

Figure 14(a) & Figure 14(b) showing the operational outputs demonstrates that the trackless tram is providing the required capacity while the metro is providing much higher capacity. Also, the number of stations required for the trackless tram is more than for metro. This shows the superiority of the trackless tram as it can meet the expected demand with much less cost than the metro.

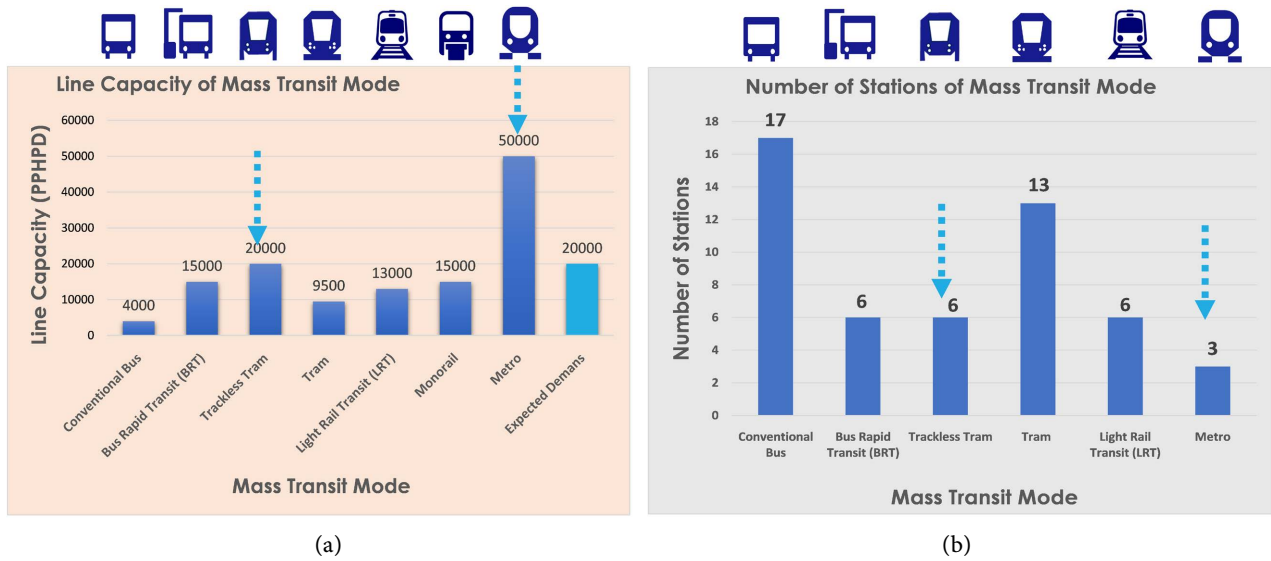


Figure 14. (a): Main Operational Outputs (Line Capacity); (b): Main Operational Outputs (Number of Stations).

Figure 15(a) and **Figure 15(b)** shows that operational speed is the highest for trackless trams and the lowest for ordinary tram systems. This shows the superiority of the trackless tram as it can meet the expected demand with much less cost than the metro. The figure also shows that LRT and monorail produce the lowest noise levels (75 dB) at 15 meters distance.

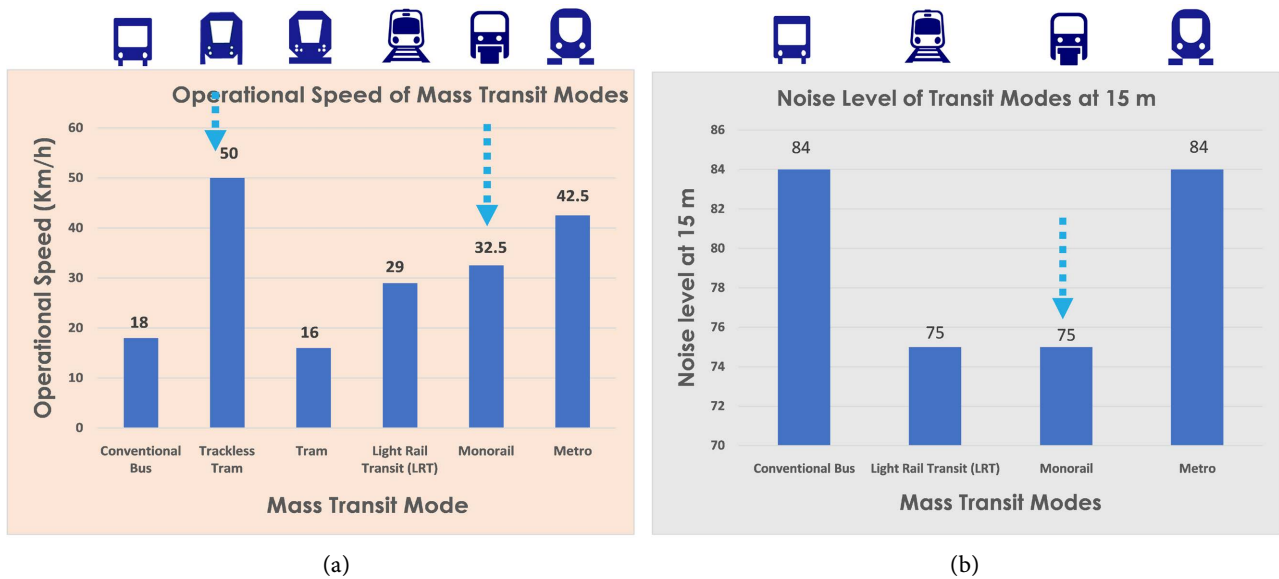


Figure 15. (a) Main Operational & Environmental Outputs (Speed); (b). Main operational & environmental outputs (noise).

Several sensitivity tests were conducted to assess and confirm the robustness of the tool's outputs to variations in input parameters.

7. Conclusions

Each Mass transit system has its advantages and limitations. Deciding which Mass

transit system is the optimum for a particular city or route is heavily dependent on the demand of the city itself and its capability to fund and secure the budget. Having a comprehensive multi-criteria tool could help significantly in deciding which mode of transport should be selected.

This research addressed a very important topic namely whether it is sustainably viable to consider replacing future planned Light Rail Transit and metro lines with Bus Rapid Transit and Trackless Tram systems. Such a question is justifiable considering the current limitations in available budgets and the capital intensity of LRT and metro projects. Instead of delaying such important projects that are extremely necessary to complete the public transport system and relieve congestion in our cities, we should seriously consider other options.

The developed Transit Decision Support System tool is very efficient and not data-hungry. Basically, it requires 2 main inputs namely corridor length and expected peak demand. The analysis is based on comparing the wealth of information collected for each criteria. The model generates a number of outputs for each mode categorized into 3 categories namely Operational, financial, safety and environmental. The tool was fully demonstrated using a hypothetical scenario.

TT/BRT can be considered to replace the metro when capital expenditure & budget are not available, or cost of funding is expensive, land acquisition is a challenge and expensive, and the expected PPHPD is on the lower limit to warrant for Metro. The medium to long-term growth along the corridor is moderate. The research also acknowledges the importance of public opinion and acceptability for the success of new public transport modes. Policies and initiatives are key enablers and success factors to any new public transport mode.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Table A1. Technical assessment

Criteria	MT Option Conventional Bus	Bus Rapid Transit (BRT)	Trackless Tram	Tram	Light Rail Transit (LRT)	Monorail	Rapid Rail Transit/Metro
Guideway	Buses follow fixed routes on street pavements, which provide lateral and longitudinal support.	Most BRT systems run on segregated median lanes of arterial streets that spread at stops to give space for passenger boarding and alighting platforms.	Trackless trams require orange lines for designating the vehicle path.	Trams require overhead wires and permanent tracks that provide lateral and longitudinal support and lateral guidance. They have extra equipment to propel the transit vehicle in the longitudinal direction.	Light rails need dual rail tracks/steel rails providing lateral and longitudinal support and guidance.	Monorails are guided and supported by a single rail or beam of reinforced steel or concrete, providing lateral and longitudinal support and guidance.	Rapid rail moves on a high-voltage third rail, which has propulsion aids.
Spacing Between Stations	200 to 400 m	800 to 1000 m	600 to 1200 m	250 to 500 m	500 to 1200 m		1000 m to 2000 m
Vehicle Dimensions	The lengths and width of conventional buses are 11.7 m and 2.67 m, respectively.	The length of an articulated and biarticulated BRT is 16-18 m and 30 m, respectively.	Trackless trams have a length of 31 m, a width of 2.65 m, and a height of 3.4 m.	The length of single-body tram vehicles is 14 to 16 m, while that of articulated tram vehicles is 20 to 50 m.	The length of single-body LRT vehicles is 14 to 16 m, while the length of articulated LRT vehicles is 20 to 50 m.		Metros have a length of 15 to 23 m and a width of 2.5 to 3.2 m.
Number of Axles	2 for conventional bus	3 for biarticulated BRT	6 for biarticulated trams	4 to 10	4		4
Axle Weight		11 tonnes	9 to 8.5 tonnes	10 tonnes	10 tonnes		
Vehicle Weight	12 to 13 tonnes		48 to 50 tonnes for a 3-car set	12 tonnes	33 tonnes		25 tonnes
Type of Wheel	Rubber tires for conventional buses and pneumatic tires for trolley buses	Rubber tires	Rubber tires	Steel wheels	Steel wheels	Rubber tires or steel wheels	

Table A2. Operational assessment.

MT Option	Conventional Bus	Bus Rapid Transit (BRT)	Trackless Tram	Tram	Light Rail Transit (LRT)	Monorail	Rapid Rail Transit/Metro
Criteria							
Number of Units	1	2 to 3	3 to 5	2 to 4	1 to 4	3 to 6	2 to 10
Turning Radius	11 to 20 m	11 m	15 m	20 m	20 to 25 m		50 to 75 m
Propulsion	Diesel, propane gas, or electric	Diesel, gas, or electric	Diesel, gas, electric, or hydrogen fuel cells	Electric - obtaining their power through pantographs from overhead wires.	Electric - obtaining their power from overhead cable through pantograph or third rail.	Onboard electric motors or trolley wires suspended along the sides of the guideway	Electric power from the third rail or overhead
Passenger Holding Capacity	80 passengers per vehicle	110 to 180 passengers per vehicle	300 passengers for a 3-car configuration and 500 passengers for a 5-car configuration.	180 passengers per vehicle	170 - 280 passengers per vehicle	190 passengers for Small four-car monorails, 350 passengers for medium four-car monorails, and 420 passengers for large four-car monorails	150 to 250 passengers per vehicle
Line Capacity	3000 to 5000 passengers per hour	10,000 to 20,000 passengers per direction per hour	10,000 to 30,000 passengers per hour per direction	4000 to 15,000 passengers per hour	6000 to 20,000 persons per hour per direction	10,000 to 20,000 passengers per hour per direction	20,000 to 80,000 passengers per hour per direction
Operating Gradient	13%	13% to 15%	13% to 15%	8% to 10%	6% to 8%	6%	4% to 6%
Acceleration/Deceleration	Acceleration = 0.7 to 0.9 m/s ² Deceleration = 3 to 6 m/s ²			Acceleration = 1.2 to 1.7 m/s ² Deceleration = up to 2.5 m/s ²	Acceleration = 1.0 to 2.0 m/s ² Deceleration = up to 3.0 m/s ²		Acceleration = 1.0 to 1.4 m/s ² Deceleration = 1.1 to 2.1 m/s ²
Operating Speed	16 to 20 km/h during the peak on urban roads 8 to 16 km/h in congested CBD		50 km/h	12 to 20 km/h	18 to 40 km/h	25 to 40 km/h	25 to 60 km/h
Maximum Technical Speed	60 km/h	90 km/h	70 km/h	60 to 70 km/h	60 to 120 km/h	60 to 90 km/h	130 km/h

Table A3. Level of service assessment.

Criteria	MT Option Conventional Bus	Bus Rapid Transit (BRT)	Trackless Tram	Tram	Light Rail Transit (LRT)	Monorail	Rapid Rail Transit/Metro
Headway	5 to 10 mins for busy routes and 15 to 30 minutes for other routes	Less than 10 minutes	2 to 3 minutes	5 minutes	2 to 3 minutes	2 to 3 minutes	5 to 10 minutes or a busy route or less than 30 minutes for other routes
Frequency	60 to 180 TU/h	60 to 300 TU/h		60 to 120 TU/h	40 to 60 TU/h		20 to 40 TU/h
Punctuality	The performance of buses is primarily a function of traffic conditions.	BRT buses operate in their lanes and receive priority at signalized intersections, allowing them to provide regular uninterrupted service transport.			LRT's punctuality increases with the provision of fast and affordable feeder bus service to/from the LRT station.	High	High
Comfort	Buses typically have low floors, roughly 35 cm above the ground, that permit easy boarding and alighting. However, their comfort is lower than BRT.	BRTs offer high-riding quality but can vibrate. Adequate bus corridors have smooth curvature and gradients that improve riding comfort.	Trackless trams offer high riding quality because they have sensors that can detect and expect bumps in the road, allowing the vehicle to adjust like rail bogeys. As a result, they are less likely to vibrate or jump.	Tram vehicles have low floors, making boarding comfortable.	LRTs have high comfort due to low-floor and more spacious vehicles.	Straddle and suspended monorails offer a smooth flight. The air springs in straddle systems provide suspension that reduces the forces exerted by curves.	Smooth and stable riding quality, high comfort
Reliability	Low to medium	Medium to high	Medium to high	Low to medium	High	High	Very high

Table A4. Financial and economic assessment.

MT Option Criteria	Conventional Bus	Bus Rapid Transit (BRT)	Trackless Tram	Tram	Light Rail Transit (LRT)	Monorail	Heavy Rail Transit/Metro
Total Capital Cost	\$250K to \$2 million per mile (\$155.34K to \$1.24 million per km)	\$5 to \$30 million per mile (\$3.11 to \$18.64 million per km)	16 million Australian dollars per km (10.86 million US dollars per km)	\$30 to \$80 million per mile-including vehicles (\$18.64 to \$49.71 million per km)	49 to 100 million Australian dollars per km, (33.16 to 67.68 million US dollars)	41.67 million per km	\$100 to \$600 million per mile (\$62.14 to \$373.82 million per km)
Capital cost per passenger		\$8.4 million (2000 US\$/km)	\$6 - \$8 million per km		\$21.5 million (2000 US\$/km)	Average of \$83.9 million per km	\$104.5 million (2000 US\$/km)
Guideway Cost	\$215.6 million			\$2569.4 million	\$2569.4 million	\$27 million to \$73 million per km	\$2344.4 million
Stations Cost	\$443.8 million			\$307.7 million	\$307.7 million		\$1718.5 million
Vehicle cost	\$2361.9 million				\$312.1 million	\$25 million to \$55 million	\$441.1 million
Operational cost per passenger	\$0.57 per passenger km	\$2.94 million (2000 US\$ Per vehicle revenue km)		\$0.43 per passenger km	\$0.43 per passenger km/ \$7.58 million (2000 US\$ Per vehicle revenue km)		\$0.28 per passenger km/ \$5.30 million (2000 US\$ Per vehicle revenue km)
Maintenance Cost	A bus costs £0.5M but lasts only 12 - 15 years. Maintaining buses is around twice as expensive as for trams, even allowing for OHLE costs.	Maintenance of each BRT stations costs \$64,763 a year.		A tram costs around £1M and £2.5M for the 20- to 44-metre range of lengths.			Jakarta's MRT operation and maintenance costs \$8.44 million per kilometer per year.
Fare Structure		Off-board fare collection	Off-board fare collection	On-vehicle fare collection	On-vehicle and at-station fare collection		At-station fare collection (prepaid fares)

Table A5. Safety and environmental assessment.

Option	MT Conventional Bus	Bus Rapid Transit (BRT)	Trackless Tram	Tram	Light Rail Transit (LRT)	Monorail	Rapid Rail Transit/Metro
Safety and Security	Buses have low safety because they share space with other vehicles.	BRT safety is low if its route is shared with other vehicles and high if it is segregated.	Trackless trams have high safety due to their segregation.	Trams have medium safety.	LRTs have a high when segregated. Also, they maintain safety in pedestrian areas by decreasing their speeds.	Monorails have high safety due to their protected guideway, which eliminates the collision risk. However, passengers may find it difficult to escape in emergencies.	Metros have the highest safety since they are fully separated from vehicles and pedestrians, reducing the risk of accidents. In addition, they use fail-safe train control systems.
Environmental Impacts (Air Pollution)	Buses with diesel motors release higher greenhouse gas emissions, which can reduce with the shift to electric motors. The CO2 emission of buses tends to be 53 g/passenger-km.	BRTs have higher greenhouse gas emissions from diesel motors, which can reduce with the shift to electric buses.	Trackless tram emissions largely depend on the energy source. Because they tend to be electric, their impact on air quality is low.	Trams are generally electric, which means they produce no pollution. They release a fraction of the tire-clad vehicles on the tarmac	LRTs have low emissions from the use of electric vehicles.	Monorails have low greenhouse gas emissions because they run on electricity. Their CO2 emissions tend to be 23.6 g/passenger-km.	Metros release negligible emissions per passenger km. Their CO2 emissions tend to be 22 g/passenger-km.
Environmental Impacts (Noise Pollution)	Buses with diesel motors produce higher noise, which can reduce with the implementation of electric motors, such as trolleybuses. The noise level for a bus traveling 50 km/h is 80 dBA for the interior and 84 dBA for the exterior at 15 m from the bus's plain ground.	BRTs generate higher noise from engines and rubber-roadway; however, it can reduce with the implementation of electric buses.	Trackless trams are quiet because they function via batteries on their roofs.	Trams release a high-pitched tonal noise (squeak) when turning in sharp curves.	LRTs are quiet, only using bells in pedestrian areas. Their noise level is 70 dBA for the interior and 70 to 80 dBA for the exterior at 15 m from the track.	For monorails, rubber tires result in quieter operation. In addition, concrete structures, which are becoming a substitute for steel structures, further lessen noise. As a whole, the noise level of monorails tends to be 75 dBA.	Metros generate low noise. Underground metros have even less noise because of damping effect. Their average operating noise is 63 to 80 dBA for interior and 78 to 90 dBA for exterior
Energy Consumption	Santa Barbara, California, USA, found average diesel bus efficiency of 6.0 mpg-US.			Trams consume less energy because of their lower friction.	LRTs are 58 times more energy efficient than driving.	Monorails have Higher energy consumption and resistance to motion	Metros have high energy efficiency from electric traction.

Table A6. Other assessment.

Criteria	Conventional Bus	Bus Rapid Transit (BRT)	Trackless Tram	Tram	Light Rail Transit (LRT)	Monorail	Rapid Rail Transit/ Metro
Ease of Implementation	The planning and implementation of buses is easy since buses can operate over existing road systems. Also, changing bus routes is simple, and the schedule can be modified to match demand.	Implementing BRT is simple and quick because it does not require new system technology or rail placement along the path.	Implementation of trackless trams is easy because it does not require placing overhead wires or rails along the path. Instead, it only requires painted lines on the ground.			Monorail's implementation is simple given that it reduces disruption to existing infrastructure and requires minimal space horizontally and vertically.	Metros require extensive construction and high investment, and it causes disruptions to future lines.
Time of Implementation	Short time to expand and implement	1 - 2 years (less than 18 months)	Less than a year		2 - 3 years		4-10years
Maturity		BRT technology has been extensively studied, and there are many manufacturing companies.	The first trackless tram technology was tested in China in 2017, making it relatively new and lacking detailed studies.	Trams have been the primary street transit mode since the 1950s. However, their popularity declined with the rise of private vehicles		The straddle-beam monorail, pioneered by the German company ALWEG, was first implemented at Walt Disneyland in California.	
Iconic Image	Buses are the standard transit in all cities; however, their image is variable. Their identity is power from the lack of fixed facilities.	The car's appearance, including its color and logo, is integral to its unique branding,	The vehicle has a unique style that makes it distinguishable.	Trams have a more distinct image compared to other transit highway modes.	LRT is the most built and used rail transit in the world. The public loves them because of their high accessibility.	Because monorails are aerial, they give passengers a nice view of the city. They have a good (exotic and new) image	Metros give a strong image of permanence, encouraging developments around its stations and lines. It also becomes a unique city characteristic
Service Life	6 to 10 years	18 to 25 years	More than 30 years	30 years or more		30 years or more	30 years
Coverage	Buses provide more extensive area coverage than fixed-route transit modes.			Trams have extensive coverage and good network capability.	LRTs have adequate CBD branching coverage		Metros have some CBD coverage, primarily in radial form.