Aswan University Journal of Science and Technology Volume 5, issue 1, March 2025

Comparing fixed and flexible transit systems for connecting high speed railway station with urban transport network: Aswan as a case study

Mostafa Ramadan, Ayman Othman, and Seham Hemdan*

Civil Engineering Department, Faculty of Engineering, Aswan University, P.O. Box 81542, Aswan, Egypt.

Abstract

Public transportation plays a crucial role in promoting economic growth, decreasing environmental damage, and providing fair access to key services. This study offers a comparative analysis of fixed and flexible transit systems, considering costs for both operators and users. The research employs a genetic algorithm to analyze transportation scenarios in New Aswan city, Egypt. The outcomes represented in optimal bus size, fleet size, number of zones, and headways for each system. The findings indicate that, in Aswan scenario, a bus size of seven seats give lower costs for the flexible transit system, whereas larger buses give higher cost in the fixed transit system. When comparing the two systems under varying demand conditions, the fixed system proves superior for high demand (exceeding one trip per minute). This research is the first of its kind for Aswan city and could improve transportation planning with enhance the integration of high-speed train stations accessibility.

Keywords: Public Transportation; Fixed transportation; Flexible transportation; Transit cost analysis.

1. Introduction

For as long as humans have existed, transportation has been crucial to the development of trade, commerce and social interaction. Economic needs have been the primary driver of transportation, encompassing both individual travel for the exchange of goods and commodities as well as travel for food or work.

Transportation networks are divided into two categories, public and private transport. Compared to private vehicles, public transit getting more important due to its accessibility, price, and environmental advantages compared to private vehicles. public transit significantly lowers emissions and reduce traffic congestion since it is moving large numbers of people. Additionally, it offers reasonable travel options especially for people who do not have private cars. because it is less expensive, it has accesses to essential services such as education and employment achieves social equity. Public transportation encompasses a variety of modes, including:

Fixed transportation which characterized by predetermined routes, scheduled stops, publicized timetables, and designated networks. Include automobiles like buses. Flexible transportation, sometimes referred to as demand responsive transit (DRT), which offers flexible and customized service in place of conventional fixed-route, fixed-schedule, and mass transit lines. This research paper discusses the possibility of designing a fixed and flexible transportation system in Aswan city through a computational model that performs a cost-based optimization process, taking into account the operator user cost.

*Corresponding author E-mail: seham.hemdan@aswu.edu.eg

Received December 15, 2024, received in revised form, January 05, 2025, accepted January 05, 2025.

(ASWJST 2021/ printed ISSN: 2735-3087 and on-line ISSN: 2735-3095) https://journals.aswu.edu.eg/stjournal

The paper is structured as five sections. Section 1 introduce the problem statement and the objective of this paper. Section 2 reviews relevant literature on transit system design. Section 3 outlines the methodology, including the formulation of the optimization model. Section 4 presents and discusses the results obtained from applying the proposed model. Section 5 concludes the study by summarizing the findings and their implications.

2. Literature Review

Many studies have provided research on public transportation in an effort to create and enhance it. It has been classified into two types; fixed and flexible transportation. Some studies considered the flexibility type of problem seeks to improve the efficiency of the flexible system through optimizing many factors such as stations location as illustrated in [1]. They employed a Monte Carlo simulation-based optimization technique in high demand areas to improve station locations in a way that enhances service efficiency while minimizing energy consumption. However, they did not define the vehicle size and used a single vehicle. Similarly, Sipates and Gonzales [2] studied a model that balances agency and user expenses while determining the optimal size of the service area and stopping distances in order to minimize cycle time and costs in flexible transportation systems. It improved stopping lengths and flexible service restrictions using continuous approximation methodologies, resulting in user gains of up to 35% over fixed route systems, particularly in low-demand corridors. They examined only two buses in the service region, without taking capacity into account.

Regarding rejection rates and increase service efficiency, Zheng et al. [3] developed a meeting point strategy to increase the reliability of flex-route transportation services. They estimated that rejection rates might decline by up to 24% based on simulation data. Lower charges are suggested for both customers and transit operators. However, they didn't consider fleet or vehicle size by a genetic mechanism. Zhang et al. [4] compared the effectiveness of shared bicycle networks to flex-route transit, which takes into account a variety of passenger types and limitations in order to reduce overall costs associated with vehicle operation and passenger travel, emphasizing the importance of understanding customer preferences and streamlining routing to improve public transportation efficiency.

Seo and Asakura [5] introduced a multi-objective linear optimization problem designed to improve the strategic decision-making of shared autonomous vehicle (SAV) systems. It optimizes a variety of aspects, including route, passenger pickup and delivery, fleet sizing, road network design, and parking space allocation. The model aimed to reduce expenses associated with overall travel time, distance traveled by SAVs, the number of SAVs, and infrastructure expenditures. Allowing planners to choose solutions that match with social goals. The suggested model for SAV systems is limited in terms of demand estimates and passenger boarding times. They assumed that the demand is known; however, real-world demand is sometimes unpredictable or variable. Furthermore, the model did not consider the time and cost for passengers entering and exiting SAVs, which impacted the system's overall efficiency.

Shan et. al. [6] provided a mixed-integer programming approach for optimizing combined railway transit services (RTS) and SAV services. Their goal was to minimize overall costs and commuter wait times. The findings show that the combined RTS-SAV service is more economical when operated than both of them alone, according to key data. with a total cost of 69,775 Australian dollars and an average waiting time of 7.75 minutes. The study underlines the need of coordinating RTS and SAV services based on demand patterns. Which improves operational efficiency and commuter accessibility in less densely populated areas.

A novel split delivery model for the feeder-bus network design problem (FBNDP) was introduced by [7] utilizing a genetic algorithm (GA) that aimed to include both operator and user costs. The model aims to reduce passenger travel costs, improve network structure, and allocate passenger demand among different routes. Nevertheless, the model's behavior and applicability on a large-scale network were not properly investigated.

For fixed and feeder systems, Dandan Jiang [8] developed an approach for calculating the optimal feeder bus routes for subway stations that considers transfer characteristics, passenger flow demand, and bus operating costs. Their study focused on transfer behavior, transfer duration, and passenger comfort to address their impact for lowering overall bus operating and travel expenses. Consider the study's flaws. The effects of feeder bus routes on the overall operation cost of public transportation are not evaluated, despite the fact that this might be a substantial factor. The case study region is small and does not include the entire subway line, limiting the generalizability of the findings.

Owais et al. [9] suggested a genetic algorithm based-transit route network optimization method in order to maximize demand coverage and minimize operator expenses. However, this study did not incorporate fleet flexibility or vehicle capacity. Despite numerous advancements, most studies failed to address fleet selection flexibility or vehicle capacity comprehensively. Additionally, few have explored the cost-effectiveness of fixed versus flexible systems.

Despite numerous advancements, most studies failed to address fleet selection flexibility or vehicle capacity comprehensively. Additionally, few have explored the cost-effectiveness of fixed versus flexible systems. Research on urban transportation networks in global contexts has been extensive, yet Aswan's transport network remains underexplored. To the best of our knowledge, no prior studies have specifically addressed Aswan's unique transportation dynamics. This research fills a critical gap by focusing on the design and optimization of fixed and flexible systems in Aswan network, offering valuable insights into the region's transportation challenges and opportunities.

3. Methodology

The suggested model is an optimization approach that tries to reduce overall costs for both passengers and operators by optimizing bus fleet size and headways based on earlier studies [10], [11], [12], and [13].

To simplify the mathematical formulation, the proposed model incorporates several assumptions. First, each inhabited zone has its own transit system that connects consumers to high-speed railway (HSR) stations. Passenger demand within each region is assumed to be constant and uniformly distributed. Passengers arriving randomly and uniformly at station locations. To streamline the flexible bus formulation, each region is divided into N equal zones. Where the area of each studied region is calculated as $A=L \cdot W/N$, with L and W representing the dimensions of the region.

Abbreviations

Parameter	Discerption	unit
V_{bus}	Bus travelling speed	mi/min
C_{total}	Total service cost for region	LE/min
C_{transf}	Transfer cost for region	LE/min
$C_{in\text{-}veh}$	In-vehicle cost for region	LE/min
C_{oper}	Operating cost for region	LE/min
C_{wait}	Waiting cost for region	LE/min
ϑ_f	Monetary value of transfer time	LE/min
ϑ_w	Monetary value of waiting time	LE/min
ϑ_ϑ	Monetary value of in vehicle time	LE/min
H_{fix}	Hourly fixed cost coefficient	LE/bus min
H_{var}	Hourly variable cost coefficient	LE/seat min
A	The area of the studied region	mi^2
C_{bus}	Bus operating cost= $H_{fix} + H_{var} *S$	LE/min/bus
D_{bus}	Equivalent line haul distance for flexible bus on region = (L+W+2J)/Y	mi
F	Fleet size	Buses
h	Headway	Min/bus
J	Line haul distance	mi
L	Length of region	mi
N	Number of zones	-
Q	Demand density	Trip/min
Q_{transf}	Transfer demand density	Trip/min
S	Bus size	seats
X	Passenger per stop	-
W	Width of region	mi
Y	Nonstop ratio (fixed /flexible)	1.8/2
ϕ	Flexible equation constant	1.15
σ	Standard deviation	-
ϑ_x	Value of access time	LE/min
V_{pass}	Passenger speed	mi/min
L_f	Load factor	1Pass/seat
D_{trip}	Equivalent average trip distance (J+0.5 W)/Y+0.5L	mi

In the operational model, buses travel from the HSR station along a line-haul distance at a non-stop speed V_{bus} to the center of each zone. Covering an average non-stop distance of (L+W)/2 miles at the same speed. They collect (or distribute) passengers at their door steps through an efficiently routed tour of n stops over a distance D_{trip} at a local speed V_{bus}.

This modeling approach aims to optimize the performance of transit systems by balancing operator and user costs. The proposed model provides a structured framework for analyzing and designing flexible transit systems connected to HSR stations. The proposed model adaptability to changing input parameters allows it to be used in metropolitan settings outside Aswan. In addition to its scalability ensures it can be expanded or scaled down to accommodate cities of different sizes and characteristics.

3.1 Formulation and Analytical Optimization

3.1.1 Flexible Systems

The total cost of the flexible transportation system can be expressed as the sum of its components, including operational costs, vehicle costs, transfer costs, and waiting costs. The corresponding equations can be written as:

$$C_{total} = \sum_{k=1}^{k} \left(C_{oper} + C_{in-veh} + C_{wait} + C_{transf}\right) \tag{1}$$

$$\mathrm{C_{oper}} = \frac{D_{bus}*C_{bus}*N}{\mathrm{V}_{bus}*h} + \frac{\phi*C_{bus}}{\mathrm{V}_{bus}}\sqrt{\frac{L*W*Q}{X}} \tag{2}$$

$$\mathrm{C}_{in-veh} = \frac{\vartheta_{\vartheta}*Q*D_{bus}}{V_{bus}} + \frac{\emptyset*\vartheta_{\vartheta}*Q}{2V_{bus}*N}\sqrt{\frac{L*W*Q*h}{X}} \tag{3}$$

$$\mathrm{C_{wait}} = \vartheta_w * Q * \frac{h}{2}\left(1 + \frac{\sigma^2}{h^2}\right) \tag{4}$$

$$\mathrm{C_{transf}} = \vartheta_f * Q_{transf} * \frac{h}{2}\left(1 + \frac{\sigma^2}{h^2}\right) \tag{5}$$

By substituting Equations (2) to (5), into Equation (1), the total flexible bus cost in region k becomes:

$$C_{total} = \frac{D_{bus}*C_{bus}*N}{\mathrm{V_{bus}}*h} + \frac{\emptyset*O_c}{\mathrm{V_{bus}}}\sqrt{\frac{L*W*Q}{X}} + \frac{\vartheta_{\vartheta}*Q*D_{bus}}{2\mathrm{V_{bus}}} + \frac{\emptyset*\vartheta_{\vartheta}*Q}{2\mathrm{V_{bus}}*N}\sqrt{\frac{L*W*Q*h}{X}} + \frac{\vartheta_w*Q*h}{2} + \frac{\vartheta_w*Q*\sigma^2}{2h} + \frac{\vartheta_f*Q_{transf}*\mathrm{h}}{2} + \frac{\vartheta_f*Q_{transf}*\sigma^2}{2\mathrm{h}} \tag{6}$$

$$\mathrm{F} = \frac{D_{bus}}{\mathrm{V_{bus}}*h} + \frac{\emptyset}{\mathrm{V_{bus}}*N}\sqrt{\frac{L*W*Q}{h*X}} \tag{7}$$

3.1.2 Fixed Systems

The total cost of the fixed system is as the flexible cost in addition to the access cost calculated as equation (8).

$$C_{total} = C_{bus} * N * F + \frac{\vartheta_{\vartheta}*Q*D_{trip}}{V_{bus}} + \frac{D_{trip}*\left(\vartheta_w*Q+\vartheta_f*Q_{transf}\right)}{2F*V_{bus}} + \frac{\sigma^2*F*V_c*(\vartheta_w*Q+\vartheta_f*Q_{transf})}{D_{trip}} + \frac{\vartheta_x*Q}{4\mathrm{V_{pass}}}\left(\frac{W}{N} + D_{bus}\right) \tag{8}$$

And the number of zones which give the minimum solution is obtained from roots for the following equations:

$$16(\mathrm{C_{bus}})^2(\mathrm{V_{pass}})^2(N)^4 - 2(\vartheta_x)^2 D*\mathrm{C_{bus}}(Q)^2(\mathrm{W})^2*\mathrm{V_{bus}}N - (\vartheta_x)^2*(Q)^2(\mathrm{W})^2(\mathrm{V_{bus}})^2(\vartheta_w Q + \vartheta_f \mathrm{Q_{transf}}) = 0 \tag{9}$$

$$\mathrm{F_c} = \frac{\vartheta_x*Q*W}{4B*V_{bus}*(N)^2} \tag{10}$$

$$\mathrm{h_{max}} = \frac{S*L_f*N}{Q} \tag{11}$$

3.2 Calculation Steps

To solve the suggested model and determine the most cost-effective transportation plan, a methodical technique was adopted. The process began with preparing and organizing the input data, followed by the implementation of an appropriate solution strategy. A crucial component of the planning phase was splitting the research population area into many separate areas. This division improved the analysis of the transportation network by focusing on more manageable, smaller components. Each region's dimensions were calculated using demographic and geographic information.

Furthermore, financial elements have been identified and measured, as they form the foundation of the cost structure. These variables cover a wide variety of subjects, including operational costs and value of the user's time. Each of these aspects is critical in determining the overall cost-effectiveness of the transportation system.

3.3 Regions Dimensions

To analyze the transportation network, the boundaries of each neighboring residential region were first determined using ArcGIS tools, as shown in Figure (1). This allowed for the identification of each region's length (L), width (W), and the distance from the region to the HSR station (J). Given that real-world regions are often irregular in shape, each residential region was converted into a regular, equal-shaped zone with the same area. To ensure consistency with demand estimations and facilitate model application. The distance from each region to the HSR station was calculated using Google Maps to ensure accuracy in measuring accessibility.

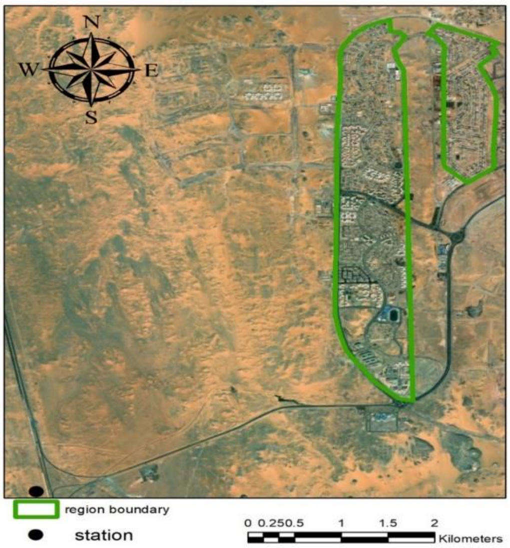

Figure 1. Determining regions border using ArcGIS

In terms of demand density, a range of 0.1 to 10 trips per minute is considered, and the model is evaluated for each demand value; however, only two vehicle size possibilities are provided: 7 and 14 seats. Based on the findings in [14] financial factors were quantified to assess the overall cost structure. Notably, transfer time contributes for 80% of the hourly average revenue, while waiting time and in-vehicle time are both valued at 50%.

3.4 Model Solution

The results of the model aim to determine three key parameters: the number of zones, fleet size, and headway. he objective of the flexible system seeks to optimize these parameters obtaining the minimal cost, as represented in Equation (6). Due to the complexity of the equation, a genetic algorithm is employed to solve it. The optimized values for the number of zones (N) and headway (h) are then used in Equation (7) to calculate the resultant fleet size (F).

MATLAB is used to create the genetic algorithm, which runs with 200 generations in a single iteration. Resulted in a total of 41,800 runs which ensure a robust optimization process. The model is solved using a device equipped with an Intel(R) Core(TM) i3-3217U CPU @ 1.80GHz.

For the fixed system, the optimum number of zones is obtained from equations roots and then calculated the headway, fleet size, and the total cost. This approach allows for a comparative analysis of both the flexible and fixed transportation systems. Considering the most cost-effective solution for each scenario.

4. Experimental Results and Case Study

The new Aswan city is selected as a case study to compare fixed and flexible transportation systems. This due to its efficient planning and the presence of a high-speed railway station in need of enhanced accessibility. As well as the unique characteristics of Aswan. The case study was conducted for two distinct regions within Aswan city, as shown in Figure 2, with detailed dimensions for both regions provided in Table 1.

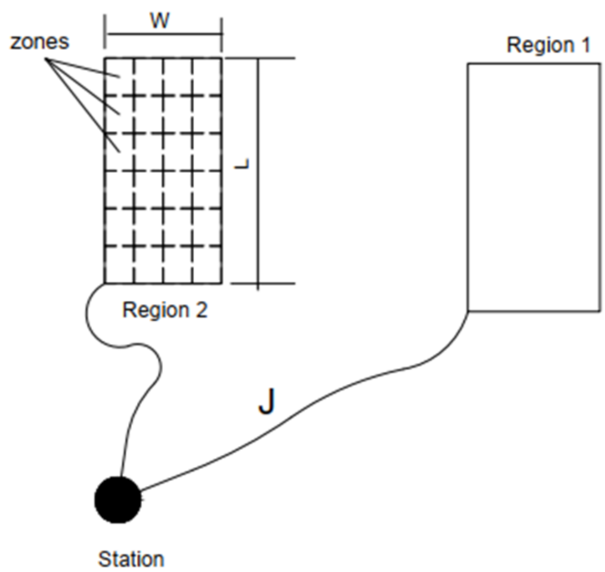

Figure 2. Schematic diagram for defining region dimensions

Table 1. Regions dimensions for new Aswan city

Regions	Length (mi)	Width (mi)	Distance to the station (mi)
1	1.16	0.63	5.59
2	2.27	0.35	5.60

These two regions were chosen to represent different areas of Aswan, allowing for a comprehensive analysis of how the fixed and flexible systems perform under varying conditions. The geographic features, population distribution, and demand densities in each region are taken into account to ensure the analysis reflects the city's actual transportation needs. The cost-related coefficients for Aswan were derived using real data provided by the Central Agency for Public Mobilization and Statistics [15]. The operational cost C_{bus} is calculated as follows:

$$C_{bus} = H_{fix} + H_{var} * S \quad (12)$$

Where:

- H_{fix} represents the fixed cost per minute (0.36 LE/min),
- H_{var} is the variable cost per minute per seat (0.0128 LE/min),
- S is the number of seats (either 7 or 14 seats, depending on the vehicle size used).

Additionally, the hourly average income in Aswan is 0.6118 LE/min, according to the Central Agency for Public Mobilization and Statistics [15].

After running the computational operations for both vehicle sizes (7 seats and 14 seats), the results for the flexible and fixed transportation system are summarized in Table 2 and Table 3 respectively. These tables will allow for a detailed comparison between the flexible and fixed systems. Highlighting the most cost-effective solution for Aswan city's transportation network.

Table 2 shows the results for flexible systems with different bus sizes, S=7 and S=14. For region 1, the cost of both systems, S=7 and S=14, rises gradually as demand rises. This is obviously, as a higher demand requires higher operational costs. The costs for S=7 are generally lower than those for S=14, especially at lower demands. At lower demands (e.g., 0.1–0.5), the cost differences between S=7 and S=14 are relatively minor, indicating that both system sizes are effectively managing the demand. Similar to region 1, the costs increase with demand for both S=7 and S=14 in region 2. The increase is slightly less steep compared to region 1. Which suggested that region 2 handles higher demands more efficiently. At low demands (e.g., 0.1–0.5), the cost differences between S=7 and S=14 are small. However, the gap widens at higher demands. for S=7 generally results in lower costs compared to S=14, showing its efficiency in managing moderate demands. Even at higher demands (such as 9–10), S=14 is still competitive in area 2, in contrast to region 1. This implies that region 2 gains more from larger systems' added flexibility.

Table 3 provides the results for fixed systems. For region 1, both S=7 and S=14, as demand increases, N (number of servers/resources) increases to accommodate higher demand. Costs also rise with demand but are slightly lower for S=14 at most demand levels. For S=14, the costs are consistently lower or almost similar compared to S=7, which suggests higher efficiency in the fixed system at greater capacities. For region 2, similar patterns are observed with increasing N and cost as demand grows. Once more, S=14's cost is typically less than S=7's, indicating its relative efficiency. For low demands (e.g., 0.1), the differences in cost between S=7 and S=14 are minimal, which indicates that system capacity has less impact at lighter demand. Higher demand scenarios amplify the cost differences between the two systems, with S=14 consistently outperforming S=7.

When comparing the two system types, for fixed systems, Table 3 shows that the cost increases steadily as demand rises for both S=7 and S=14. However, the cost in the fixed systems is overall higher compared to flexible systems. At higher demand levels, fixed systems have significant cost increases. This suggests that the fixed system have limitations when managing high demand efficiently. For moderate to low demand levels, fixed systems are more economical. In contrast to flexible systems, they are typically less flexible and more expensive at greater demand levels.

Figure 3 illustrates the relationship between demand and cost for fixed and flexible systems with S=7 and S=14. Showing that the costs rise for all systems as demand increases. The increase becoming clearer at higher demand levels. At low demand (0.1–1), fixed systems (size 7 and size 14) show slightly lower costs compared to flexible systems, indicating their efficiency for low-demand conditions. However, the flexible systems demonstrate better adaptability for larger system sizes (S=14) as demand increases, with higher costs. For S=7 system maintains lower costs compared to S=14, especially under higher demands, which highlights its cost efficiency for moderate demands. On the other hand, S=14 systems provide greater capacity and flexibility when managing high-demand environments despite being more expensive when handling high demand. Overall, the flexible systems offer greater adaptability in case of higher demand, whereas fixed systems are more expensive for low demand. Based on this observation, a comparison between the two systems, considering the flexible system with 7 seats and the fixed system with 14 seats, is done.

This comparison is visually represented in Figure 4, which compares the costs of a fixed system (size 14) and a flexible system (size 7) as demand increases. At low demand levels (0.1–1), the flexible system has slightly lower costs than the fixed system, indicating its efficiency for lighter loads. However, the cost of the flexible system grows more steeply, as demand rises beyond 1, which significantly exceeds the fixed system at higher demand levels (near 10). This pattern shows that although flexible systems are adaptable, they become expensive as demand rises. On the other hand, fixed systems continue to grow more economically, which makes them more economical for managing large demands.

Based on these results, smaller buses (7 seats) in flexible systems are typically preferred for flexible transportation systems. These systems frequently use dynamic routes that can be modified in response to passenger demand in real time. Narrow streets and residential areas may be traversed by flexible paths. In such situations, smaller buses are more economical as they are less likely to run below capacity. Additionally, they are easier to handle in urban areas, which is essential for crossing restricted areas and providing effective service. Smaller vehicles' adaptability fits with flexible systems' objective of providing specialized, effective services that address the demands of each passenger.

On the other hand, fixed systems usually prefer large buses, such as those with 14 seats. Because these buses can carry more people on each trip, fewer trips are required to meet demand, and each passenger pays less. Additionally, larger buses help alleviate traffic congestion by reducing the number of vehicles needed on a specific route, thereby maximizing the use of available road space.

Table 2. Results for flexible systems

Region	Demand Trip/min	S = 7				S = 14			
		N	h	F	Cost LE/min	N	h	F	Cost LE/min
1	0.1	1	7	2	1.28	1	7	2	1.39
	0.2	1	5	3	1.96	1	5	3	2.11
	0.3	1	5	3	2.54	1	5	3	2.73
	0.4	1	4	4	3.06	1	6	3	3.29
	0.5	1	4	4	3.56	1	4	4	3.82
	0.6	1	4	4	4.04	1	4	4	4.32
	0.7	1	4	5	4.51	1	4	4	4.81
	0.8	1	4	5	4.96	1	4	5	5.29
	0.9	1	4	5	5.40	1	4	5	5.75
	1	1	3	6	5.84	1	4	5	6.21
	2	1	3	8	9.96	1	3	8	10.50
	3	1	2	10	13.92	1	2	9	14.58
	4	1	2	11	17.82	1	2	11	18.60
	5	2	2	11	21.72	1	2	12	22.59
	6	2	2	11	25.58	2	2	11	26.57
	7	2	2	11	29.39	2	2	11	30.49
	8	2	2	12	33.16	2	2	11	34.37
	9	2	2	12	36.89	2	2	12	38.21
	10	2	2	12	40.59	2	2	12	42.01
2	0.1	1	8	2	1.33	1	8	2	1.44
	0.2	1	6	3	2.03	1	6	3	2.19
	0.3	1	6	3	2.63	1	6	3	2.83
	0.4	1	4	4	3.18	1	4	4	3.42
	0.5	1	5	4	3.70	1	5	4	3.97
	0.6	1	4	5	4.20	1	5	4	4.49
	0.7	1	4	5	4.68	1	4	5	5.00
	0.8	1	4	5	5.16	1	4	5	5.49
	0.9	1	3	6	5.62	1	4	5	5.98
	1	1	3	6	6.07	1	3	6	6.45
	2	1	3	8	10.37	1	3	8	10.93
	3	1	2	10	14.50	1	2	10	15.19
	4	1	2	12	18.57	1	2	11	19.37
	5	2	2	11	22.63	1	2	12	23.54
	6	2	2	12	26.65	1	2	13	27.68
	7	2	2	12	30.62	2	2	12	31.77
	8	2	2	12	34.54	2	2	12	35.81
	9	2	2	13	38.43	2	2	12	39.81
	10	2	2	13	42.28	2	2	12	43.77

Table 3. Results for fixed systems

Region	Demand Trip/min	S = 7				S = 14			
		N	h	F	Cost LE/min	N	h	F	Cost LE/min
1	0.1	1	18	1	7.33	1	18	1	6.97
	0.2	2	18	1	6.36	2	18	1	6.09
	0.3	2	18	1	6.06	2	18	1	5.82
	0.4	3	18	1	5.98	3	18	1	5.77
	0.5	3	18	1	6.01	3	18	1	5.82
	0.6	3	18	1	6.10	3	18	1	5.93
	0.7	4	18	1	6.23	4	18	1	6.07
	0.8	4	18	1	6.39	4	18	1	6.24
	0.9	4	18	1	6.57	4	18	1	6.43
	1	5	18	1	6.76	4	18	1	6.63
	2	7	18	1	9.05	7	18	1	8.95
	3	9	18	1	11.55	9	18	1	11.48
	4	11	18	1	14.12	10	18	1	14.06
	5	13	18	1	16.72	12	18	1	16.66
	6	14	17	1	19.32	13	18	1	19.27
	7	16	16	1	21.93	15	18	1	21.88
	8	17	15	1	24.54	16	18	1	24.50
	9	18	14	1	27.15	17	18	1	27.11
	10	20	14	1	29.76	19	18	1	29.72
2	0.1	1	22	1	8.80	1	22	1	8.35
	0.2	1	22	1	7.53	1	22	1	7.18
	0.3	2	22	1	7.09	2	22	1	6.79
	0.4	2	22	1	6.93	2	22	1	6.66
	0.5	2	22	1	6.91	2	22	1	6.66
	0.6	3	22	1	6.97	2	22	1	6.74
	0.7	3	22	1	7.08	3	22	1	6.87
	0.8	3	22	1	7.23	3	22	1	7.02
	0.9	3	22	1	7.40	3	22	1	7.20
	1	3	21	1	7.59	3	22	1	7.40
	2	5	18	1	9.96	5	22	1	9.82
	3	6	14	1	12.64	6	22	1	12.51
	4	8	14	1	15.41	7	22	1	15.29
	5	9	13	1	18.21	8	22	1	18.10
	6	10	12	1	21.03	9	21	1	20.93
	7	11	11	1	23.87	10	20	1	23.77
	8	12	11	1	26.71	11	20	1	26.61
	9	13	11	1	29.55	12	19	1	29.45
	10	14	10	1	32.39	13	19	1	32.29

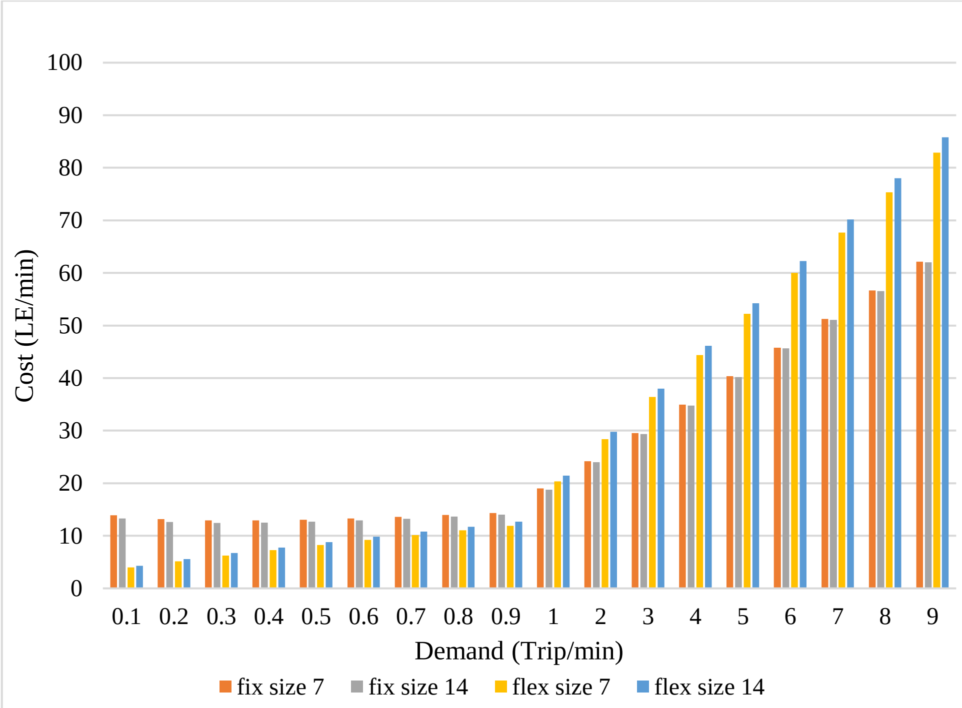

Figure 3. The relationship between demand and cost for fixed and flexible systems with S=7 and S=14

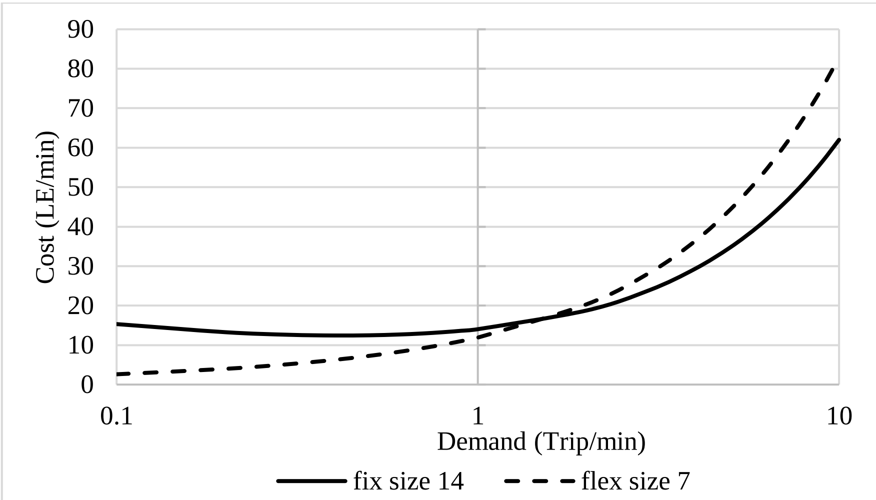

Figure 4. The costs of a fixed system (S=14) and a flexible system (S=7) for different demand

It can be concluding that, the decision between flexible and fixed systems is based on the particular demand conditions. The fixed systems are best suited for high-demand areas, while flexible systems are better suited for low-demand ones.

5. Conclusion

This research developed a design model for both fixed and flexible transportation systems using genetic algorithms. The objective is connecting New Aswan city with a high-speed railway station. A genetic algorithm is used to optimize bus size, number of zones, headways, and fleet size.

This study provides a comparative analysis of fixed and flexible transportation systems in Aswan city as a case study. Explore the city's unique characteristics and assess the suitability and preference for each transportation system. The case study of New Aswan city was chosen due to the observed gaps in public transportation services, making it an ideal candidate for this research.

The experimental results highlight the following findings:

1. For a flexible system, for all demand scenarios, a 7-seat bus is optimal. Furthermore, the flexible system performs better than the fixed system in low-demand situations (less than 1 trip per minute).

2. For a fixed system, for all demand scenarios, a 14-seat bus is the most economic. Furthermore, the fixed system performs better than the flexible system in high-demand situations. This illustrates the efficiency of the fixed system for a large number of passengers.

These findings suggest that the flexible system is better suited for low-demand areas with fewer passengers, while the fixed system is more effective for high-demand areas. where larger buses and predictable schedules can handle the volume more efficiently.

References

[1] Li, M.; Tang, J. Simulation-Based Optimization Considering Energy Consumption for Assisted Station Locations to Enhance Flex-Route Transit. *Energy* 2023, *277*, 127715. https://doi.org/10.1016/j.energy.2023.127715.

[2] Sipetas, C.; Gonzales, E.J. Continuous Approximation Model for Hybrid Flexible Transit Systems with Low Demand Density. *Transp. Res. Rec.* 2021, *2675*, 198–214. https://doi.org/10.1177/0361198121997131.

[3] Zheng, Y.; Li, W.; Qiu, F.; Wei, H. The Benefits of Introducing Meeting Points into Flex-Route Transit Services. *Transp. Res. Part C Emerg. Technol.* 2019, *106*, 98–112. https://doi.org/10.1016/j.trc.2019.07.012.

[4] Zhang, J.; Li, W.; Wang, G.; Yu, J. Feasibility Study of Transferring Shared Bicycle Users with Commuting Demand to Flex-Route Transit—A Case Study of Nanjing City, China. *Sustainability* 2021, *13*, 6067. https://doi.org/10.3390/su13116067.

[5] Seo, T.; Asakura, Y. Multi-Objective Linear Optimization Problem for Strategic Planning of Shared Autonomous Vehicle Operation and Infrastructure Design. *IEEE Trans. Intell. Transp. Syst.* 2022, *23*, 3816–3828. https://doi.org/10.1109/TITS.2021.3071512.

[6] Shan, A.; Hoang, N.H.; An, K.; Vu, H.L. A Framework for Railway Transit Network Design with First-Mile Shared Autonomous Vehicles. *Transp. Res. Part C Emerg. Technol.* 2021, *130*, 103223. https://doi.org/10.1016/j.trc.2021.103223.

[7] Deng, L.; He, Y.; Zeng, N.; Zeng, J. Optimal Design of Feeder-Bus Network with Split Delivery. *J. Transp. Eng. A Syst.* 2020, *146*, 03020003. https://doi.org/10.1061/jtepbs.0000305.

[8] Cao, Y.; Jiang, D.; Wang, S. Optimization for Feeder Bus Route Model Design with Station Transfer. *Sustainability* 2022, *14*, 2780. https://doi.org/10.3390/su14052780.

[9] Owais, M.; Osman, M.K.; Moussa, G. Multi-Objective Transit Route Network Design as Set Covering Problem. *IEEE Trans. Intell. Transp. Syst.* 2016, *17*, 670–679. https://doi.org/10.1109/TITS.2015.2480885.

[10] Fan, W.; Gu, W.; Xu, M. Optimal Design of Ride-Pooling as On-Demand Feeder Services. *Transp. Res. Part B Methodol.* 2024, 102964. https://doi.org/10.1016/j.trb.2024.102964.

[11] Kim, M.E.; Levy, J.; Schonfeld, P. Optimal Zone Sizes and Headways for Flexible-Route Bus Services. *Transp. Res. Part B Methodol.* 2019, *130*, 67–81. https://doi.org/10.1016/j.trb.2019.10.006.

[12] Kim, M.; Roche, A. Optimal Service Zone and Headways for Flexible-Route Bus Services for Multiple Periods. *Transp. Plan. Technol.* 2021, *44*, 194–207. https://doi.org/10.1080/03081060.2020.1868086.

[13] Kim, M.E.; Schonfeld, P. Integration of Conventional and Flexible Bus Services with Timed Transfers. *Transp. Res. Part B Methodol.* 2014, *68*, 76–97. https://doi.org/10.1016/j.trb.2014.05.017.

[14] U.S. Department of Transportation. *The Value of Travel Time Savings: Departmental Guidance for Conducting Economic Evaluations Revision 2 (2016 Update)*. Available online: http://www.dot.gov/policy/transportation-policy/economy (accessed on 26 May 2025).

[15] Egyptian Central Agency for Public Mobilization and Statistics. *Annual Bulletin of Employment, Wages and Working Hours Statistics*; CAPMAS: Cairo, Egypt, 2022.