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# Opportunities for Adopting Sustainable Transportation Modes by University Commuters through Population Survey and FAH Process

***Eltayeb H. Onsa Elsadig [1)*], Anis Ben Messaoud [2)], Ghassan M.T. Abdalla [3)],***

***Wael S. Al-Rashed [4)], Abderrahim Lakhouit [5)], Ahmed H.A. Yassin [6)]***

[1)] *Professor, Civil Engineering Dept., Faculty of Engineering, University of Tabuk, Tabuk, KSA.*
** Corresponding Author. E-Mail: e.onsa@ut.edu.sa*
[2)] *Assistant Professor, Civil Engineering Dept., Faculty of Engineering, University of Tabuk, Tabuk, KSA.*
*E-Mail : amasud@ut.edu.sa*
[3)] *Assistant Professor, Electrical Engineering Dept., Faculty of Engineering, University of Tabuk, Tabuk, KSA.*
*E-Mail : gabdalla@ut.edu.sa*
[4)] *Assistant Professor, Civil Engineering Dept., Faculty of Engineering, University of Tabuk, Tabuk, KSA.*
*E-Mail : walrashed@ut.edu.sa*
[5)] *Associate Professor, Civil Engineering Dept., Faculty of Engineering, University of Tabuk, Tabuk, KSA.*
*E-Mail : a.lakhouit@ut.edu.sa*
[6)] *Assistant Professor, Industrial Engineering Dept., Faculty of Engineering, University of Tabuk, Tabuk, KSA.*
*E-Mail : a.yassin@ut.edu.sa*

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ABSTRACT

Campus transportation is representative of citywide transportation problems, making sustainable mobility solutions more important considering rising environmental concerns and traffic congestion. This paper investigates the mobility patterns of the population of the University of Tabuk (UT) commuting to the main campus using survey data and explores the opportunities to adopt new sustainable mobility alternatives from the commuters and experts' points of view. Five transportation mode alternatives are investigated and assessed through a direct survey among a considerable number of UT population. The opinions of 9 experts and decision makers are studied by applying Fuzzy Analytic Hierarchy Process (FAHP) adopting five criteria: Environment, Safety, Economy, Time and Social perception. The experts selected "Safety" as the most important criterion for the selection of a sustainable mode of transport, followed by Economy and Environment. The analysis indicates that more than 86% of UT members commute with private cars. The trip duration is between 10 minutes and 20 minutes for 70% of UT population. For almost all the alternatives, male single students with higher trip duration are the most interested profile in sustainable transportation options. Based on the weights of criteria, FAHP results show the alternative bus from the residence to the university as the best sustainable alternative, followed by the park-and-ride inter-campus bus, which was the second-highest alternative in the campus population survey. The findings can provide a basis for developing transportation strategies for UT aimed at alleviating traffic issues and congestion in the surrounding area and enhancing environmental conditions on campus and its vicinity.

***Keywords:*** Fuzzy hierarchy decision-making, Population survey, Sustainable transportation, Campus commuters, Mobility pattern.

## INTRODUCTION

Transportation systems impose environmental effects in view to their substantial contribution to air pollution (Ajay et al., 2023). The increasing dependence on vehicles for commuting to work and study places poses many challenges, like environmental degradation, health concerns (Amini et al., 2023) and noise pollution (Al-Masaeid & Badandi, 2024). It is essential to establish a sustainable transportation infrastructure that emphasizes energy efficiency (Alamelu et al., 2022). Thus, the environmental impacts of transportation should always be assessed on ways to adopt the best modes bearing in mind air pollution and global warming as the major problems (Kopelias et al., 2020). Hence, establishing a sustainable transportation mode for UT main campus is important for creating an environmentally friendly, safe, and efficient campus. With the growing population at Tabuk City, due to the ongoing establishment of nearby mega projects, the need for sustainable commuting options is crucial to address concerns related to pollution and traffic congestion. Shifting towards sustainable transportation will align with UT goals and Saudi Arabia's Vision 2030, which emphasizes sustainability and improved quality of life (Dahim, 2023). Relying on private cars eventually contributes to bad air quality and global warming (Pietrzak & Pietrzak, 2020). Therefore, establishing a durable infrastructure (Sattar et al., 2024) and sustainable methods of transport, such as buses, carpooling, or cycling, can reduce the carbon footprint and improve air quality in campuses (Fissi et al., 2021; Ismael et al., 2022). This shift supports the 11$^{th}$ sustainable development goal (SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable) defined by the United Nations (UNDP, 2025) and the Saudi Arabia Vision 2030's goal of mitigating climate change and promoting eco-friendly initiatives to safeguard the KSA environment by reducing all types of pollution. Among the 6 objectives of the KSA Vision 2030, objective #2 states: "*Offer a fulfilling & healthy life*", by ensuring environmental sustainability (Saudi Vision 2030, 2024). Traffic congestion is another issue that sustainable transportation can address. Implementing sustainable transport solutions, like shuttle services or park-and-ride options, would reduce vehicle numbers on campus and make commuting smoother, enhancing accessibility for students, faculty members, and staff. By reducing vehicle density, sustainable transportation options can create safer commuting environments for everyone on campus (Shah et al., 2021). Economic factors further support the need for sustainable transportation, bearing in mind that the costs associated with private-vehicle use can be burdensome, and alternative transportation options could provide more affordable commuting solutions while reducing the need for a costly parking infrastructure (Palit et al., 2022).

The environmental impacts of transportation and air pollution are among the most significant challenges (AlQuhtani, 2022). Among the transportation modes, the transportation using private vehicles is a major contributor to the emission of carbon dioxide (Alghuson, 2023). Relying on fossil fuels in traditional transportation systems creates a cycle of pollution that affects both local environments and the global climate (Pamucar et al., 2021). Therefore, reducing the environmental impacts of transportation through sustainable practices, such as increasing the use of public transportation and promoting more efficient travel systems, is important for mitigating these effects (Chirieleison et al., 2020).

As nations strive to fulfill the objectives of the Paris Agreement, they are progressively incorporating transportation into their Long-Term Low Emission Development Strategies (LT-LEDS) and Nationally Determined Contributions (NDCs) (UNDP, 2025).

Usually, national plans and strategies incorporate a number of actions, including electrifying fleets of both private and public vehicles; investing into public transit networks, which include facilities for charging and electric buses, extending networks for bicyclists and pedestrians, utilizing clean energy and biofuels, creating Sustainable Urban Mobility Plans (SUMPs) and thorough transportation master plans (UNDP, 2025).

These strategies can be enforced by developing and promoting the use of emerging technologies for sustainable transportation, such as electric vehicles, alternative fuels, smart cities and smart traffic management using machine learning algorithms and artificial intelligence tools (Etukudoh et al., 2024).

The proposed solutions should reinforce the application and the alignment with Saudi Arabia's Vision 2030 and the SDG's goals, and ensure equity in the transportation mode and strategy, by allocating expenses and benefits equally among individuals with comparable needs and capacities, and attempt to make up for the disparities between groups by giving those with greater needs more advantages and placing more costs on those with superior ability (Theobald, 2001).

In many of the advanced economies, emission controls are enforced through the improvement of transport modal split between private transport *versus* public transport (Hörcher & Tirachini, 2021). Universities are known worldwide as large trip generators and attractors. To minimize commuting environmental impacts, universities around the world tend to implement strategies for reducing dependence on private cars and increasing using alternative transport modes (Cattaneo et al., 2018).

Increasingly, many education institutions are addressing their environmental impact and particularly their contribution to climate change, including the implementation of environmental management systems (Sobuz et al., 2024; Sultana et al., 2018). When implementing sustainable policy decisions, universities and their partners have paid great attention to sustainability. Yet, students still have a negative attitude toward road and environmentally related obstacles, compared to staff and faculty members (AlQuhtani, 2022). A life-cycle approach was used to assess transportation and parking strategies to reduce greenhouse gas emissions by commuters traveling to the University of Coimbra main campus (Portugal) (Cruz et al., 2017). The innovative integrated modeling adopted considers the effective potential of combined traffic and parking management measures for green commuter transportation. Parking empowers more and more people to engage in such transformative changes locally, regionally, nationally and globally (Cruz et al., 2017). In the Kingdom of Saudi Arabia (KSA), car ownership is comparatively high due to the lack of other transportation alternatives, low cost of fuel, and higher income. Moreover, 95% of work and school trips in the KSA are commuted by private cars, creating less sustainable travel patterns, which are associated with many negative environmental, social, and economic impacts (AlQuhtani, 2022). A similar conclusion was reported from studies on Jaddah and Al-Khobar Cities, KSA (Assi et al., 2020). Furthermore, mode selections for students in public schools in Al-Khobar City are limited to the use of personal passenger cars and walking in hindered conditions (Assi et al., 2018).

Despite the increasing global interest in sustainable transportation modes, it is noticed that the existing literature about commuting behaviors in Saudi universities is still limited. Previous studies have primarily addressed the environmental and economic impacts of transportation and emphasized technical solutions for reducing emissions and promoting alternative modes. Bakioglu (2024) carried out sensitivity and comparative analyses for the selection of sustainable transportation strategies for campuses using a hybrid decision-making approach to confirm the consistency and reliability of the results. His results indicated that short-term strategies, such as providing facilities for bike riders and re-organizing campus parking, ranked highest due to their immediate feasibility and cost-effectiveness. Olayode et al. (2024) identified the impact of and barriers to using e-bikes on different modes of transportation, as well as the barriers to e-bike integration in public transportation.

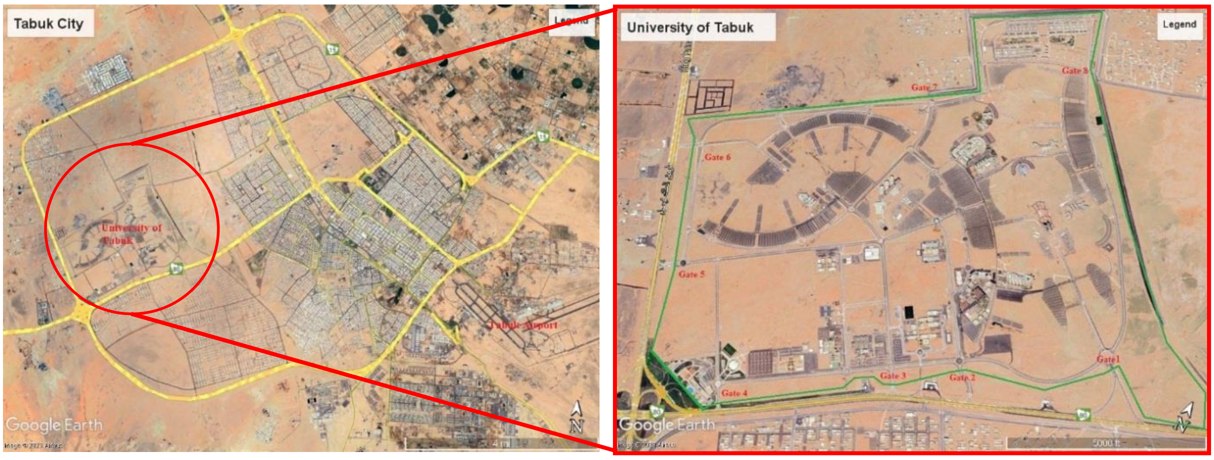
Unfortunately, till now, the socio-economic and demographic factors influencing commuting choices in Saudi Arabia's universities are still not well explored.

The novelty of this research lies in the following points:

- It focuses on understanding the commuting behaviors and acceptance levels of UT population toward sustainable transportation options.
- Unlike previous studies, this work combines survey-based analysis with the FHA to identify not only the most suitable sustainable mobility alternatives, but also the critical factors influencing their adoption.
- Based on the limitations of previous studies, this study analyzes mobility patterns, investigates the socio-economic and demographic factors influencing the acceptance of sustainable alternatives, and proposes actionable recommendations for implementing the most effective solutions.
- Furthermore, the results of this study contribute to a broader understanding of sustainable mobility in university settings and can inform similar initiatives across the KSA and comparable contexts globally. By integrating quantitative criteria, such as safety, economy, and environmental impact with qualitative insights from campus population surveys, this study provides a holistic framework for assessing and implementing sustainable transport systems.

**Study Area**

In this study, the University of Tabuk (UT) was selected to conduct the questionnaire survey as well as the Fuzzy Analytic Hierarchy Process (FAHP) study. UT is a public university that was established in 2006 as the largest university in the northern zone of Saudi Arabia. The main campus was established in Tabuk city and there are five smaller campuses distributed in different cities within the Tabuk Province. The main campus is on the western outskirts of the city of Tabuk, Figure 1(a). Its total area is approximately 1 2km$^2$. It houses 13 colleges and many established facilities (e.g. administrative buildings, support deanships, a university hospital, a sports and entertainment center, public-school buildings, housing for students and faculty members, and a hotel), along with others under construction, Figure 1(b). UT main campus population is composed of 23,494 students (9,522 males and 13,972 females), 1,373 faculty members and 933 employees.




(a) (b)

**Figure 1.** (a) location of UT in the city of Tabuk and (b) main campus of UT

The campus has eight gates, and the transportation infrastructure is composed of some 32 km of roads connecting all the parts and facilities in UT's main campus. The roads are composed of main arterials of six and four divided lanes, collectors and local roads. The area of the paved car park is estimated to be 1.78 km$^2$. This developed infrastructure encourages the use of private cars, which is manifested by the important traffic inside and outside the campus, which causes jams and accidents inside the campus and in the neighborhood.

## RESEARCH METHODOLOGY

The proposal for sustainable alternatives for mobility on campus was based on previous studies and experience in sustainable urban transportation. The principle is to encourage modes that are safe, affordable, and low-emission or emission-free. In practice, alternatives that encourage the population to abandon or reduce the use of private cars were selected. The following alternatives were selected:

**A1:** Carpooling, also known as ridesharing, is a mode of transport where people with similar commutes or destinations share the same vehicle.

**A2:** Bus (from residence to UT campus) is a public mode of transport.

**A3:** Park-and-ride intercampus bus is a mode based on the hub principles, where parking lots are arranged at the principal gates of the campus, and inside mobility is ensured by intercampus bus.

**A4:** Park-and-ride an electric bike (e-bike), which follows the same principle as A3, but the inside campus mobility will be by electric bikes to reduce air pollution.

**A5:** Park-and-ride bicycles, the same as A3, and bicycles are used to ensure intercampus mobility.

Due to the large size of the campus, walking is not a viable alternative and, hence, was not considered. Two methods of assessment were used to find the optimal method for sustainable mobility. The first method is a population survey, while the second method uses experts' opinions and Fuzzy Analytic Hierarchy Process (FAHP) (Mosadeghi et al., 2015) to find the best alternative.

### Population Survey

To collect information about UT population's behavior in transportation and sustainability, a set of questionnaires was prepared using Google Forms and sent to the main campus population: students, faculty members, and administrative staff. The questionnaires were designed to identify the characteristics of trips to UT campus and the population's tendency to switch to sustainable modes of transport. The questionnaire was composed of 37 questions. The first part was related to socio-demographic and economic information (position, age, marital status, gender, residence location in the city, car ownership), while the second part was about characteristics of the trips (mode of transport, number of trips, cost, duration, times of arrival to and leaving the campus, entry and exit gates). The last part was about the acceptance level to switch to a sustainable mode of transport to UT among the five alternatives: car-pooling, bus (from residence to UT campus), park-and-ride intercampus bus, park-and-ride electric bike, and park-and-ride bicycles. For each alternative, the first question was asked if the respondent is ready to switch to the respective mode, then a five-point scale was used to measure the tendency to adopt it, ranging from ‘Strongly Agree’ to ‘Strongly Disagree.’ The last question was open to suggestions for improvements to the traffic inside and near UT campus.

The questionnaire link was sent to all UT students, faculty members, and administrative staff through an official e-mail from the Deanship of Scientific Research. Further, the participants were asked to evaluate the possibility of switching to one of the five alternatives. A five-point scale was used to measure the tendency to adopt an alternative. An additional question was asked to the respondent to choose from a scrolled list the reason that discouraged him/her from adopting the alternative. The survey results were then used to calculate an average score for each alternative, and the relationship between the socio-demographic and mobility patterns of the respondents was investigated.

**FAHP Survey**

In addition to the population survey, an experts’ survey was conducted to rate the above five alternatives. Five criteria were considered for rating the alternatives; namely: Environmental impact (C1), Economic cost (C2), Time (C3), Safety (C4), and Social perception (C5). The questionnaire provided an explanation of each one of these criteria. A brief description of the five criteria follows:

- Environmental impact (C1): Air pollution and Noise pollution.
- Economic cost (C2): Investment cost and Operation cost.
- Time (C3): Travel time and Waiting time.
- Safety (C4): Accidents and personal safety.
- Social perception (C5): Self-perception and Society perception.

The selection of criteria was based on the main factors that influence the choice of an adequate transportation mode (cost, time, safety), to which the environmental criterion was added that is primordial for the selection of the sustainable alternative, and the social perception was also added, since s it is believed that it can influence the rate of some proposed modes.

The survey contained two parts. In the first part, the experts were asked to rate the importance of these criteria relative to each other; i.e., C1 *vs.* C2, C1 vs C3, … etc. The experts’ ratings were then converted into fuzzy numbers, as outlined in Table 1. Several FAHP algorithms were proposed in the literature (Wang et al., 2005). In this study, the interval weight algorithm was then applied to calculate the weights of the criteria due to their accuracy (Wang et al., 2005).

**Table 1. Fuzzy linguistic terms**

| Judgement | Abbreviation | Explanation | Fuzzy Weight |
|---|---|---|---|
| Much less important | VL | A criterion is strongly inferior to another | $\frac{1}{4}, \frac{1}{3}, \frac{1}{2}$ |
| Less important | LI | A criterion is slightly inferior to another | $\frac{1}{3}, \frac{1}{2}, 1$ |
| Equally important | EI | Two criteria contribute equally to the object | 1, 1, 1 |
| More important | MI | Judgement slightly favors one criterion over another | 1, 2, 3 |
| Much more important | VM | Judgement strongly favors one criterion over another | 2, 3, 4 |

In the second part of the survey, the experts were asked to compare the alternatives for each criterion using the same rating shown in Table 1. Based on their comparisons, fuzzy weights were calculated for each alternative under each criterion using the interval weight algorithm. Each of these scores was then multiplied by the corresponding criterion weight and sums are calculated to obtain the overall alternatives' scores.

## RESULTS AND ANALYSIS

### *Results of Population Survey*

**Mobility Pattern**

The total number of participants in the survey was 403, guaranteeing a 95% confidence level and a margin of error below 5%. The socio-demographic information and mobility pattern of the participants are outlined in Table 2.

**Table 2. Respondents' socio-demographic and mobility patterns**

| | Group | Number | % |
|---|---|---|---|
| Position | Student | 345 | 85.6 |
| | Faculty member | 46 | 11.4 |
| | Administrative | 12 | 3.0 |
| | Total | 403 | 100.0 |
| Gender | Male | 309 | 76.7 |
| | Female | 94 | 23.3 |
| Marital status | Single | 349 | 86.6 |
| | Married | 54 | 13.4 |
| Household status | With the family | 342 | 84.9 |
| | Alone | 30 | 7.4 |
| | With friends | 31 | 7.7 |
| Car ownership | 0 | 13 | 3.2 |
| | 1 | 61 | 15.1 |
| | 2 | 106 | 26.3 |
| | 3 | 123 | 30.5 |
| | 4 | 47 | 11.7 |
| | >4 | 53 | 13.2 |
| Mode of transport to UT | Bus | 7 | 1.7 |
| | Carpooling | 18 | 4.5 |
| | Private car alone | 348 | 86.4 |
| | Taxi | 29 | 7.2 |
| | Walking | 1 | 0.2 |
| Number of trips to UT per day | 1 | 216 | 53.6 |
| | 2 | 150 | 37.2 |
| | 3 | 21 | 5.2 |
| | 4 | 9 | 2.2 |
| | >4 | 7 | 1.7 |
| Estimated cost of trips to UT SAR/week | <50 | 39 | 9.7 |
| | 50 – 100 | 196 | 48.6 |
| | 100 – 150 | 97 | 24.1 |
| | 150 – 200 | 40 | 9.9 |
| | 200 – 250 | 12 | 3.0 |
| | >250 | 19 | 4.7 |
| Trip duration from residence to UT (minutes) | <10 | 45 | 11.2 |
| | 10 – 15 | 119 | 29.5 |
| | 15 – 20 | 170 | 42.2 |
| | 20 – 25 | 46 | 11.4 |
| | 25 – 30 | 12 | 3.0 |
| | >30 | 11 | 2.7 |

Table 2 (continued)

| | | | |
|---|---|---|---|
| Arrival time to UT | Before 8:00 AM<br>8:00 – 9:00 AM<br>9:00 – 10:00 AM<br>After 10:00 AM | 243<br>102<br>40<br>18 | 60.3<br>25.3<br>9.9<br>4.5 |
| Entry gate | 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8 | 206<br>46<br>22<br>8<br>38<br>0<br>8<br>75 | 51.1<br>11.4<br>5.5<br>2.0<br>9.4<br>0.0<br>2.0<br>18.6 |
| Exit time from UT | Before 1:00 PM<br>1:00 – 2:00 PM<br>2:00 – 3:00 PM<br>3:00 – 4:00 PM<br>4:00 – 5:00 PM<br>After 5:00 PM | 33<br>76<br>168<br>71<br>40<br>15 | 8.2<br>18.9<br>41.7<br>17.6<br>9.9<br>3.7 |
| Exit gate | 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8 | 134<br>77<br>22<br>16<br>9<br>3<br>13<br>129 | 33.3<br>19.1<br>5.5<br>4.0<br>2.2<br>0.7<br>3.2<br>32.0 |

The respondents consisted of 345 students, 46 faculty members, and 12 employees. The majority of them are males (76.7%) and single (86.6%). It was noted that 85% of the respondents are living with their families, and 55.4% of them have more than two cars per household. The major mode of transport to UT is the private car (86.4%), which explains the intense traffic toward and inside the campus and the increasing problem of parking. The use of carpooling and buses in the sample is limited to 4.5% and 1.7%, respectively. Only one participant uses walking in his trips to UT campus; statistically, the relative results for this mode are not significant and will not be accounted for in the next parts of this work.

Most of the respondents arrive at UT before 8 AM (60.3%) and enter from gate 1, which explains to some extent the heavy traffic and jams observed at rush hours in the vicinity of the campus. Leaving UT is concentrated in the time interval 1-3 PM, which corresponds to the second rush hour in the city. Most of the exits are from gates 1 and 8 (33.3% and 32%, respectively).

**Alternatives' Scores**

The survey results give the five proposed alternatives A1, A2, A3, A4 and A5 the following scores: 2.48, 2.29, 3.40, 2.94 and 2.29, respectively. The results show that A3 is the most favorable alternative, followed by A4. A2 and A5 were the least favorable alternatives.

**a. A1: Carpooling**

The average score for the carpooling alternative for all respondents was 2.48 and 56% of the population said that they are ready to switch to this mode; the tendency of students to use this alternative is the highest among the respondents (2.57), whereas the lowest score was for employees. This can be due to their familial engagement and tasks that might require a private car, since it was found that married employees scored for this option 2.06 on average compared to 2.54 for single employees. Other factors that can affect this alternative include the number of daily trips to UT and gender. From the responses, it was noted that the relationship between the number of trips and the alternative's score is obviously decreasing, as shown in Figure 2. People with a high number of daily trips need more flexibility and independence to move, which cannot be afforded by carpooling. Females scored 2.23 on average, while people who are already using carpooling have selected this option with the highest score, 3.44.

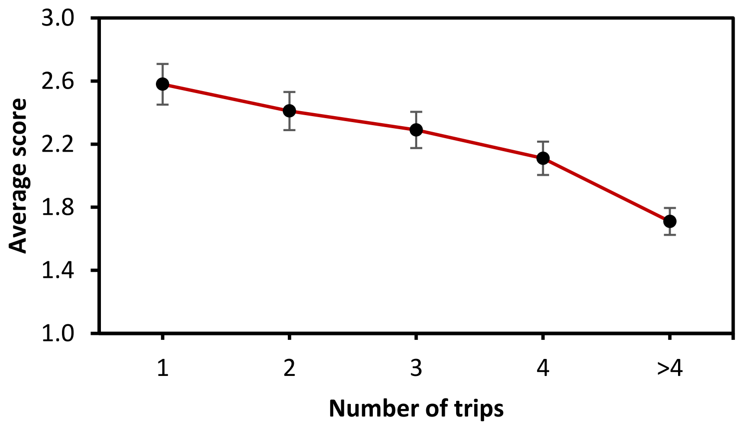



**Figure 2.** Alternative A1 - average score *vs.* the number of daily trips to UT

**b. A2: Bus from Residence to UT**

The total average for this alternative is 2.29, and only 35% of the respondents are willing to switch to this mode, which appears to be the last selected alternative. Gender does not seem to play a crucial role in the selection of this mode of transport, whereas marital status shows that married people are less likely to switch to this mode of transport than single people (27.7% for married and 35.8% for single) for the same reason as for carpooling. However, the tendency to adopt this alternative increases with the trip duration, as shown in Figure 3. This is understood by the fact that the longer the trip's duration, the higher the cost is, and the less the number of trips; so, this choice is the best from an economic and practical point of view.

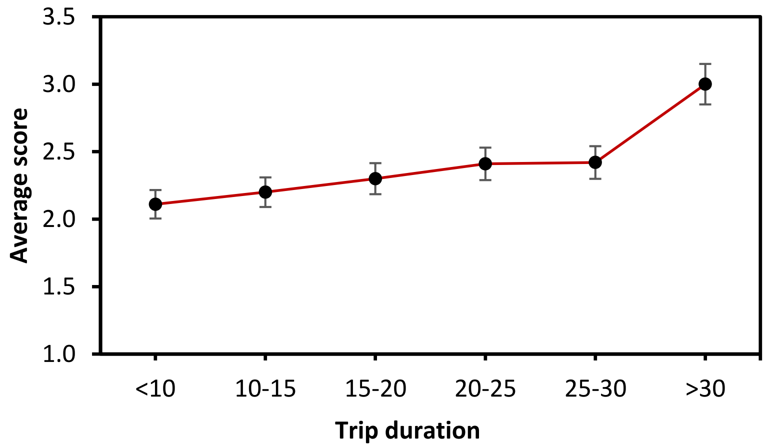



**Figure 3.** Alternative A2 - average score *vs*. trip duration in minutes

**c. A3: Park-and-ride the Intercampus Bus**

This alternative collected the highest score, 3.40, and 80% of the respondents are ready to switch to this transportation mode; it has the advantage of keeping the commuter independent and free to plan his/her schedule and avoiding campus jams and parking problems with the intercampus bus. The main reason for not selecting this alternative was "restricted to specific times ".The difference in gender choice is not important, but it is clearer between single and married people; single people are more motivated for this alternative (3.47) than married persons (3.00).

The relationship between the score of this alternative and the trip duration is not obvious; however, a decreasing relationship between the scores and the number of trips, as shown in Figure 4, was detected, which can be explained by the fact that people with commitments outside the campus avoid any options that replace the private car. Similar findings have been observed in a study conducted by Al-Rashid et al.

(2020), where marital status and external commitments significantly influenced the adoption of sustainable transportation options. Married individuals and those with additional responsibilities showed a preference for private vehicles due to the flexibility that they offer. These parallels underscore the importance of considering personal and socio-economic factors when designing and implementing sustainable transportation solutions, as these variables play a critical role in determining acceptance and usability.

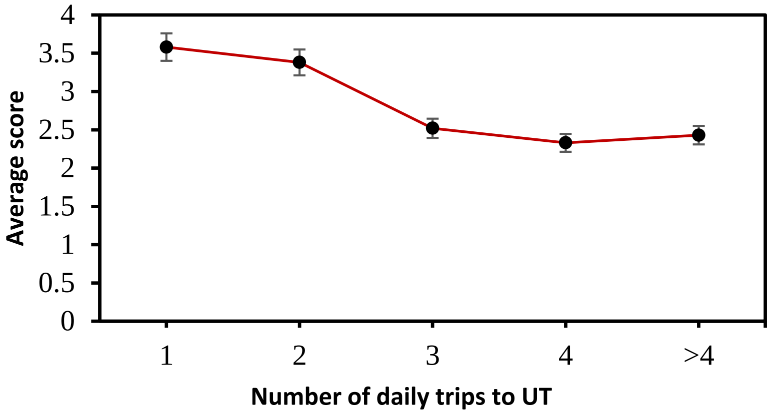



**Figure 4.** Alternative A3 - average score *vs*. the number of daily trips to UT

**d. A4: Park-and-ride an Electric Bike**

This alternative has the second score among the five alternatives, and 68% of the sample are in favor of this option. The major protagonists of it are males with a score of 3.07 and students with a score of 3.15. For females, married people and staff, the motivation is low, with scores of 2.51, 1.70 and 1.85, respectively. The number of trips and the duration had no clear effect on choosing this alternative. However, external factors, such as the long distances between the potential bike parking areas near campus gates and the colleges, play a critical role in discouraging the adoption of this alternative. Additionally, extreme weather conditions, including high temperatures and prolonged sun exposure for much of the year, further deter individuals from considering bikes as a viable commuting option. These environmental barriers are particularly pronounced in regions with climates similar to that of Saudi Arabia, where physical exertion under such conditions can be impractical and uncomfortable. Similar findings were reported in studies conducted by Al-fouzan and Almasri (2024), who noted that weather and infrastructure constraints significantly hinder the adoption of cycling alternatives in urban and educational settings.

**e. A5: Park-and-ride Bicycles**

Like the option "bus from residence to UT campus," this alternative also obtained the lowest score of 2.29, and only 49% of the sample support this option. In addition to the reasons cited previously, parking and riding a bicycle are discouraged by the topography of the campus (ramps and slopes) and the official long open-ended uniform for students and staff, which is not suitable for cycling. The scores recorded for this alternative are affected by gender, position and marital status. The disparity related to gender was reported in previous studies and factors such as safety perception, and social and environmental factors, were found to influence bicycle choice (Emond et al., 2009). Females, administrative and married persons are the most repulsive to this option; with scores of 2.09, 1.72 and 1, respectively. There is no clear influence of the number of trips or their duration on the selection of this alternative.

**f. Alternative Adopter Profile**

Table 3 illustrates the respondents' profiles with the highest likelihood of adopting each transportation alternative, considering variables such as gender, marital status, job position, number of trips to the UT, and trip duration. This demographic exhibits the greatest potential for transitioning to sustainable transportation modes.

**Table 3. The most probable profile for each alternative**

| | Gender | Marital status | Position | Number of trips to UT | Trip duration (min.) |
|---|---|---|---|---|---|
| **A1: Carpooling** | Male | Single | Student | 1 | 25-30 |
| **A2: Bus (from residence to UT campus)** | Female | Single | Student | 3 | >30 |
| **A3: Park-and-ride an intercampus bus** | Male | Single | Student | 1 | 15-20 |
| **A4: Park-and-ride an e-bike** | Male | Single | Student | 2 | 10-15 |
| **A5: Park-and-ride bicycles** | Male | Single | Student | 3 | 25-30 |

***Results of FAHP Survey***

Nine experts participated in the FAHP survey. They compared, in the first part of the survey, the importance of each criterion relative to the other four criteria. Table 4 shows the weights of the criteria calculated from the experts' scores using Table 1 and the interval weight algorithm. Five experts rated safety as the most crucial criterion, three experts rated the environment as the most important criterion, and two rated social perceptions as the most important criterion. Hence, the safety criterion got the highest weight, followed by economy, environment, and social perception, whereas time was considered the least important criterion. The difference between the weights of environment and economy criteria is very small (< 0.002), indicating that these two criteria are almost equally important. Similarly, social perception and time are almost equally important.

**Table 4. Weights of criteria**

| Criteria | Environment | Economy | Time | Safety | Social perception |
|---|---|---|---|---|---|
| | **C1** | **C2** | **C3** | **C4** | **C5** |
| ***Expert 1*** | 0.28522 | 0.20101 | 0.12529 | **0.31206** | 0.07642 |
| ***Expert 2*** | 0.28090 | 0.20350 | 0.13345 | **0.31876** | 0.06339 |
| ***Expert 3*** | 0.09115 | 0.25054 | 0.15300 | **0.27922** | 0.22609 |
| ***Expert 4*** | 0.11677 | 0.18447 | 0.26355 | **0.26995** | 0.16527 |
| ***Expert 5*** | 0.08892 | 0.17621 | 0.17621 | 0.26979 | **0.28888** |
| ***Expert 6*** | **0.23738** | 0.17844 | 0.12957 | 0.21724 | **0.23738** |
| ***Expert 7*** | **0.32541** | 0.24505 | 0.17066 | 0.12495 | 0.13393 |
| ***Expert 8*** | **0.26883** | **0.26883** | 0.13117 | 0.20000 | 0.13117 |
| ***Expert 9*** | 0.12066 | 0.12109 | 0.21173 | **0.35293** | 0.19360 |
| **ACW** | 0.20169 | 0.20324 | 0.16607 | **0.26054** | 0.16846 |
| **Std. dev.** | 0.09010 | 0.04313 | 0.04366 | 0.06585 | 0.07095 |

ACW, average criterion weight.

In the second part of the FAHP survey, the experts rated each alternative for each criterion in comparison to the other four alternatives. These ratings were converted into fuzzy numbers using Table 1 and the interval weight algorithm to calculate the weight of each alternative. Table 5 shows the scores of the alternatives for each expert calculated from all criteria.

**Table 5. Experts' alternative scores**

| | A1 | A2 | A3 | A4 | A5 |
|---|---|---|---|---|---|
| **Expert 1** | 0.18971 | **0.26864** | 0.20912 | 0.16813 | 0.16441 |
| **Expert 2** | 0.15795 | **0.32043** | 0.24288 | 0.15993 | 0.11881 |
| **Expert 3** | 0.18173 | **0.24134** | 0.19625 | 0.17058 | 0.21011 |
| **Expert 4** | **0.25607** | 0.24016 | 0.19511 | 0.15484 | 0.15381 |
| **Expert 5** | **0.23147** | 0.18836 | 0.18653 | 0.19639 | 0.19725 |
| **Expert 6** | 0.19833 | **0.25184** | 0.19917 | 0.16979 | 0.18087 |
| **Expert 7** | 0.23465 | **0.24760** | 0.18287 | 0.19413 | 0.14076 |
| **Expert 8** | 0.16754 | 0.17811 | 0.18868 | 0.22476 | **0.24091** |
| **Expert 9** | 0.16421 | **0.25355** | 0.21947 | 0.18330 | 0.17947 |
| **Alternative score** | 0.19796 | **0.24334** | 0.20223 | 0.18021 | 0.17627 |
| **Std. dev.** | 0.03307 | 0.03954 | 0.01795 | 0.02069 | 0.03497 |

Six out of nine experts gave alternative A2 the highest score; two gave A1 the highest score, whereas only one rated A5 as the best alternative. Overall, A2 received the highest score **(0.24)**. Table 6 shows the alternatives' scores for each criterion averaged from all experts. A2 was rated highest in C1, C4, and C5 with scores of 0.048, 0.075, and 0.042, respectively. Due to its very high score in C4, and since it was the most crucial criterion, A2 was selected as the best alternative by the FAHP algorithm. The last row of Table 6 shows the final alternatives' scores.

**Table 6. Total alternatives' scores with distribution of criteria**

| | A1: Carpooling | A2: Bus (from residence to UT campus) | A3: Park-and-ride an intercampus bus | A4: Park-and-ride an e-bike | A5: Park-and-ride bicycles |
|---|---|---|---|---|---|
| **C1** | 0.03452 | 0.04817 | 0.03786 | 0.04252 | 0.03862 |
| **C2** | 0.03178 | 0.04289 | 0.03879 | 0.04122 | 0.04856 |
| **C3** | 0.04299 | 0.03593 | 0.03002 | 0.03010 | 0.02704 |
| **C4** | 0.04770 | 0.07450 | 0.06255 | 0.03948 | 0.03632 |
| | | | | | |
| **C5** | 0.04098 | 0.04185 | 0.03301 | 0.02689 | 0.02573 |
| **Alternative Score** | 0.19796 | **0.24334** | 0.20223 | 0.18021 | 0.17627 |

## DISCUSSION

### *Comparison of Experts' and Population Choices*

While the expert evaluation identified alternative A2 (bus from residence to UT campus) as the most suitable sustainable transportation option with a score of 0.24, survey results ranked A3 (Park-and-Ride Intercampus Bus) as the preferred choice with a score of 0.25. This discrepancy highlights the differing priorities between experts' judgements and user preferences. Upon further analysis of the reasons for rejecting A2, the primary concern cited by 53.4% of male and 47.8% of female respondents was its "restriction to specific bus times" feature, as depicted in Figure 5. Additional reasons varied by demographic groups: 31.6% of male respondents emphasized "restriction of mobility," while 30.4% of female respondents expressed concerns over a "lack of privacy". These findings underline the importance of mobility freedom and personal convenience in shaping transportation preferences among the campus population.

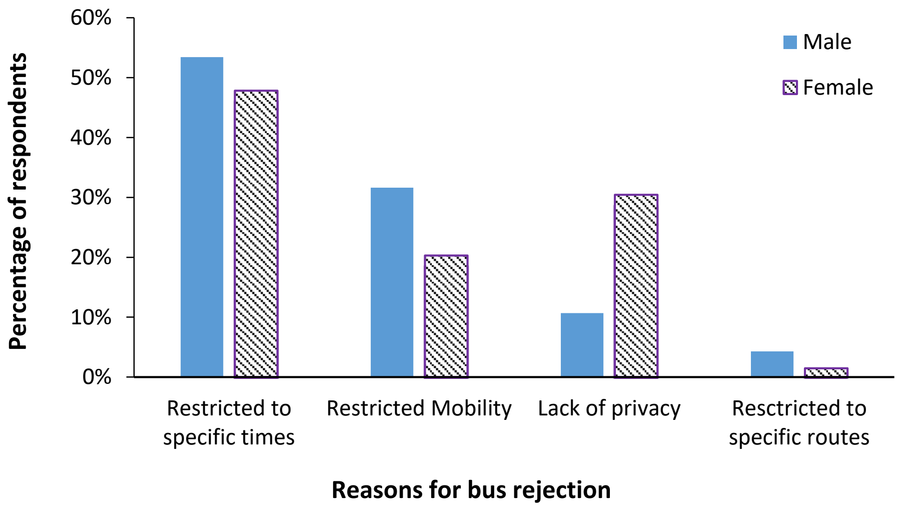



**Figure 5.** A2 bus rejection reasons

Alternative A3 was the second best FAHP alternative (score = 0.20), but it was the most favorable one by the population with the highest score = 0.34. A4 (park-and-ride an electric bike) was the second favorite alternative in the survey, but it was rated fourth with FAHP. Time schedules or specific routes do not restrict A4; thus, it provides the population with freedom of mobility and, hence, it achieved a high score in the survey. A5 (park-and-ride bicycles) was the least favorable alternative for both methods (scores = 0.17 and 0.18) due to the large campus area, difficult terrain and weather conditions. Figure 6 compares the scores of the two methods. The survey scores were normalized to fit the same scale as FAHP weights.

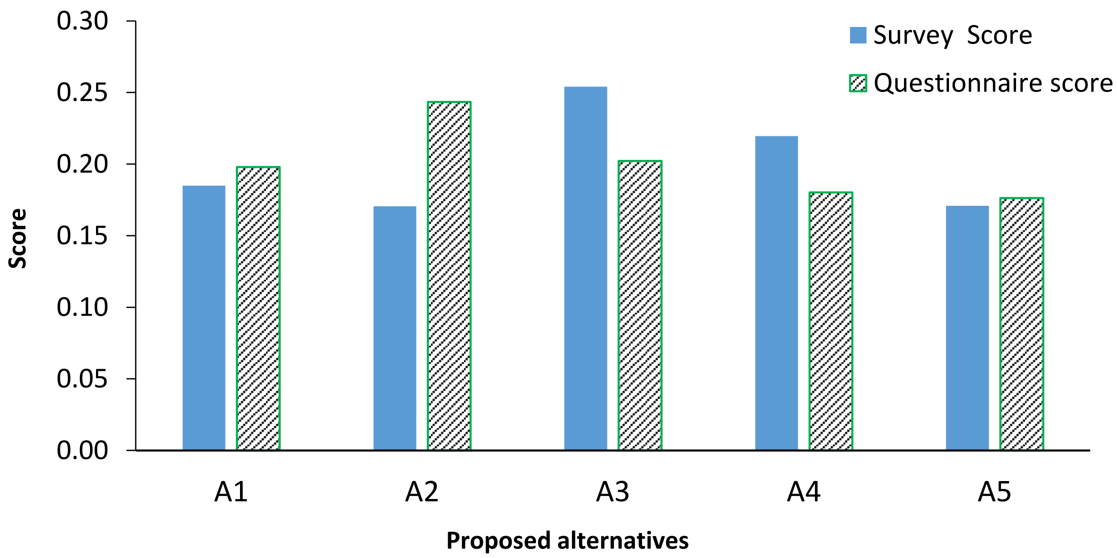



**Figure 6.** Comparison of alternatives' scores

From the survey results, it can be drawn that the ability to plan trips flexibly and maintain autonomy plays a significant role in the acceptance of any alternative, especially in a context where reliance on private vehicles is deeply ingrained (Ji et al., 2021). This suggests that future evaluations of transportation options must incorporate mobility freedom as a critical criterion. Additionally, gender-specific concerns, such as privacy for female commuters, indicate the need for tailored solutions that address diverse user needs. This could involve implementing strategies to increase privacy and comfort in shared transportation modes, as well as offering more adaptive scheduling to mitigate the perceived inflexibility of bus services.

The structure of the FAHP process can be a factor in the difference in results between the FAHP and classical surveys; this process provides a systematic approach to decision-making that includes multiple criteria and alternatives, allowing for a more profound analysis. In contrast, the classical-survey results reflect the different interpretations of the priorities of respondents. The comparison of the results between FAHP and other methods for selection over various alternatives was studied in many previous works (Baalousha et al., 2023; Ishizaka, 2014; Natarajan et al., 2022). However, the comparison between the FAHP and classical-survey results was not studied in numerous works. Şahin et al. (2021) found a difference between FAHP and classical survey results, and the authors concluded that the results from the former process are more valid, since the survey process is more accurate and sensitive.

In the current study, the observed difference in alternative order between the experts' judgement and the users' preferences can be explained by:

- **The main decision criteria**: The main criteria that govern each expert's judgement or user's preference is a crucial factor in the final decision. In fact, among the 9 experts, five marked "safety" as the most important criterion, while three chose "the environment", see Table 4. For the direct survey, where most respondents are students (85.6%), the lack of mobility is the major reason for alternative rejection, which means that the main criterion for users' choice is to maintain the maximum mobility freedom.
- **The targeted population:** The objective of the experts' judgement is to select the best mobility alternative that can serve the campus users as an entire population, whereas the survey results show that user preferences are linked to their personal conditions and limited to their interest without considering the impact on the environment or on the mobility fluency of the campus population; the only proposed alternative where the user abandons his/her car (bus from residence to UT) has the lowest score. The users' choices are self-interest preferences whereas the experts' judgements are community serving.
- **The choice objectivity:** The experts give professional judgements where they are conducted by clear and precise criteria, whereas the users' choices can be affected by personal assessments. The experts' judgements are objective, whereas the users' choices are more subjective.

**Proposed Alternative**

Based on the previous comparison, it is proposed to adopt the experts' judgement and select the bus from residence to the university as a sustainable mobility alternative; however, the results of the population questionnaire should be used to define the characteristics of the designed bus system.

For the bus-route selection, the system should focus on zones with the respondents' highest scores to ensure acceptance and pre-disposition to switch to the bus system. Figure 7 presents the percentage of acceptance to switch to the bus mode among the respondents' residential zone in Tabuk City. As it can be seen, Alwurud demonstrates the highest acceptance level at 53% (out of 33 respondents), followed by Ashifa at 50% and Albawadi at 45% (out of 6 and 33 respondents, respectively). In contrast, zones such as Almuruj and Alhamra exhibit lower acceptance rates, at 24% (out of 71 and 25 respondents, respectively). Given the observed variation in the sample size of participants from these zones, the acceptance rates should be considered as indicative.

The schedule of the bus trips should consider the distribution of the percentages of respondents who agreed to switch to the bus mode, as shown in Figure 8. Most of the trips should be scheduled before 8:00 am to 9:00 am, which corresponds to the first rush hour and explains the desire to avoid driving cars at this time. In the second rush hour, the majority should be scheduled between 1 pm and 3 pm.

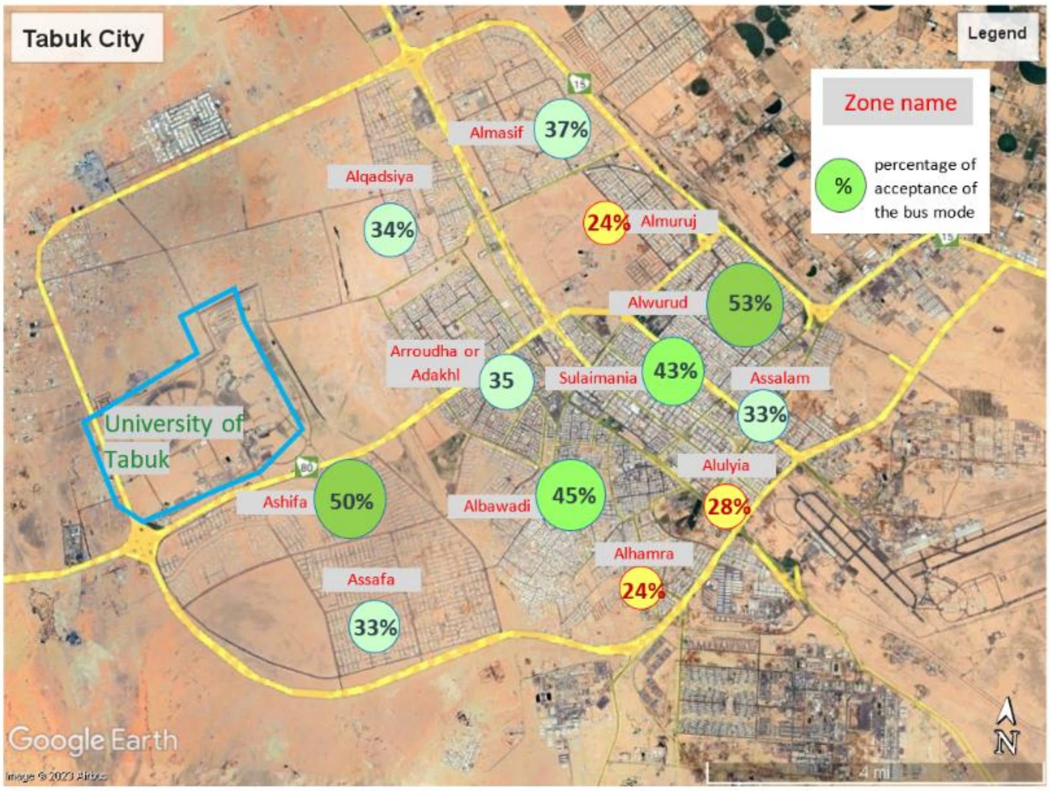



**Figure 7.** Distribution of percentages of bus acceptance by respondents' residential zone

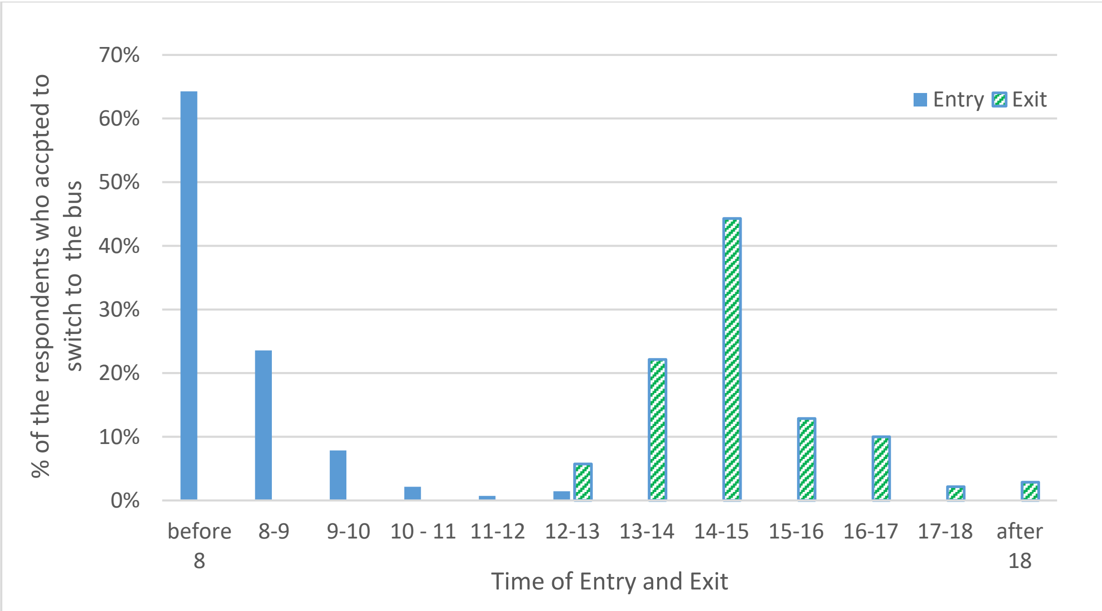



**Figure 8.** Distribution of entry and exit times of the respondents who agreed to switch to the bus mode

Incentives and financial tools can play a crucial role in encouraging commuters to adopt new sustainable modes of transport. Among the proposed modes in this study, the tools include low bus subscription, free intra-campus bus and free or low bicycle and e-bike subscriptions. To encourage campus commuters to switch to any mode, the monthly subscription should be lower than the average cost of travel declared by the participants in the questionnaire.

The results showed that 88% of the respondents spent on travel (mainly fuel cost or taxi fees) more than 50 SAR per week (1$ = 3.75 SAR), equivalent to 200 SAR per month. On the other hand, 59% of the commuters would accept a monthly bus subscription for less than 100 SAR, whereas 31% would be favorable to a monthly subscription up to 200 SAR. Based on these features, a reasonable bus subscription can be selected.

**Study Limitations**

Despite being applied to the University of Tabuk campus, the study process and results can be extended to similar institutions in the region. However, the study has the following limitations; first, the limited number of participants in the questionnaire; a greater sample will improve and strengthen the results. Second, the FAHP criteria can be revised and the criteria as "lack of privacy" and "restricted mobility" can be added and may affect the experts' decisions.

## CONCLUSIONS

The University of Tabuk (UT) main campus population's mobility patterns and the potential for implementing sustainable transportation options were examined in this study. The study investigated the most sustainable mobility alternatives and the factors that influence acceptance and rejection using survey data and the Fuzzy Analytical Hierarchy Process.

Based on the results of this study, the following points were concluded:

1. Over 86% of UT members commute by private cars and the majority of trips take from 10 minutes to 20 minutes per trip. During peak hours, traffic is concentrated around Gates 1, 2, and 8, resulting in severe congestion.
2. The population survey indicated that the park-and-ride intercampus bus is the most accepted sustainable option and 80% of the campus commuters are ready to switch to this mode, whereas the bus from residence to campus was accepted by only 35% of the population.
3. Factors such as gender, restricted mobility, fixed schedules, familial responsibilities, and commuter roles influenced acceptance levels.
4. Single male students with longer commutes constitute the profile with the higher interest to switch to the proposed sustainable alternatives.
5. On the other hand, the FAHP results show the alternative bus from the residence to the university as the best sustainable alternative (score = 0.24), followed by the park-and-ride intercampus bus (score = 0.20).
6. The experts selected "Safety" as the most important criterion for the selection of a sustainable mode of transport, followed by "Economy" and "Environment", while "Time" was the last one, with the respective weights 0.26, 0.20, 0.20, and 0.16.

Ultimately, the findings of this study can provide a basis for developing new sustainable transportation strategies and options, not only for the University of Tabuk, but also for educational institutions with similar conditions, aimed at alleviating traffic issues and congestion in the surrounding area and enhancing environmental conditions on campus as well as in the neighborhood. These strategies may include:

1. Improving the campus infrastructure to encourage walking and biking: Design the campus to be pedestrian-friendly by reducing car access.
2. Carpool Programs: Create a carpooling app or platform where students, faculty members, and staff can find ride-sharing partners.
3. Mobility Hubs: Develop mobility hubs at the campus gates where various transportation options (bike, public transit, electric bikes) are available in one location.
4. Sustainability Awareness Campaigns: Launch campaigns that educate students, faculty members, and staff about the environmental impact of transportation and the benefits of using sustainable options.

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The article was written with the collaboration of all the contributors. All the authors contributed equally to the scientific information collection, analysis of the data, writing and editing of the article, and concept design and study proposal. All authors have read and agreed on the published version of the manuscript.

## Data Availability

The article includes the data supporting the findings of the study.

## Conflicts of Interests

The authors have no conflict of interests to delare.

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