# Optimizing National Resource Usage through the Integration of University Shuttle Service with the Public Rail: The Case Study in Qatar University

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## Abstract

Qatar University is the largest public educational institution in the State of Qatar. The university community has diverse committed faculty who not only teaching but also conducting research studies contributing actively to the needs of the society. Qatar University aims to improve the transportation network inside the campus and reduce the traffic congestions. This work aims to provide the transportation department at Qatar University with a unique network design integrating the rail terminal with the in-campus shuttle system. The new design mainly aims to facilitate the transition of students, faculty members, staffs, and visitors between Qatar University Campus's buildings and Qatar Rail terminal leading to encourage customers to use the Qatar rail service. Consequently, shuttle stations locations are optimized, routes are designed, and sufficient number of buses is specified for each route based on the density in each building inside the campus. The performance of the new network design is evaluated using ProModel® software.

**Keywords**:
Qatar National Vision 2030, Resource Usage Optimization, Qatar University

## Introduction

Qatar University is the largest public institution of higher education in the State of Qatar. The university community has more than 16,000 students and 600 Academic faculties. As one of its roles towards the achievement of the goals of Qatar National Vision 2030 in the high education sector, the university will be opening several of administrative, educational, and service buildings over the next few years. In light of this, the traffic density and road-users volume are expected to grow up – the matter that may lead to a significant increment in the likelihood of traffic congestions and jams inside the university campus. However, over the last few years, many studies were established discussing the traffic issue either in general or in campus level. Most of the studies that were concerned about the traffic issue in university-level agreed that the solution to reduce the congestion is by having an efficient transport system in the campus that is integrated with some sort of public transportation. Further, researches tend to encourage people to use the public transit to reduce congestion problems in roads. Moreover, some papers emphasized the importance of designing effective shuttle routes that will assist to reduce the congestion problems.

Several research works have been conducted over the last decade for enhancing the efficiency of both public and private transportation networks. Ceder *et al*. (2001) reported that the route design procedure should include interaction loops and the selection of the routes should consider both the effective routes and the operational schedule components. The authors also stated that three perspectives function objectives should be taken into account as follows: 1) Minimizing the total waiting time of the passengers, 2) Minimize the total unused seats capacity so that they will have more possible public transport services, and 3) Minimize the total loss if all the public transport passengers are switched to the shortest path. Aldrete-Sanchez *et al.* (2010) proposed a systematic approach to investigate the issues related to the interaction and incorporation between the University campus transportation system and the urban transportation system to develop solutions to these issues. They study was started by developing a survey to faculty, staff, and students asking them about their perception on the campus transportation system. As a result, a Multi-resolution simulation modeling methodology was used, which provided the output of the current and future transportation system showing the integration and interaction between settings in the University campus. In 2012, Jain *et al*. emphasized on that the traffic congestions problem is the major problem in most of the cities in the world, especially in developing regions. This problem lead to huge delays, increase the fuel waste and financial losses. The reasons behind the traffic jams are the poor planned road networks and the poor traffic management. To overcome the congestion issue, Jain *et al.* presented a local protocol that coordinates traffic signal behavior in small area and stops jams collapse. The local protocol showed an excellent performance in enhancing road volume and stop car accidents in localized setting as proved by simulation based analysis. Aoun, *et al.* (2013) used Transportation Demand Management (TDM) lessons from five North American case studies in order to come up with a new mobility solution at the University of Beirut (AUB). The new solution is a dynamic taxi sharing service that can be the same as the higher vehicle use of the shared taxi as well as the comfort of the private taxi with a less cost of a public transport fare. Rahane and Saharkar (2013) declared that the major metropolitan transportation problem is the traffic congestion. Due to this issue, there is a probability of collapses because of the poor traffic management. Thereby, it is necessary to resolve this issue by eliminating road accidents to save human life. Rahane and Saharkar (2013) studied performance of the transportation network in Talegaon Dab hade city, one of the crowded areas in the world, and proposed a solution based on expanding road lanes, improving road infrastructure, and applying penalties for whoever breaks the law in the street. Abdul-Wahab and Fadlallah (2014) considered the traffic congestion at Sultan Qaboos University (SQU) in Muscat, Oman and used the CALPUFF software for modeling and investigating the concentration dispersion of the most dominant vehicle emissions carbon monoxide (CO), Mononitrogen oxide ($NO_X$), and carbon dioxide ($CO_2$). The results showed that it is not good to let the students enter the University campus with their vehicles since there are some side effects that may happen from the emission of high concentrations of carbon monoxide (CO), Mononitrogen oxide ($NO_X$), and carbon dioxide ($CO_2$). Thus, they recommended to add parking that are away from the campus, external parking, and a shuttle buses will be provided there so the students might take one to the classes. The shuttle buses must be in a suitable condition with low emissions and minimal pollutants.

This work aims to reduce the traffic issue in campus by designing shuttle transport system in Qatar University that is integrated with the rail station. This transportation system will lead to encouraging people to use the national resources, which will lead to reducing the congestion problems in Qatar University that occurred due to the increasing population in the University.

# 1 Existing system

In order to study the existing system, team members went to the transportation department in the University to get knowledge about their current and future plans. After discussing with the transportation department, it has been noticed that Qatar University did not plan yet to integrate the current shuttle system with the Qatar rail service. Therefore, to achieve this, team members studied the current shuttle system for improvement purpose. As Qatar University is expanding, the number of students is expanding as well, see Figure 1.

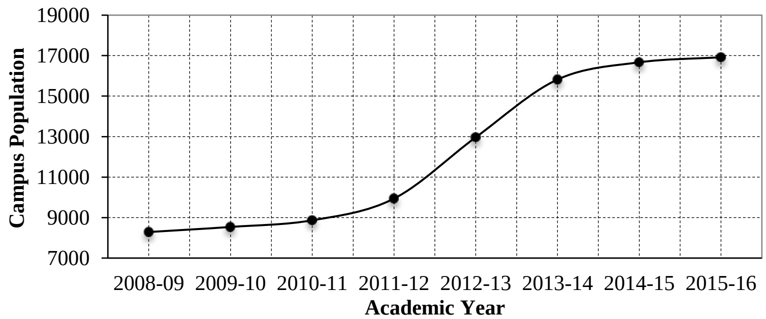


**Figure 1:** Changes of students in QU over the period 2008 to 2016

The existing system consists of several buses routes for male and female students; four routes are specified for female students, and only one route is specified for male students. MEGA, GCR, Success, and Shortcut are the four routes used by female students. Mega-male is the route used by male students. There are 10 stations are located for female students and 4 stations for male students. Further, there are four routes for the female students that cover all the stations and one route for male students. For each route, there are specified numbers of buses that are rented per month. The number of buses was determined based on the demand for each route as shown in the following table:

**Table 1:** Number of buses in the existing system

| **Female** | |
|---|---|
| **Route Name** | **Number of Buses** |
| MEGA Route – Female | 5 |
| GCR Route | 3 |
| Success Route | 1 |
| Shortcut Route | 4 |
| **MALE** | |
| **Route Name** | **Number of Buses** |
| MEGA Route- Male | 4 |

Faculty members and staff are not considered in any transportation mean, in which they do not have shuttles to transport them between buildings. However, faculty members and staff might use the rail service in the University. Therefore, it is important to design a shuttle system for them as per their request.

# 2 Methodology of the Study

After studying the current system, it is important to improve it by designing an efficient transport system that will solve the traffic issue and enhance the usage of the national sources. Therefore, by designing a good transportation system in the University that eases the mobility from and to the rail station, people will be encouraged to use the rail service as well as the shuttle service provided by the University. This design will include several stations dedicated to male and female societies in the University, shuttles that transport people from to rail station and between buildings, and routes specified to each shuttle type. In order to improve the system, a specific methodology was followed, which is used based on the framework of Holtzapple and Reece (2008) engineering design.
The design method has four elements: synthesis, analysis, communication, and implementation. In the first element, which is synthesis, the first step is to identify the need and define the problem. In this paper, the needs are identified by applying an interview survey to the customers (Voice of customer) and noted their needs regarding the current shuttle transportation system in Qatar University. This step assisted to define the problem that customer face in the

current system. The second step is to identify the constraints, which are the limitations that are found in this work such as, environmental, economical, health and safety, social, political, ethical and sustainability constraints. After identifying the constraints, designed alternatives are developed. Design alternatives are different from each other in terms of locating the stations and specifying the routes. Each alternative is developed based on certain method; Building Density-based Design (BD-D), Area Density-based Design (AD-D), and Customer Flow Design (CF-D). Brainstorming was used between team members to design each alternative. The next element is the synthesis and analysis. The first step in this element is to analyze each potential solution, in which after developing the design alternatives, some criteria are generated to evaluate each design alternative. A decision matrix is used to compare the design alternatives using the criteria. The next step is to choose the best solution, in which one alternative is chosen after getting the highest total in the decision matrix. Further, in the communication element, the designed solution is written and described in a report form. Finally, comes the implementation element, in which the solution is constructed by developing a prototype using ProModel® and Matlab that is detailed showing how will the system work. If things went well in the simulation, then the design could be implemented.

## 2.1 Search for solutions

In this step, design alternatives are developed. This paper will propose three design alternatives for the shuttle service inside Qatar University campus. Each of these design alternatives will be developed based on a particular method for locating stations, and each design alternative may have different number of stations. In addition, different routes for the shuttle bus will be developed in each design alternatives. Further, all design alternatives have drop-off points with routes specified to Qatar University employees. These routes will not be discussed in any alternative, as all of them will have the same drop-off points based on the most buildings that employees transfer to. In addition, same route distance which is based on the shortest time route. Therefore, there is no point of comparing in terms of these routes.

The number of buses used in each route of each alternative excluding employees routes, is based on criteria that depends on the total distance of the route. The table below illustrates the criteria.

**Table 2:** Total route distance range with suitable number of buses

| Range of total distance of the route (Km) | Number of buses used for the route |
|---|---|
| Distance $< 3$ | 1 |
| $4.5 >$ Distance $\geq 3$ | 2 |
| $6 >$ Distance $\geq 4.5$ | 3 |
| Distance $\geq 6$ | 4 |

*Building Density-based Design (BD-D)*

In this design alternative, data related to the density of each building were used to classify the buildings in to three categories- high density, medium density, and low density. The buildings on Qatar University Master Plan were classified based on these 3 categories. Doing this classification on Qatar University map, will be guidance in allocating stations near to the buildings with high densities. Therefore, not all buildings will have a station in which the shuttle bus will stop at; instead, an optimized number of stations will be located. For instance, in case of having two neighbored buildings in which both have high density, then each building will have its own station. In addition, if one of them has high density and the other has low density, then one station is going to be located close to the highest populated and will serve both buildings. Figure 2 shows the stations locations based on the buildings' density.

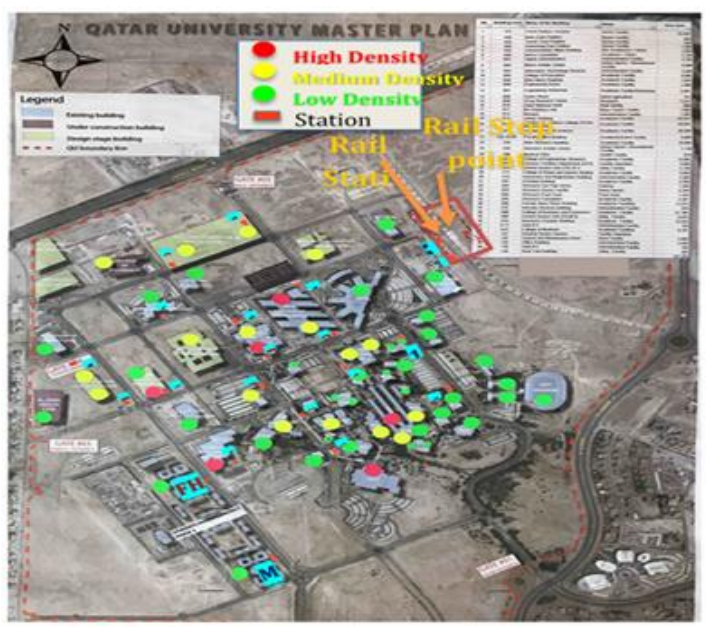


**Figure 2:** Design Alternative 1 (BD-D)

Tables below illustrate the important data of this alternative design solution. Table 3 shows the served buildings by each female station. The served buildings have a condition in which the building is not far from the station by more than 200 meters. For instance, station 5 serves New College of Law (NCL) and Al Jama Health Care (JHC). Table 4 shows which male station serving which buildings. Refer to Appendix A for building names with building ID.

**Table 3:** BD-D Covered buildings by each female station.

| Female Station No. | Covered buildings |
|---|---|
| 1 | C01, C05, C06, D01, C04 |
| 2 | D04, C11, C07, C08, C09 |
| 3 | D05, D04, |
| 4 | D06, D03, |
| 5 | NCL, JHC |
| 6 | NCEd, NSA |
| 7 | H08, NSA, C12 |
| 8 | NCEn, H10 |
| 9 | NCM, CF |
| 10 | I03, NSA |
| 11 | B07, B13, C09, C08 |

**Table 4:** BD-D Covered buildings by each male station

| Male Station No. | Covered buildings |
|---|---|
| 1 | B01, B02, B03,B04, B05, B06, BCR, C02,C03,,A02,A03,A04 |
| 2 | B07, B09, B10, B11, B12, B13,A06, A05 |
| 3 | NCEn, H10, NAA |
| 4 | H08,NSA,C12 |
| 5 | NCM, |
| 6 | NCL,JHC,I02,NCE |

For the routes that the shuttle will cut, number of stations in each route and shuttle routes details are illustrated in tables 5 and 6 for female and male students, respectively.

**Table 5:** BD-D Female routes details

| Female Routes Name | Number of stations | Sequence of shuttle travel | Distance of the route | Bus waiting time | Time of the route | Number of bus used in the route |
|---|---|---|---|---|---|---|
| R1 | 7 | FS,8,7,3,1,2,11,FS | 3.07 Km | 7 min | 12 min | 2 |
| R2 | 6 | FS,9,5,HF,4,6,FS | 6.75 Km | 6 min | 16 min | 4 |
| R3 | 3 | 10,11,7,10 | 2.05 Km | 3 min | 6 min | 1 |
| R4 | 3 | 1,4,7,1 | 3.46 Km | 3 min | 8 min | 2 |
| **Total** | **19** | | **15.33 Km** | **19 min** | **42min** | **9** |

**Table 6:** BD-D Male routes details

| Male Routes Name | Number of stations | Sequence of shuttle travel | Distance of the route | Bus waiting time | Time of the route | Number of bus used in the route |
|---|---|---|---|---|---|---|
| R1 | 5 | MS,16,17,15,14,MS | 4.04 Km | 5 min | 11 min | 2 |
| R2 | 3 | MS,13,12,MS | 2.10 Km | 3 min | 6 min | 1 |
| R3 | 6 | 13,12,16,17,15,14,13 | 5.45 Km | 6 min | 14 min | 3 |
| R4 | 5 | 15,14,13,12,MH,15 | 6.08 Km | 5 min | 14 min | 4 |
| **Total** | **19** | | **17.67 Km** | **19 min** | **45 min** | **10** |

*Area Density-based Design (AD-D)*

Dividing Qatar University's master plan into equal square districts is the main method used for this alternative. For every 380 meters, one district has identified to ensure that each district has a full building or at least half of a certain building. After dividing the master plan into regions, each district will be classified either to be with high, medium, or low density. This classification is done based on the density of each building inside each region. For example, a region with two medium density buildings will be considered as high-density district. This design alternative will consider allocating stations on each zone based on the density of each district. For example, for a high density zone, two stations will be located inside this zone, the location of the station will be on the applicable areas for locating a station that is along the road and to be close to the entrance of the higher density buildings in that zone. Figure 3 shows the second design alternative.

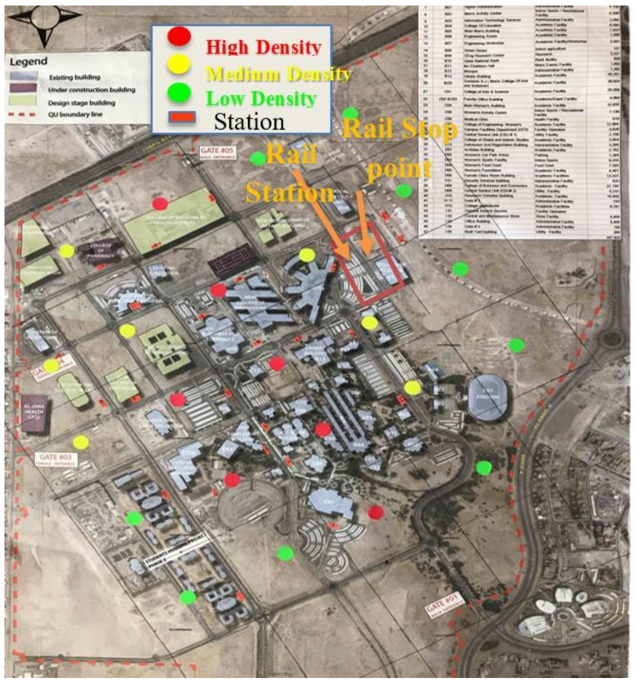


**Figure 3:** Design Alternative 2 (AD-D)

Further, tables below illustrate the important data of this alternative design solution. The details of served buildings by both genders' stations and the routes details for each gender. Refer to Appendix A for building names with building ID.

**Table 7:** AD-D Covered buildings by each female station

| Female Station No. | Covered buildings |
|---|---|
| 1 | C01 |
| 2 | C05,C06,C07,D01,C04 |
| 3 | D01, D04,C07,C06,D03 |
| 4 | C07,C08,C09,C11,D04 |
| 5 | D05 |
| 6 | D06,D03 |
| 7 | NCL,JHC, |
| 8 | H08, NCEn |
| 9 | NCEd |
| 10 | B13 |
| 11 | I03 |
| 12 | COP |
| 13 | NCM |

**Table 8:** AD-D Covered buildings by each male station

| Male Station No. | Covered buildings |
|---|---|
| 14 | B01, B03,B05,B06,BCR,B04 |
| 15 | B10, B11,B12,B13 |
| 16 | H10 |
| 17 | NCEn |
| 18 | H08 |
| 19 | NCL |
| 20 | NCM |

**Table 9:** AD-D Female routes details

| Female Routes Name | Number of stations | Sequence of shuttle travel | Distance of the route | Bus waiting time | Time of the route | Number of bus used in the route |
|---|---|---|---|---|---|---|
| R1 | 6 | FS,8,5,3,2,4,FS | 2.8 Km | 6 min | 10 min | 1 |
| R2 | 7 | FS,8,9,7, HF,6,10,FS | 5.9 Km | 7 min | 16 min | 3 |
| R3 | 7 | FS,13,12,7,5,3,10,FS | 4.9 Km | 7 min | 14 min | 3 |
| R4 | 4 | 13,3,1,10,13 | 6.51 Km | 4 min | 14 min | 4 |
| **Total** | **24** | | **20.16 Km** | **24 min** | **54 min** | **11** |

**Table 10:** AD-D Male routes details

| Male Routes Name | Number of stations | Sequence of shuttle travel | Distance of the route | Bus waiting time | Time of the route | Number of bus used in the route |
|---|---|---|---|---|---|---|
| R1 | 6 | MS,20,19,18,17,16, MS | 5.08Km | 6 min | 14 min | 3 |
| R2 | 4 | MS,16,15,14,MS | 2.16 Km | 4 min | 7 min | 1 |
| R3 | 5 | MH,19,18,17,20,MH | 6 Km | 5 min | 14 min | 3 |
| R4 | 5 | MH,15,14,20,19,MH | 7.36 Km | 5 min | 16 min | 4 |
| **Total** | **20** | | **20.594 Km** | **20 min** | **51 min** | **11** |

*Customer Flow Design (CF-D):*

In this alternative, Customers' flow was observed at the peak hours per day to show where the most populated areas are and to locate stations on that base. This was shown via representing the movement flow of customers as arrows on Qatar University master plan. The head of the arrow shows the direction of the movement of the population. The area which has group of arrows directed towards the same point will give an indication that the flow in this area is high and a station should be placed on this point. On the other hand, individual and separated arrows shows that low frequent people move in this area, which indicate a low flow area that does not require stations. Figure 4 shows this alternative, as two colored arrows were drawn – red and blue arrows. Red arrows represent female flow and blue arrows show male flow.


**Figure 4:** Design Alternative 3 (CF-D)

Tables below illustrate the important data of this alternative design solution. The details of served buildings by both genders' stations and the routes details for each gender. Refer to Appendix A for building names with building ID.

**Table 11:** CF-D Covered buildings by each female station:

| Female Station No. | Covered buildings |
|---|---|
| 11 | C01, C05, D01,C04 |
| 12 | C06,C07, C04, D04 |
| 13 | D01,C11, D05 |
| 14 | C12 |
| 15 | H08 |
| 16 | NCEn,B13 |
| 17 | D06,D03,D04 |
| 18 | NCEd, NSA |
| 19 | NCL,JHC |
| 20 | I03 |
| 21 | COF, NCM |

**Table 12:**CF-D Covered buildings by each male station:

| Male Station No. | Covered buildings |
|---|---|
| 1 | A01,A02,A03,A04 |
| 2 | B01,B02, B03,B05,B06,BCR,B04, |
| 3 | A05, A06, A04 |
| 4 | B10, B11,B12,B13,B09 |
| 5 | H12 |
| 6 | H10 |
| 7 | NCEn |
| 8 | H08,I03 |
| 9 | NCM |
| 10 | NCL |

**Table 13:** CF-D Female routes details:

| Female Routes Name | Number of stations | Sequence of shuttle travel | Distance of the route | Bus waiting time | Time of the route | Number of bus used in the route |
|---|---|---|---|---|---|---|
| R1 | 5 | FS, 16, 15, 18,19,FS | 3.3 Km | 5 min | 10 min | 2 |
| R2 | 6 | FS,17,13,11,12,14,FS | 4 Km | 6 min | 12min | 2 |
| R3 | 4 | 16,15,20,FH,16 | 6 Km | 4 min | 13 min | 4 |
| R4 | 5 | FS,21,19,FH,13,FS | 7.3 Km | 5 min | 16 min | 4 |
| Total | 20 | | 20.6 Km | 20 min | 51 min | 12 |

**Table 14:** CF-D Male routes details

| Male Routes Name | Number of stations | Sequence of shuttle travel | Distance of the route | Bus waiting time | Time of the route | Number of bus used in the route |
|---|---|---|---|---|---|---|
| R1 | 7 | MS,9,10,HM,1,3,5,MS | 7.12 Km | 7 min | 18 min | 4 |
| R2 | 5 | MS,6,4,2,5,MS | 2.96 Km | 5 min | 9 min | 1 |
| R3 | 4 | MS,9,8,7,MS | 3.61 Km | 4 min | 9 min | 2 |
| R4 | 5 | MH,8,7,9,10,MH | 5.81 Km | 5 min | 14 min | 3 |
| Total | 21 | | 19.5 Km | 21 min | 50 min | 10 |

## 2.2 Analyze each potential solution

After developing the design alternatives, some criteria are generated to evaluate each design alternative. A decision matrix is used to compare the design alternatives using the criteria.

**Design Selection Criteria**
Design selection criteria are determined after setting the design specifications and objectives. These criteria will be used to compare between the three alternatives and choose the best alternative. There are two types of criteria- quantitative and qualitative criteria.

**1- Quantitative criteria Evaluation:** Quantitative criteria are the criteria that require numbers to do the assessment and compare between the alternatives.

Operational cost: This cost considers the consumed gas per bus that will be calculated with assuming 40 km/h as a speed for each bus and estimating the gas consumed per each bus in each day from the distance travelled. Further, the operational cost includes also the rented shuttles cost as these shuttles are not bought, but rented from certain company with the driver. Operational cost for each alternative was calculated using some data related to each alternative, for instance the type of the buses used in QU – Toyota coaster has a fuel capacity of 95 liters. Comparing these alternatives will focus only in the students' shuttles, as the employee shuttles are the same in every alternative therefore, there is no point of comparing in terms of employees shuttles. Further, the price of fuel consumption per each liter is QR 1.6/liter since this type of bus is using diesel and this number is stated by the Ministry of Energy and Industry in Qatar. The following tables show the operational cost for each alternative:

**Table 15:** Total Operational cost for Alternative 1 (BD-D)

| Total Fuel Consumption cost (QR/month) | Total Rental cost/day (QR/month) | Total Operational cost (QR/month) |
|---|---|---|
| 49782.86 | 288838 | 338620.86 |

**Table 16:** Total Operational cost for Alternative 2 (AD-D)

| Total Fuel Consumption cost (QR/month) | Total Rental cost/day (QR/month) | Total Operational cost (QR/month) |
|---|---|---|
| 63360.00 | 334444 | 397804.00 |

**Table 17:** Total Operational Cost for Alternative 3 (CF-D)

| Total Fuel Consumption cost (QR/month) | Total Rental cost/day (QR/month) | Total Operational cost (QR/month) |
|---|---|---|
| 63360.00 | 334444 | 397804.00 |

The following table shows the total operational cost for different alternatives:

**Table 18:** Total Operational cost for different alternatives

| Criteria | Alternative 1 (BD-D) | Alternative 2 (AD-D) | Alternative 3 (CF-D) |
|---|---|---|---|
| **Total Operational cost (QR/month)** | 338620.86 | 397804 | 397804 |

Installation cost: Installation cost is obtained from the transportation department in the university in which one station is being installed with a cost of around QR 80,000. Then, based on the number of stations the total installation cost will be calculated by multiplying the number of stations by the installation cost/station.

**Table 19:** Installation cost for each alternative

| Alternatives | Number of stations | Installation cost/station (QR/station) | Total Installations cost (QR) |
|---|---|---|---|
| Alternative 1 | 17 | 80,000 | 1,360,000 |
| Alternative 2 | 20 | 80,000 | 1,600,000 |
| Alternative 3 | 22 | 80,000 | 1,760,000 |

Quantitative Evaluation matrix between alternatives

Based on the values obtained from the operational and Installation costs, the following matrix was formed and team members gave score to each alternative, the score is from 1 to 5 in which 1 is poor and 5 is the best. Team members agreed on the same value for each score, then total score is obtained based on the score.

**Table 20:** Evaluation Matrix of alternatives

| Criteria | Design Alternatives | | |
|---|---|---|---|
| | Alternative 1 (BD-D) | Alternative 2 (AD-D) | Alternative 3 (CF-D) |
| **Operational Cost** | 5 | 2 | 2 |
| **Installation Cost** | 5 | 4 | 2 |
| **Total Score** | 10 | 6 | 4 |

From the evaluation matrix, it is clear that alternative 1 has the highest score in terms of cost. This gives an indication that implementing this design will not cost much as implementing either alternative 2 or 3.

**2- Qualitative criteria Evaluation:**

These criteria are criteria that are not measured numerically, but by observations of the system design. Qualitative criteria that will be used to compare between alternatives are listed below:

- Serve-ability of stations locations

Serve-ability of stations locations is by checking the total covered buildings by stations in each alternative. The following table shows the buildings being covered by stations in each alternative, the total number of buildings in Qatar University, and the percentage of covered buildings by stations in the University.

**Table 21:** Percentage of covered buildings per each alternative

| Criteria | Alternative 1 (BD-D) | Alternative 2 (AD-D) | Alternative 3 (CF-D) |
|---|---|---|---|
| **Total covered buildings by stations** | 51 | 31 | 42 |
| **Total number of building in QU** | 62 | 62 | 62 |
| **Percentage of covered buildings (%)** | 82 | 50 | 68 |

- Serve-ability of rail station

This is by checking all the routes in which the shuttle will stop at the rail station, then estimate the number of stations covered per each route. After that, the covered stations are compared to the total stations found in each alternative to get the percentage of covered stations. The following table illustrates the percentage of covered stations that pass by the rail station per each alternative.

**Table 22:** Percentage of covered stations per each alternative

| Criteria | Alternative 1 (BD-D) | Alternative 2 (AD-D) | Alternative 3 (CF-D) |
|---|---|---|---|
| **Total covered stations by routes pass by the rail** | 16 | 17 | 20 |
| **Total number of stations** | 17 | 20 | 22 |
| **Percentage of covered stations (%)** | 94 | 85 | 91 |

Qualitative comparison between alternatives

Table 23 shows the qualitative comparison between alternatives, the comparison was mainly due to the results obtained from tables 21 and 22.

**Table 23:** Qualitative Comparison between alternatives

| Criteria | Alternative 1 (BD-D) | Alternative 2 (AD-D) | Alternative 3 (CF-D) |
|---|---|---|---|
| **Serve-ability of stations locations** | Highest covered buildings by the stations, this makes it the best choice among alternative in terms of covered building. Another advantage added to this is that this alternative got the lowest number of stations that are able to cover highest percentage of the buildings in QU. | This alternative got the lowest percentage of covered building, which means that this alternative is not useful in terms of covered buildings because all stations are covering only 50% of the buildings. | Using the (CF-D) design will ensure covering around 68% of the buildings by stations. Therefore, comparing this percentage to 82%, which found in the first alternative, we could say that this alternative is not led preferred than the first alternative. |
| **Serve-ability of rail station** | Alternative 1 got the highest percentage in terms of covered stations by the routes passing by the rail station. Therefore, this alternative is most preferable in terms of covered stations by shuttle passing by the rail station. | Alternative 2 got also the lowest percentage of covered stations per routes passing by the rail. This also means that this station is least preferred in terms of covered stations. | In terms of covered stations, this alternative was relatively close to the first alternative since the difference is only 3%. However, alternative 3 used more stations than the first alternative, which makes it a less preferable choice in terms of cost, and stations covered than the first station. |

Based on both evaluation types, it has been concluded that design alternative 1 – Building Density-Based Design (BD-D) got the highest rank among all alternatives. This means that the best solution is BD-D and it will be implemented.

To implement the prototype, two software programs were used- ProModel® and Matlab. In ProModel® one route was constructed to show how will the bus move and at which points it will stop. Further, for all the routes Matlab was used. ProModel® Software is used to simulate the system and analyze the performance of the system by analyze the movement of people and shuttles around the University. ProModel® shows the average waiting time in bus stations and other details related to the average time and number of people. Figure 5 shows the implemented Male Students/Visitors route using ProModel®, which shows the movement of the bus that carries male students between stations. Further, Matlab code was constructed to simulate the system. The code simulates one cycle per route in one run; therefore, 5 replications were simulated for each route for accuracy purpose. Simulation results were concluded from Matlab software that showed the average waiting time, blocked customers, the times that the bus blocked and many results. This design solution considered everyone in Qatar University- students, faculty members, staff, and visitors.

**Figure 5:** Male Route on ProModel

## 3 Discussion

It is difficult to compare between the current shuttle transport system and the new designed shuttle system since the new shuttle system will be integrated with the Qatar rail terminal, where the shuttles will carry the students and faculty members from the terminal to their required buildings. For the current station, there are more types of buses for female campus than the male campus. The current shuttle transport system only serves female and male students without considering the staff, faculty members, and visitors. Therefore, faculty, staff, and visitors will find it difficult to reach to their desired buildings because of not having a shuttle buses that will carry them as well as the congestion they face along the roadway to their required building. Further, there are several stations in Qatar University besides each building. These stations are the waiting area for people who will use the shuttle buses. Additionally, the current shuttle transport system does not serve the buildings based on their population, where traffic congestions mostly found close to certain buildings where the population is high, such as College of Science and College of Business. Thus, the current shuttle transport system will not be able to accommodate the increasingly population density in Qatar University after some years. Whereas, the new designed shuttle transportation system will be integrated with the rail station that will be in Qatar University to encourage people to use the railway rather than using their own cars and to adapt the large population size. The new shuttle transportation system will consider the current buildings and the upcoming buildings as well. In addition, it will consider the students and employees to use the shuttle buses. Further, stations will be close and reachable to customers and located in a location that will cover several buildings. The implementation of this design solution will assists in reducing the traffic congestions in Qatar University, integrating the upcoming buildings with the existing ones, and integrating the rail service with the current shuttle transportation system.

## 4 Conclusions and Future Work

### 4.1 Conclusions and Recommendations

In this paper, a system is designed based on the population in buildings that aims to integrated shuttle transportation system with the rail service in Qatar University, which is Building Density-Based Design (BD-D). This step will encourage people in Qatar University to use the rail service and hence will reduce the traffic congestion in Qatar University roads. Building Density-Based Design (BD-D) considers the population of the buildings in which stations are located close to the high-populated buildings. Stations were located as follows: 11 stations for Female Students/Visitors and 6 stations for Male students/Visitors, each station serves many buildings. Faculty members and staff do not have stations; rather they have stopping points in certain buildings. The reason behind this is that faculty members and staff population is low compared to students' population and they are flexible in their transitions, in which they can order the shuttle at any time they prefer to carry them to their desired location. Routes were assigned based on brainstorming by team members in which trial and error was used to determine the best routing that will pass by most stations. Female students/visitors have 4 routes, Male Students/visitors have 4 routes, Female Faculty/Staff has 1 route, and Male Faculty/Staff have 1 route. Each route serves many stations in the University including the rail station. Further, Number of buses was defined based on the distance for each route, for example if the total distance of the route is more than 6 km then 4 buses are specified for this route, if the distance between 4.5 km to 6 km then 3 buses are specified for this route, and so on. Therefore, Female Students/Visitors have 9 buses; Male Students/Visitors have 10 buses, and two buses for faculty members and staff, one bus for each gender.

Based on the designed solution, some recommendations have been made to the transportation department in Qatar University as follows:

- Transportation department should put in consideration to construct the station in vacation period, to ensure that these stations are ready to use in the official working days.
- For the stations that are located in a way that will have crossroads, crosswalk should be provided for pedestrian safety as per the Environment, Health, and Safety Technical Guideline, Driving and Pedestrian Safety Standards and regulations that states that cross walk mark should be identified to minimize the risk of accidents.
- For each crosswalk located on the main road, traffic signals should be provided to ensure pedestrian safety.
- For each bus stop, there should be a specific parking for the buses to increase people's safety and not to interrupt any coming vehicle.

**4.2 Future Work**

- To improve quality service, a mobile-based application can be designed that will let customers know where is the nearest station and at what time the shuttle will arrive at any station. Further, this mobile-based application will help the shuttle service's customers in 1) real-time tracking of the shuttle movement, 2) identify the nearest shuttle station, and 3) providing the shortest route for customers to arrive a certain station.
- The implementation of the proposed design could be improved by designing stations with solar panels to ensure sustainability of these stations that could work for longer time, reduce the billing cost by reducing the amount of electricity used, and using clean electricity that is eco-friendly rather than the electricity coming from the fossil fuel.
- For further environmental benefits, the implementation of the designed solution could have electrical buses rather than the regular ones that use fuel. This will save the atmosphere by reducing the emission of the hazardous gases coming from the fuel in the regular buses.

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# Appendix A: QU Building Details

| Building ID | Building Type | Building Name |
|---|---|---|
| NAA | Administrative | New Administrative Affairs |
| B01 | Administrative | Higher Administration |
| A05 | Administrative | Human Resources building |
| C03 | Administrative | Faculty office building |
| C12 | Administrative | Admission and Registration Building |
| C08 | Administrative | Campus Facilities Department |
| F01 | Administrative | Security Service Building |
| I02 | Administrative | Central and Maintenance Store |
| C09 | Administrative | Central Service Unit |
| NSA | Educational | New students Affairs building (M) |
| NSA | Educational | New students Affairs building (F) |
| NCM | Educational | New College of medicine and health science (F) |
| C01 | Educational | Female College of Arts & Sciences |
| BCR | Educational | Corridors A-J |
| H08 | Educational | College of Business and Economics (F) |
| NCEd | Educational | New College of Education (F) |
| NCEn | Educational | New College of Engineering (Male) |
| B04 | Educational | College of Education (F) |
| NCEn | Educational | New College of Engineering (Female) |
| C07 | Educational | College of Engineering - Women |
| C04 | Educational | Main Women's Building |
| H08 | Educational | College of Business and Economics (M) |
| D06 | Educational | Female Classroom Building |
| NCM | Educational | New College of medicine and health science (M) |
| I03 | Educational | New college of law (F) |
| B13 | Educational | Library building (F) |
| B05 | Educational | Main men’s building |
| D05 | Educational | Women's Foundation |
| NCP | Educational | New College of Pharmacy |
| C11 | Educational | College of Sharia and Islamic Studies |
| B13 | Educational | Library building (M) |
| I03 | Educational | New college of law (M) |
| D01 | Educational | Al Bidaa Building |
| A06 | Educational | Men’s Foundation |
| H10 | Educational | Research Complex Building |
| NCEd | Educational | New College of Education (M) |
| H12 | Educational | College of Medicine |
| B04 | Educational | College of Education (M) |
| B07 | Educational | Engineering workshop |
| FH | Service | Female Housing (F) |
| MH | Service | Male Housing (M) |
| D04 | Service | Women's Food Court |
| B03 | Service | Information Technology services |
| B02 | Service | Men’s Activity Center |
| B12 | Service | Mosque |
| C05 | Service | Women's Activity Centre |
| JHC | Service | New Aljama Health Care (F) |
| JHC | Service | New Aljama Health Care (M) |
| C06 | Service | Medical Clinic (W) |
| B10 | Service | Qatar National Bank |
| B11 | Service | Ibn khaldoon Multi-purpose Hall |
| H09 | Service | Central Service Unit #2 |
| B06 | Service | Engineering Annex |
| B09 | Service | CEng research center |
| A04 | Service | Swimming pool pavilion |
| D03 | Service | Women's Sport Facility |
| A03 | Service | Tennis court pavilion |
| D02 | Service | Women's Car Park Arena |
| A01 | Service | Arena pavilion complex |
| A02 | Service | Male court pavilion |
| B08 | Service | Green house |
| MS | Service | Male shuttle rail station |
| FS | Service | Female shuttle rail station |