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Research Article

Study on CNG filling station distribution in an inter-city network

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Abstract

The current world is following strategies to exit from energy crisis. In Bangladesh changing the vehicle fuel to the Compressed Natural Gas (CNG) is the priority enforcement. Recently, the number of CNG fuel based vehicles in Bangladesh is growing rapidly due to low price and availability of CNG. This change needs some planned substructures. One of the most important substructures is the CNG refueling stations distributions. Necessity of making a systematic process to locate CNG stations is vital because at present there is no fixed system to locate CNG stations throughout the country. This research estimate the optimum number of CNG stations in the selected intercity network and present an investigation prevailing queuing system and performance of the existing CNG filling stations. Simulation of single server queuing system is used for this purpose. On the basis of investigation and results from analysis suggestions are put forward to improve the situation.

Keywords: Compressed Natural Gas (CNG) Vehicles, CNG Refueling Station, Single Server Queuing System, Fuel Demand Method, transportation, Bangladesh

Introduction

In the last decades, air pollution has become a major problem in metropolises. Therefore using alternatives for common fuels, especially gasoline was ordered. In a country like Bangladesh, with huge natural gas resources, compressed natural gas (CNG) is the most important choice. Off all human activities, driving motor vehicles produces the CO_2 emission and other toxic gases. A single tank gasoline releases 140 to 180 kilograms CO_2. However CNG releases about one quarter to one third less CO_2 than petroleum fuels [1]. Some of the noxious emissions are less than this. Again, the use of CNG fuel as an alternative to the conventional fuel in public and private transport vehicles benefits by reducing air pollutants like carbon monoxide and particulates [2, 3].

Like China and India, in Bangladesh, various conservative measures or strategies are being considered by the Government in order to deal with the environmental problems. One of these strategies is to millions of vehicles used in public fleet including private car, passenger car, microbus, three-wheeler, trucks from gasoline to CNG. This conversion will bring significant economic and environmental benefits of the country; will reduce dependency on the imported fuels, increasing national security and lowering foreign trade deficit [4]. Due to the government strategic policy the CNG-run vehicles is rapidly increasing throughout the country. The country is saving around Tk. 3.91 billion a month, in terms of fuel oil import, from increased use of CNG by motorized vehicles. Over 1,77,555 vehicles have until December 2009 switched over to CNG. As a result the number of CNG refueling stations is growing in keeping pace with the ever-increasing demand. Currently, there are about 500 CNG refueling stations in around the country. Among them 213 have started operation during 2008-2009 fiscal year (FY) [5]. A planned network/distribution of CNG refueling stations is the present demand in this sector due to the rapid growing of CNG-run vehicles and CNG refueling stations. To find the better location pattern of CNG filling stations, the optimum number of stations in the intercity network should be known first. In this research, the optimum number of CNG stations in selected intercity network is estimated using the fuel demand method.

Waiting or queuing is a common phenomenon in service organization like CNG filling stations. In general, the vehicles do not like to wait in the filling station. But reduction of the waiting time usually requires extra investment. To decide whether or not to invest, it is important to know the performance of the existing distribution system. So we need models and techniques to analyze such situations [6]. Though the queuing analysis is performed in different hospitals and dental clinics [7] in Bangladesh but first time this research treats single server queuing system to analyze the performance of the existing CNG refueling stations. Our attention is restricted to models with single queue and single server. The results find that there is an unplanned location of CNG filling stations in two intercity networks and suggest the optimum number of CNG refueling stations in that intercity network.

CNG Expansion Activities in Bangladesh

Natural gas is major source of energy for Bangladesh meeting 70% fuel requirements of the country. The country has witnessed a tremendous growth of compressed natural gas-run vehicles in the recent years (Figures 1 and 2). A sizeable number of gasoline-run vehicles have been converted to CNG-run vehicles. The rising cost of auto fuel in the recent years contributes to conversion of vehicles engines to CNG. This growth of CNG-run vehicles contributes to the rapid growth of CNG filling stations and workshops (Figures 3 and 4).

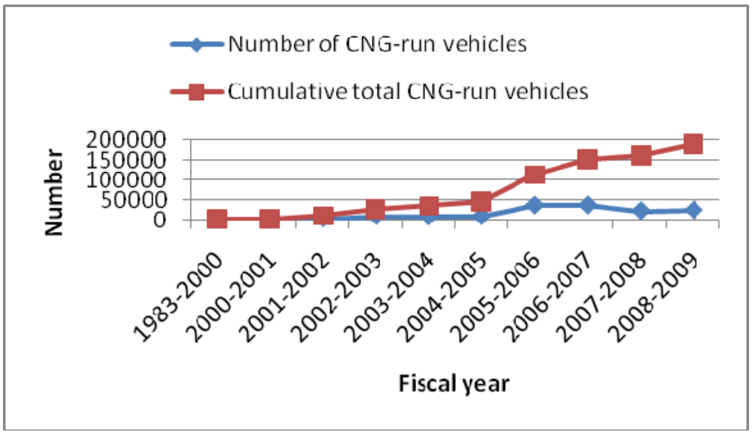

Figure 1. CNG-run vehicles growth between 1983 and 2009 [source: RPGCL].

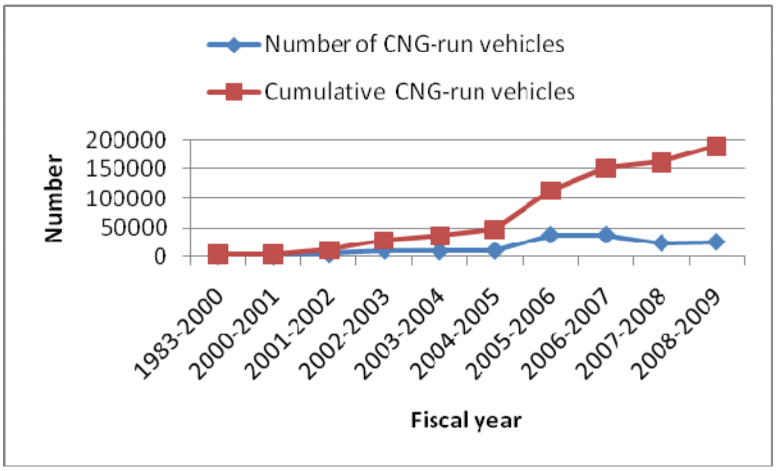

Figure 2. Converted vehicle growth between 1983 and 2009 [source: RPGCL].

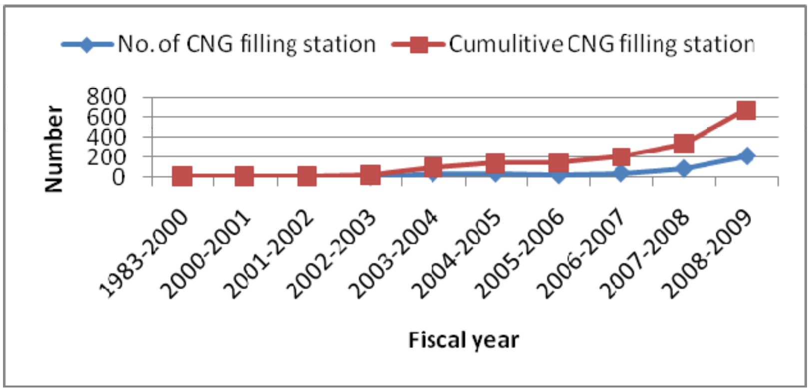

Figure 3. CNG filling station growth between 1983 and 2009 [source: RPGCL].

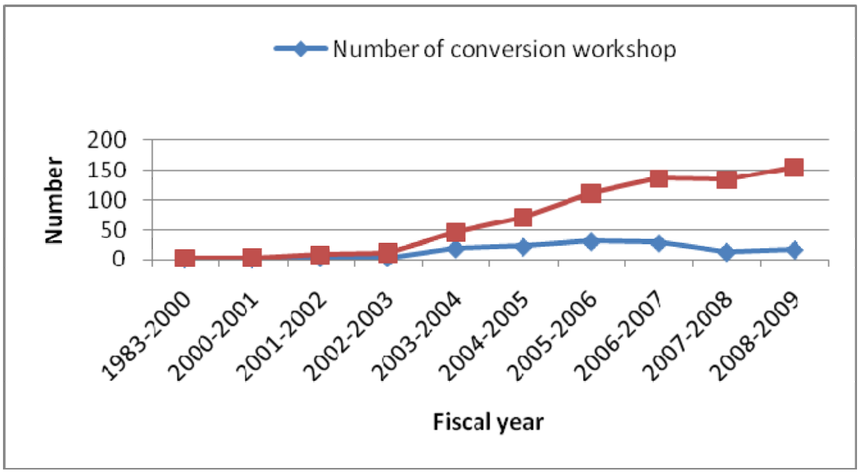

Figure 4. CNG workshop growth between 1983 and 2009 [source: RPGCL].

Materials and Methodology

For the proper distribution of CNG filling stations, the need of using case-study is obligated. So two intercity networks, Sylhet-Jaflong and Sylhet-Dhaka are chosen as case study. In order to estimate the optimum number of CNG stations in these roads, this research used an estimated fuel demand method to estimate demand of total fuel amount. A single server queuing system is used to measure the performance of the stations. The two methods are explained below.

Estimated Fuel Demand Method

For determining the number of CNG stations on the road, the demand of fuel amount should be estimated. For estimating the fuel demand in the selected road, there should be use of machines measurement kilometer and fuel consumption average of different vehicles in the road network to the following equation:

$$D = \sum (L_l T_{vl}) \eta_v \quad \textbf{(1)}$$

where,

l is road index, v is vehicle type index, L_l is length of road l, T_{vl} is amount of passing vehicles in type of v in the way of a distinguish time output and η_v is the amount of vehicle special fuel consumption from type of v in the distance unit.

According to the capacity of a standard fueling station, the amount of required CNG station would be calculated by the following equation [4]:

$$NR = \frac{D}{SC} \quad \textbf{(2)}$$

where, NS is amount of required CNG station in the a study range, D is total estimated demand in study range and SC capacity of a CNG station for preparing the fuel demand.

A single server queuing system [8]

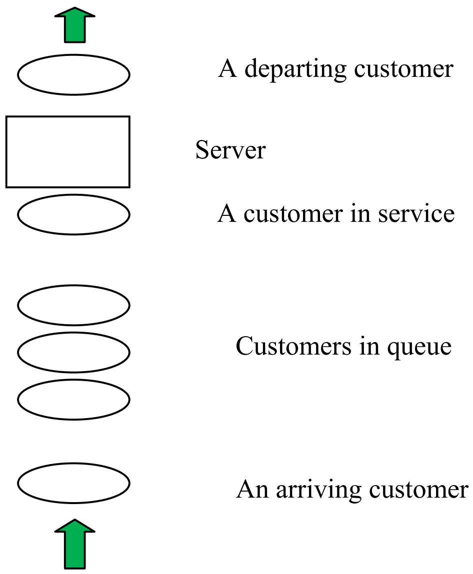

Figure 5. A single-server queuing system.

A queuing system can be simple described as customers arriving for service, waiting for service if it is not immediate and if having waited for service, leaving the system after being served [9, 10, 11]. Consider a single server queuing system (Figure 5) for which the inter arrival times A_1, A_2 . . . are Independent and Identically Distributed (IID) random variables. A customer who arrives and finds the server idle enters service immediately and the service times S_1, S_2, of the successive customers are IID random variables that are independent of the inter-arrival times. A customer who arrives and finds the server busy joins the end of a single queue. Upon completing service for a customer, the server chooses a customer from the queue in a first-in, first-out (FIFO) manner. Firstly, we will estimate the expected average delay in queue of the *n* customers completing their delays during the simulation time; we denote this quantity by *d (n)*. From a single run of the simulation resulting in customer delays $D_1, D_2, \cdots, D_n$ an obvious estimator of $d(n)$ is

$$\hat{d}(n) = \frac{\sum_{i=0}^{n} D_i}{n} \qquad \textbf{(3)}$$

This is just the average of the n D_i's that was observed in the simulation.

Secondly, we will estimate the expected average number of customers in the queue which is denoted by *q (n)*. Let *Q (t)* denote the number of customers in queue at time *t*, for any real number, $t \geq 0$ and let $T(n)$ be the time required to observe our n delays in queue. If we let p_i be the expected *proportion* of the time that $Q(t)$ is equal to *i*, then a reasonable definition of $q(n)$ would be

$$q(n) = \sum_{i=0}^{n} ip_i \quad \textbf{(4)}$$

Thus, $q(n)$ is a weighted average of the possible values i for the queue length $Q(t)$. To estimated $q(n)$ from a simulation, we simply replace the p_i's with estimates of them, and get

$$\hat{q}(n) = \sum_{i=0}^{n} i\hat{p}_i \quad \textbf{(5)}$$

Where $\hat{p}_i$, the observed (rather than expected) is proportion of the time *during the simulation* that were i customers in the queue.

If we let T_i be the *total* time during simulation that queue is of length i, then $T(n) = T_0 + T_1 + T_2 + T_3 \cdots$ and $p_i = \frac{T_i}{T(n)}$ so that we can rewrite equation (5) above as

$$\hat{q}(n) = \sum_{i=0}^{n} \frac{iT_i}{T(n)} \quad \textbf{(6)}$$

Finally, we will estimate the performance of this system which is the *total utilization* of the server. This *utilization* of the server is a measure of how busy the server is.

Table 1. Vehicles run on Sylhet-Jaflong road (Length: 57 km).

Type T_{vi}	**Number** (per day)	**Fuel consumption** (per metre), η_v (m^3)
four stroke	2750	4.07×10^{-5}
car / micro	1140	4.07×10^{-5}
Laguna	600	4.07×10^{-5}
bus	600	1×10^{-4}
truck	468	1×10^{-4}

Table 2. Vehicles run on Sylhet-Kanaighat road (Length: 54 km).

Type T_{vi}	**Number** (per day)	**Fuel consumption** (per metre), η_v (m^3)
four stroke	144	4.07×10^{-5}
car / micro	70	4.07×10^{-5}
Laguna	96	4.07×10^{-5}
bus	96	1×10^{-4}
truck	48	1×10^{-4}

The *utilization* of the server is denoted by $u(n)$. The proportion of time the server is busy is defining the "busy function".

$$B(t) = \begin{cases} 1 & \text{if the Server is busy at time } t \\ 0 & \text{if the Server is idle at time } t \end{cases}$$

Since the height of *B (t)* is always either 0 or 1. Thus,

$$\hat{u}(n) = \int_0^{T(n)} \frac{B(t)dt}{T(n)} \qquad \textbf{(7)}$$

Here, we can see that $\hat{u}(n)$ is the continuous average of $B(t)$ function.

Data Analysis and Results

Data are collected from two different intercity roads, Sylhet-Jaflong road and Dhaka-Sylhet road.

Case 1: Sylhet-Jaflong road

Fuel demand estimation

The total distance of the Sylhet-Jaflong road is 57 km. There are seven CNG stations in this road. These seven CNG stations are situated within 8.5 km from the sylhet side. But there is no CNG station in rest of 48.5 km.

In this road to determine the number of CNG stations required to fulfill the demand, the total number of vehicles runs in three links: Sylhet-Jaflong, Sylhet-Kanaighat and Sylhet-Gowainghat are collected and shown in Tables 1, 2 and 3.

So, the Fuel Demand for Sylhet-Jaflong Network:

$D_1 = (57 \times 2750 \times 0.0407) + (57\times 1140\times0.0407)$
$+ (57\times600\times0.0407) + (57\times600\times0.1) +$
$(57\times468\times0.1)$
$= 16503.951 \text{ m}^3$

Again, the Fuel Demand for Sylhet-Kanaighat Network, $D_2 = 1458.918 \text{ m}^3$ and the Fuel Demand for Sylhet-Gowainghat Network, $D_3 = 1481.5832 \text{ m}^3$

There are number of buses or trucks are run by diesel or petrol. The diesel run buses are T_{v1} =228 and diesel run-trucks are T_{v2} =1560. If all diesel-run vehicles are converted into CNG-run vehicles, then fuel demand,

$D_4 = (57\times228\times0.1) + (57\times1560\times0.1) = 10191.6 \text{ m}^3$

Total fuel demand according to the equation (1):

$D = D_1 + D_2 + D_3 + D_4$
$= (16503.591 + 1458.918 + 1481.5832 +$
$10191.6) \text{ m}^3 = 29635.6922 \text{ m}^3$

Now, according to the capacity of a standard fueling station, the fuel capacity of a CNG station is equal 730 m^3/ hr, i.e. 17520 m^3/ day.

So, the amount of required CNG station in the Sylhet-Jaflong road according to equation (2):

$$= \frac{28635.6922}{17520}$$

$$= 1.69 \approx 2$$

Table 3: Vehicles run on Sylhet-Gowainghat road (Length: 53 km).

Type T_{vi}	**Number** (per day)	**Fuel consumption** (per metre), η_v (m^3)
four stroke	192	4.07×10^{-5}
car / micro	56	4.07×10^{-5}
Laguna	144	4.07×10^{-5}
bus	96	1×10^{-4}
truck	24	1×10^{-4}

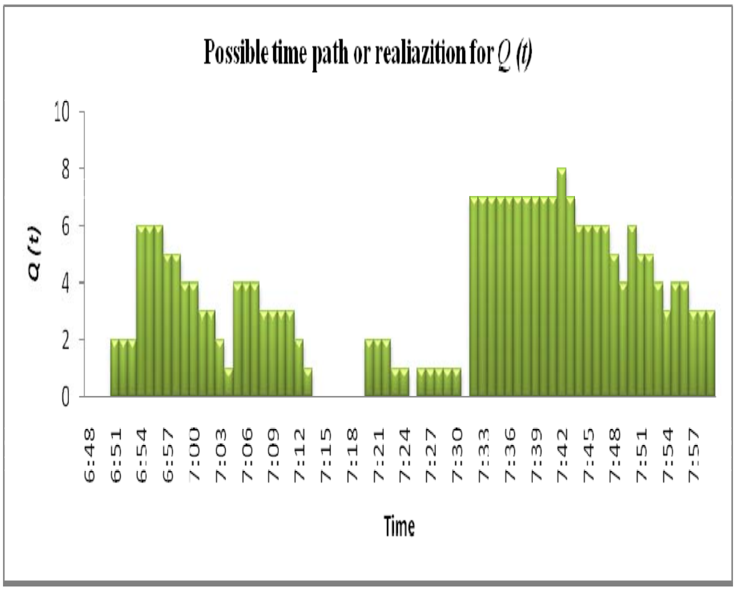

Figure 6. *Q (t)*, arrival time and departure time for a realization of a single server queuing system Station 1 in Sylhet-Jaflong Network.

The estimated number of CNG stations in Sylhet-Jaflong network found is this research is 2 while there are currently 7 existing.

Next, we calculate the average number of customers, average delay and the total utilization of the CNG station server using the simulation techniques discussed in the previous section. For this, the calculation is taken from collected data of 4 stations situated in Sylhet-Jaflong road. Calculation for station 1 is shown.

Calculation for Average Number of Customers

The collected data of station 1 in Sylhet-Jaflong network describes the different arrivals and departure time and the simulation ends at time,

$T(47) = 72$.

Figure 6 illustrates a possible time path, or realization, of *Q (t)* for this system in the case of *n* = 47. Remember in looking at Figure 6 that *Q(t)* does not count the customer in service(if any), so between times 6:51 and 6:54 there is two customers in the system being served, even though the queue is empty [*Q(t)*=0];. To compute *q (n)* we must first compute the T_i's, which can be read off figures as the interval over which *Q (t)* is equal to 0, 1, 2, and so on:

From Figure-6 we get,

T_0 = (6:51-6:48) + (7:20-7:14) + (7:26-7:25) + (7:32-7:31)
= 3+6+1+1 =11

T_1 = (7:05-7:04) + (7:14-7:13) + (7:25-7:23) + (7:31-7:26) = 1+1+2+5 = 9

$T_2 = 8$, $T_3 = 10$, $T_4 = 9$, $T_5 = 5$, $T_6 = 8$, $T_7 = 11$ and $T_8 = 1$

So, the numerator in equation (6)

$\sum_{i=0}^{n} iTi$ = (0×11) + (1×9) + (2×8) + (3×10) + (4×9) + (5×5) + (6×8) + (7×11) + (8×1)
= 9+16+30+36+25+48+77+8 = 249

And,

$T(n) = T_0+T_1+T_2+T_3+T_4+T_5+T_6+T_7+T_8$
= 72

And our estimate of the time average number in queue from this particular simulation is

$$\hat{q}(n) = \frac{\sum_{i=0}^{n} iTi}{T(n)} = \frac{249}{72} = 3.46$$

So, the expected average customer in the queue = 3.46

Calculation for Average Delay

From collected data of station 1 we get,

The total delay = 227 min

The total number of customer, *n* = 47

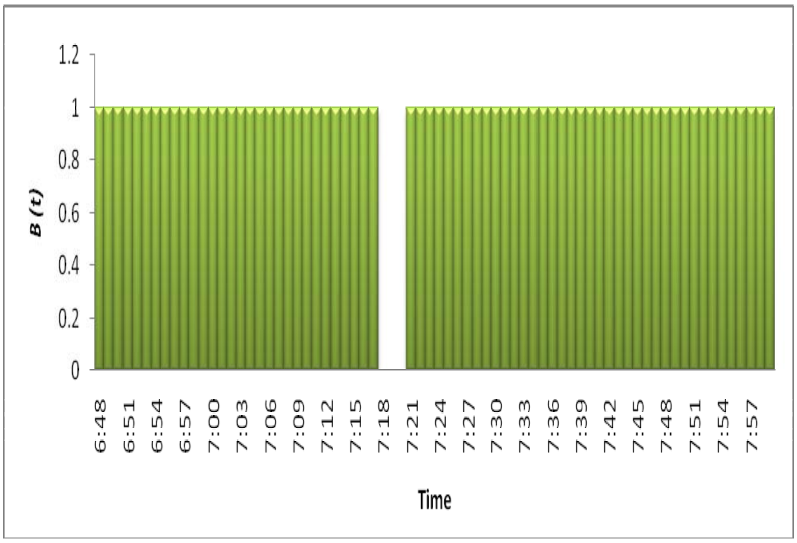

Figure 7. ***B (t)*****, arrival time and departure time for a realization of a single server queuing system of station 1 in Sylhet-Jaflong Network.**

Table 4. Server Performance (Sylhet-Jaflong).

Stations in Sylhet-Jaflong Network	**Average Delay** (Min)	**Average Number of Customers in queue**	**Utilization %**
Station 1	4.83	3.46	95.8%
Station 2	4.49	4.03	93.5%
Station 3	0.38	0.0731	43.90%
Station 4	1.7	2.56	68.2%

So the average delay $= \frac{227}{47} = 4.83\text{min}.$

Calculation for Total Utilization

The utilization could be expressed as the proportion of time that "busy function", *B (t)* is equal to 1. Figure-7 plots *B (t)* for the same simulation realization as used in figure 2 for *Q (t)*. In this case we get, Utilization,

$$\hat{u}(n) = \frac{(7:17 - 6:48) + (7:59 - 7:20)}{72}$$

$$= \frac{30+39}{72}$$

$$= 0.958$$

$$= 95.8\%$$

i.e. the server was busy about 95.8% of the time during this simulation.

Table 5. Vehicles run in Sylhet-Dhaka road (Length: 265 km).

Type T_{vi}	**Number** (per day)	**Fuel consumption** (per metre), η_v (m^3)
four stroke	6500	4.07×10^{-5}
car / micro	4500	4.07×10^{-5}
Laguna	6800	4.07×10^{-5}
bus	3500	1×10^{-4}
truck	2100	1×10^{-4}

The overall scenario of four CNG filling stations in Sylhet-Jaflong network is shown in Table 4. The results of Table 4 show that no stations are fully utilized. This support the results found in section 4.1 that there is excess CNG stations in this particular road.

Case 2: Analysis for Sylhet-Dhaka Network

We did the same calculation in Sylhet-Dhaka road. The length of the road is 265 km. But the four strokes and leguna do not travel the total length. They travel a limited distance in the local city. The average travelling distances are about to 80 km. The numbers of vehicles are mentioned below.

There are a number of buses or trucks run by diesel/petrol on that road. The number of buses or trucks is approximately:
Total number of buses = 2900 (run by diesel)
Total number of trucks = 3300 (run by diesel)

The fuel demand for Sylhet-Dhaka Network is estimated to 404539.55 m^3 and the number of required CNG station on the basis of calculated demand in Sylhet-Dhaka road is equal to twenty four stations.

According to the existence of twenty one CNG stations in the road so there is need of locating and constructing three other stations. We see that among the 21 CNG station, 18 are located in the part 85 km from Dhaka side and 3 are located in the remaining 180 km part (Bhairan-Sylhet road). For this reason we also estimate the optimum number of CNG station in Bhairab-Sylhet road.

Table 6. Vehicles run in Sylhet-Bhairab road (Length: 180 km).

Type T_{vi}	**Number** (per day)	**Fuel consumption** (per metre), η_v (m^3)
four stroke	1000	4.07×10^{-5}
car / micro	4500	4.07×10^{-5}
Laguna	1100	4.07×10^{-5}
bus	3500	1×10^{-4}
truck	2100	1×10^{-4}

Table 7. Server Performance (Sylhet-Bhairab).

Station	**Average Delay** (Min)	**Average Number of Customers in queue**	**Utilization** %
Station 1	5.72	3.41	100%
Station 2	5.72	3.42	100%

Analysis for Sylhet-Bhairab Network
In Sylhet-Bhairab network, there are three CNG stations located.

Fuel Demand Estimation
A large number of four strokes travel on this road. But they do not travel the total length. We consider that four strokes and leguna travel 65 km. out of 180 km. Table 6 shows the vehicles run on the Bhairab-Sylhet road. There are number of buses or trucks run by diesel/petrol. The vehicles run by diesel/petrol are about 6200.

After necessary calculations, the required fuel demand in this road was equal to 250922.55 m^3 and the number of required CNG station on the basis of calculated demand in Sylhet-Bhairab road is equal to fifteen stations. According to the existence of three CNG stations in the road there is need of locating and constructing twelve more stations.

The same simulation technique (as Sylhet-Jaflong network) is used to estimate the different parameters in two CNG station in the Sylhet-Bhairab network and results are shown in Table 7. We can see here that the CNG stations located in this road are 100% utilized and queuing time is more. This queuing can be reduced by locating more CNG station in that particular road.

Discussion

Using the collected data, for Sylhet-Jaflong network, amount of fuel demands is estimated and two CNG stations are projected to satisfy these demands. But there are seven CNG stations existing in this road. So there is no need to locate and construct any more stations in that road. The utilization of a CNG station located in this network is less than 100%. Therefore locating of more CNG stations in this network will reduce the utilization of existing CNG stations.

Again, the Sylhet-Dhaka road is emphasized by considering the Sylhet-Dhaka Network as a whole and Sylhet-Bhairab as a part of Sylhet-Dhaka Road. For Sylhet-Bhairab section, amount of fuel demand is estimated and fifteen CNG station is projected to satisfy these demands. The simulation results shows that two of three existing CNG station in this road is fully utilized and average delay in the queue is about 6 minutes. Existing three stations in this road, twelve remainder CNG stations should be located, thereby; the average delay will be reduced. For Sylhet-Dhaka as a whole, amount of fuel demand is estimated and twenty four CNG station is projected to satisfy these demands. Existing twenty one CNG stations (Sylhet- Dhaka) in this road, three remainder CNG stations should be located and some can be shifted from Dhaka-Bhairab to Bhairab-Sylhet road.

Conclusion

In this paper, the optimum number of CNG stations in two intercity networks are estimated using the fuel demand method. An unplanned location of CNG stations in those two intercity networks in Bangladesh is found. Again, using a single server queuing system, some performance measures of selected existing CNG stations are estimated. This study finds that utilization of servers is 100% in one road where locating of more CNG stations might avoid the long queue. Again utilization of servers is not full in another road even excess number of stations is already located. Suitable locating of CNG fuelling station would result in saving resources and expenses, reduction of delay time and increasing of the security.

Acknowledgments

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References

1. Ming Yang and Terry Kraft-Oliver, “Compressed Natural Gas Vehicles: Motoring towards a cleaner Beijing”, **Applied Energy,** Vol. 56 (1997), pp. 395-405.

2. K. Ravindra, E, Wauters, S. K. Tyagi, S. Mor and R. V. Greiken, Assesment of Air Quality After the Implemtation of compressed natural gas (CNG) as fuel in public transport in Delhi, India, **Environmental Monitoring and Assessment,** Vol. 115 (2006), pp. 405-417.

3. S. A. Jalihal and T. S Reddy, CNG: An alternative fuel for public transport, **Journal of Scientific and Industrial Research,** Vol. 65 (2006), pp. 426-431.

4. I. Hossain, G. Gurcan, Lifecycle analysis of different urban transport options for Bangladesh, **Energy Policy,** Vol 35 (2007), pp. 4909-4918.

5. http://www.rpgcl.org.bd/

6. M. Frick, K. W. Axhausen, G. Carle and A. Wkaun, Optimization of the distributed of compressed natural gas (CNG) refueling stations: Swiss case studies, **Transportation Research Part D,** Vol. 12(2007), pp. 10-12.

7. M. A. Rahman and M. Parvez, Waiting Line System in Health Sector of Bangladesh: The case of Dental Care Services in Dhaka City, Daffodil Int. University J. of Bus. Eco., Vol. 1. No. 1 (2006), pp. 102-113.

8. Averill. M. Law, W. David Kelton, Simulation Modeling and Analysis, 3rd Ed., McGraw-Hill, Singapore, 2000.

9. D. Gross and Harries C., Fundamentals of Queuing Theory, 3rd Edition, John Wiley and Sons, New York, 1998.

10. S. Y. Lim, S. Hur and S. J. Noh**,** Departure process of a single server queuing system with Markov renewal input and general service time distribution, **Computers and Industrial Engineering,** Vol. 51 (2006), Issue 3, pp. 519-525.