Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management
Istanbul, Turkey, July 3 – 6, 2012

CNG Refueling Station Distribution on the Intra and Intercity Networks: A Challenge for Energy Efficient Green Highway

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Abstract

Exhaust emissions from a typical CNG run vehicles are much lower than those from gasoline-powered vehicles. In addition dedicated CNG run vehicles produce little or no evaporative emissions during fueling and use. Due to this environ friendly behavior, low price and availability of CNG recently, the number of CNG fuel based vehicles in Bangladesh is growing rapidly. According to NGV journal, Bangladesh is one of the top ten user country of CNG driven vehicles. Currently CNG refueling stations are building up in the intra and intercity roads and highways networks to meet the rising demand of CNG vehicles without any forecasting or proper planning. This research is mainly an investigation of the current distribution of CNG refueling stations in selected roads and highways network in Bangladesh. We present the investigation prevailing queuing system and performance of the existing CNG filling stations by using ARENA simulation tool. The study finds excess and less utilized CNG refueling station in the selected city network. Within the existing condition, some refueling stations have long queue of vehicles where some other stations are left unutilized most of the time of the day.

Keywords
CNG vehicles, simulation, ARENA, fuel demand method, queuing system

1. Introduction
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 monoxides and particulates (Ming et.al, 1997, Ravindra et.al, 2006). Like in 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 (Jalihal et al, 2006). As a result the number of CNG refueling stations is growing in keeping pace with the ever-increasing demand. Currently, there are about 576 CNG refueling stations in around the country. Among them 213 have started operation during 2008-2009 fiscal year (FY) (RPGCL). 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.

Again, simulation is the imitation of some real things, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics or behaviors of a selected system. In this study the key performance of each

server in CNG stations located in the selected area is approximately measured through a simulation study using the ARENA simulation tool (Arena website). ARENA is usually used to analyze the different queuing system to reduce the waiting time and increase the utilization of the server (Othman, et. al. 2007). The statistical characteristics of different activities are found using the ARENA input analyzer. The simulation results support the result found in the fuel demand method. In the previous work (Mukaddes, et. al, 2010), all CNG stations are considered as single server queuing system and the manual simulation was used. The present study considers all running server in stations. The Sylhet metropolitan area is considered as intra-city network and Sylhet-Jaflong and Sylhet-Moulovibazar are considered as intercity network. We choose the Sylhet area because it has surplus natural gas and the tendency to build CNG station based business is very high.

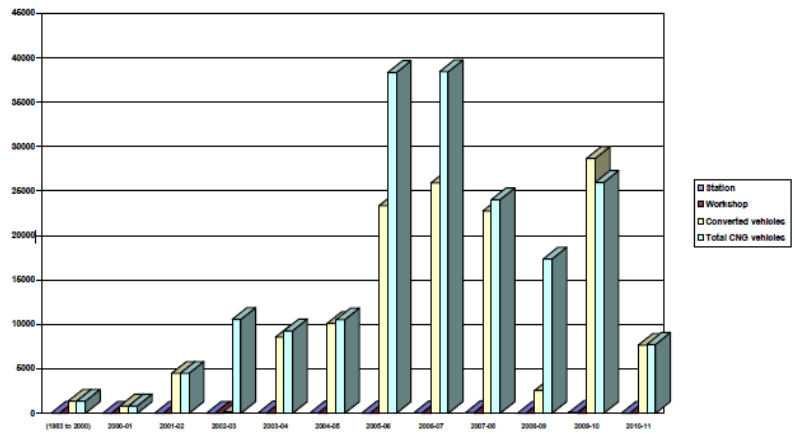

Figure 1: CNG activities expansion in Bangladesh [4]

2. CNG Stations Expansion 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 (Figure 1). A sizeable number of gasoline-run vehicles have been converted to CNG-run vehicles in the recent year. The rising cost of auto fuel 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. The Figure 1 shows that the rate of conversion is higher than the imported CNG-run vehicles.

3. Materials and Methodology

For the proper distribution of CNG filling stations, the need of using case-study is obligated. Two intercity networks, Sylhet-Jaflong and Sylhet-Moulovibazar are chosen as case study. The Sylhet metropolitan area is also studied. In order to estimate the optimum number of CNG stations in these roads, this research uses an estimated fuel demand method to estimate demand of total fuel amount. ARENA simulation tool is used to determine some performance indicators of each server of CNG stations located in the selected area. The performance indicators are utilization, average waiting time and average number of waiting cars. Both methods are described in details below.

3.1 Estimated Fuel Demand Method

For determining the number of CNG stations in 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,

$$D = \sum \left(L_l T_{vl} \right) \eta_v \qquad (1)$$

where,

l is road index, v is vehicle type index, L_l is length of road l, T_{vl} is number 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.

$$NS = \frac{D}{SC} \qquad (2)$$

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

Table 1: Vehicles run per day in Sylhet-Jaflong and connecting road

Type T_{vi}	Fuel consumption (per meter), η_v (m^3)	Sylhet-Jaflong (57 km)	Sylhet-Kanaighat (54 km)	Sylhet-Goainghat (54 km)
four stroke	4.07×10^{-5}	3250	144	192
car / micro	4.07×10^{-5}	2250	70	56
Laguna	4.07×10^{-5}	3500	96	144
bus	1×10^{-4}	600	96	96
truck	1×10^{-4}	468	48	24

3.2 Simulation using ARENA

The field data are collected by observation and interviewing method. Those data are used to estimate the characteristics of different activities using ARENA-10 input analyzer. A model of CNG station (multiple servers) is developed using the ARENA software. Using that model and its variation, the queuing system performances of each existing station is measured.

4. Data Analysis

The total number of CNG run vehicles in two intercity networks is counted as shown in Table 1 and Table 2.

4.1 Fuel demand estimation (Sylhet-Jaflong)

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. Out of seven five are running. 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 Table 1.

So, the Fuel Demand for Sylhet-Jaflong network

$$D_1 = (57 \times 3250 \times 0.0407) + (57\times 2250\times 0.0407) + (57\times 667\times 0.0407) + (57\times 600\times 0.1) + (57\times 468\times 0.1) = 20394.221\ m^3$$

Again, the fuel demand for Sylhet-Kanaighat network, $D_2 = 1458.918\ m^3$ and the fuel demand for Sylhet-Gowainghat network, $D_3 = 1481.5832\ m^3$

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,

$$D_4 = (57\times 228\times 0.1) + (57\times 1560\times 0.1) = 10191.6\ m^3$$

Total fuel demand according to the equation (1):

$$D = D_1 + D_2 + D_3 + D_4 = (20394.22 + 1458.918 + 1481.5832 +$$

10191.6) m^3 = 33526.5922 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):

$$= \frac{33526.5922}{17520}$$
$$= 1.91 \approx 2$$

4.2 Fuel demand estimation (Sylhet-Moulivibazar)

The distance between Sylhet-Moulivibazar road is 60 k.m. The total number of CNG run vehicles in this road is shown in the Table 2. Using the fuel demand method and data we find the required number of CNG station 2 while there is only one CNG station is this road.

4.2 Simulation analysis using ARENA model

Rockwell ARENA is a simulation and automation software from Rockwell Automation,Inc. ARENA is being widely used in simulating business processes and various kinds of discrete event operations. Required data for building the ARENA model are collected from the observational process**.** Statistical distributions of those collected data are found using Input analyzer incorporated in ARENA-10.

Sylhet-Jaflong road:

From the input analyzer we get the statistical distributions and expressions for inter-arrival time and service time of each server (Table 3). The developed model using the ARENA-10 is shown in Figure 2. After running the model in ARENA for several simulation replications the output is found as shown in Table3.

Table 2. CNG run vehicles in Sylhet-Moulivibazar road

Type	Number (8:01AM-7:59PM)	Fuel consumption (per kilometer), ηv (m3)
CNG Auto rikshaw	1277	0.0407
Car/ Micro Bus/ Laguna / Wagon/ SUV Other Light vehicle	757	0.1221
BUS/ Truck/ Other Heavy Automobile	424	0.3663

Table 3. Statistical distributions of different activities in CNG stations

Name of CNG station	Statistical Distribution (Expression)	
	Inter-arrival time (min)	Server
Biroti CNG station (Mirabazar)	-0.5 + LOGN(1.65, 1.33)	1. 0.5 + ERLA(0.397, 3)
		2. 0.5 + ERLA(0.778, 2)
		3. 0.5 + 5 * BETA(0.895, 1.01)
Surma Autocare center (Shivgonj)	-0.5 + WEIB(2.11, 1.31)	1. 0.5 + GAMM(0.588, 2.39)
		2. 0.5 + 4 * BETA(1.72, 1.41)
		3. 0.5 + LOGN(1.58, 1.36)
Al-jalal CNG station (Tilagor)	-0.5 + LOGN(1.77, 1.39)	1. 0.5 + 4 * BETA(1.26, 1.97)
		2. 0.5 + LOGN(1.42, 1.26)
M/S sawkat CNG station (Khadimnagor)	-0.5 + WEIB(2.18, 1.34)	1. 0.5 + GAMM(0.654, 2.21)
		2. 0.5 + GAMM(0.478, 2.36)
R Rahman & sons CNG Filling station (Pirerbazar)	POIS(1.1)	1. 0.5 + LOGN(2.05, 1.81)
		2. 0.5 + ERLA(0.413, 3)

Sylhet metropolitan area

In order to study the queuing system performance of the CNG stations located in the Sylhet metropolitan area, it is divided into three zones. They are West (A), East (B) and South(C) zone as shown in Figure 3. Total 26 CNG stations are in the Sylhet metropolitan area (Figure 3). We measure the different performance indicators of stations in three zones shown in Table 5, Table 6 and Table 7. We divide the whole day into peak (8:00 am – 8:00 p.m) and Off-peak time (8:00 p.m. – 8.00 a.m). The results show that the server utilization of all stations located in the Sylhet metropolitan area is very low. There are two servers one is low pressure (LP) and the other is high pressure (HP). The LP servers serve three wheeler while the HP server serves the heavy vehicles and cars. The LP server is less utilized compare to HP server in the off-peak time. It has no queue during the off-peak time.

Table 4. Performance indicators of servers of CNG stations(Sylhet-Jaflong)

CNG Station	Server Utilization	Avg. Num. of waiting cars	Avg. waiting time(min)
Station-1	69%	8	0.118
Station-2	42%	2	0.016
Station-3	59%	6	0.030
Station-4	52%	3	0.018
Station-5	54%	3	0.017

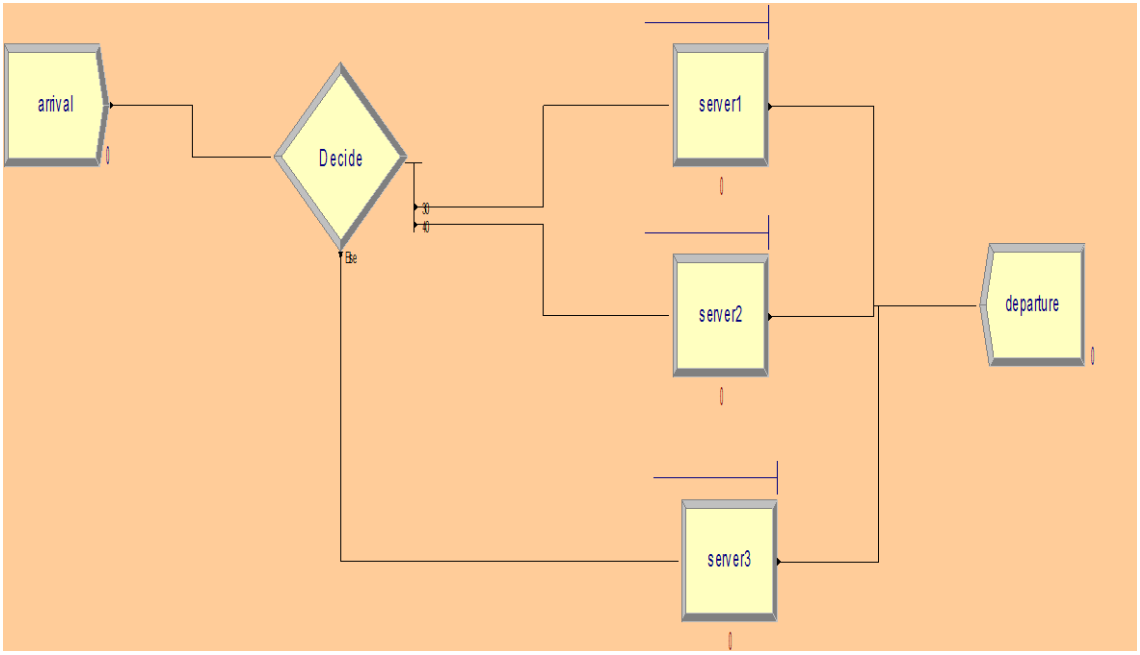

Figure 2: Simple arena model of a CNG station

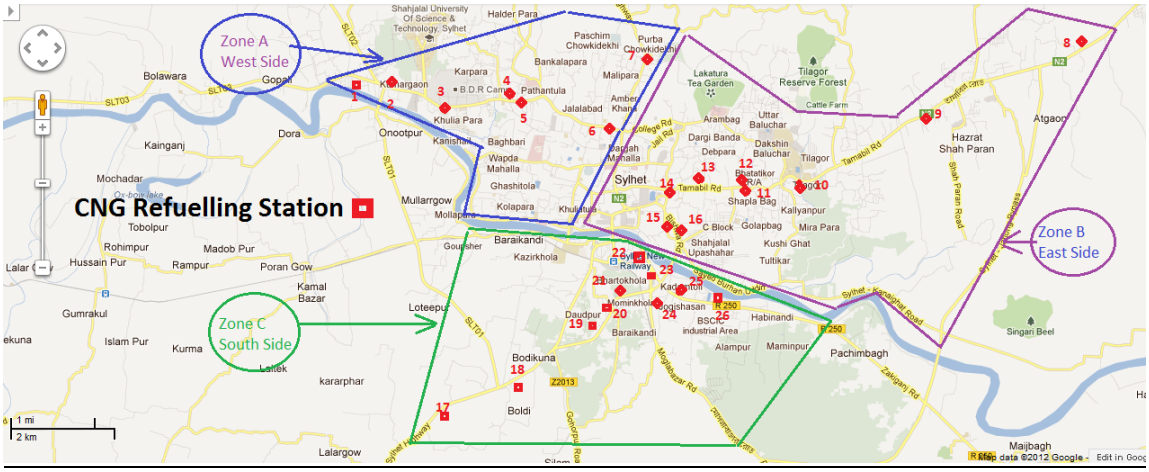

Figure 3: Location of CNG stations in Sylhet Metropoliton Area

Table 5. Performance indicator of stations located in Zone -A

CNG Stations Zone A	Peak						Off-peak					
	Server Utilization (%)		Avg. No. of waiting Vehicles		No. Of Vehicles Served		Server Utilization		Avg. No. of waiting Vehicles		No. Of Vehicles Served	
	LP	HP	LP	HP	LP	HP	LP	HP	LP	HP	LP	HP
Stat. 1	14.34	11.99	9.67	4.86	125	48	3.92	12.21	0.00	2.64	28	39
Stat. 2	13.36	13.60	10.01	0.02	113	42	2.71	20.61	0.00	0.02	21	66
Stat. 3	8.87	24.29	6.35	0.04	73	72	2.44	20.33	0.00	0.02	19	61
Stat. 4	8.92	21.11	6.07	8.26	75	82	2.77	18.29	0.00	4.36	21	63
Stat. 5	12.38	20.55	7.59	7.87	98	80	2.61	19.09	0.00	4.35	19	66
Stat. 6	19.27	20.03	13.72	7.87	168	82	6.10	23.94	0.00	5.15	43	79
Stat. 7	22.57	25.59	15.19	9.08	191	95	5.96	23.97	0.00	6.28	45	82

Table 6. Performance indicator of stations located in zone -B

CNG Stations Zone A	Peak						Off-peak					
	Server Utilization (%)		Avg. No. of waiting Vehicles		No. Of Vehicles Served		Server Utilization		Avg. No. of waiting Vehicles		No. Of Vehicles Served	
	LP	HP	LP	HP	LP	HP	LP	HP	LP	HP	LP	HP
Stat. 8	21.64	11.85	16.93	7.46	188	79	6.35	13.69	0.00	6.28	48	87
Stat. 9	10.58	9.25	8.95	5.69	94	60	2.57	11.85	0.00	4.99	18	74
Stat. 10	8.12	10.37	6.02	6.29	71	63	3.65	11.12	0.00	4.34	27	67
Stat. 11	4.91	12.22	4.52	7.08	47	73	5.46	11.67	0.00	4.10	40	71
Stat. 12	3.27	9.07	3.04	5.35	31	58	1.30	7.96	0.00	3.31	9	52
Stat. 13	11.44	10.37	8.38	6.41	90	66	4.17	13.33	0.00	5.16	31	78
Stat. 14	9.33	12.96	6.38	7.68	81	85	3.33	10.74	0.00	5.09	24	72
Stat. 15	15.92	10.19	12.42	4.69	133	57	5.25	8.76	0.00	2.87	38	53
Stat. 16	14.59	13.70	11.06	7.64	122	85	2.93	10.56	0.00	4.44	23	64

Table 7. Performance indicator of stations located in zone -C

CNG Stations Zone A	Peak						Off-peak					
	Server Utilization (%)		Avg. No. of waiting Vehicles		No. Of Vehicles Served		Server Utilization		Avg. No. of waiting Vehicles		No. Of Vehicles Served	
	LP	HP	LP	HP	LP	HP	LP	HP	LP	HP	LP	HP
Stat. 17	9.90	10.75	1.48	6.41	104	68	2.34	9.81	0.00	2.19	23	54
Stat. 18	11.74	7.96	1.82	6.65	110	56	1.35	8.70	0.00	2.40	23	49
Stat. 19	10.50	8.15	1.56	5.84	125	63	2.12	7.78	0.00	1.95	20	44
Stat. 20	8.02	9.07	1.28	6.99	107	65	2.96	9.26	0.00	2.39	15	51
Stat. 21	8.69	9.26	1.68	6.51	84	75	1.53	10.93	0.00	2.89	24	62
Stat. 22	8.25	10.18	1.20	7.88	93	85	2.91	11.85	0.00	3.42	32	69
Stat. 23	11.11	12.40	1.78	7.85	85	76	3.19	11.11	0.00	2.80	16	64
Stat. 24	9.41	11.11	1.53	8.64	116	84	2.71	13.15	0.00	3.64	28	76
Stat. 25	10.66	12.77	2.08	9.19	105	56	2.07	9.82	0.00	2.24	35	54
Stat. 26	10.35	8.15	1.47	5.94	120	56	1.91	7.03	0.00	1.70	28	40

5. Results and Discussions

We find excess CNG stations in Sylhet-Jaflong road while in Sylhet-Moulivibazar road need more CNG stations to fulfill the requirements. We did the same calculation in 2010 in Sylhet-Jaflong road and found the excess CNG stations there. This means that even the number of CNG run vehicles increases, 2 CNG stations in this road is enough to fulfill the requirements. In the Sylhet metropolitan area there are 26 CNG stations. The simulation results find them less utilized. Most of them are utilized less than 20%. Moreover CNG station takes up more space than conventional gasoline. Removing of CNG stations from metropolitan area can increase the utilization rate as well as will free some space in metropolitan area.

6. Conclusion

The required number of CNG stations in given Sylhet-Jaflong and Sylhet-Moulivibazar by the fuel demand method is estimated in this paper. ARENA model helps us to identify the performance indicators for each CNG stations in those network and Sylhet metropolitan area. The utilization of each station in the selected location is not in the satisfactory level. This study suggests that suitable number of CNG stations located properly may increase the utilization of CNG stations and reduce the space used. Suitable locating of CNG filling stations would result in saving resources and expenses, reduction of delay time and increasing of the security.

7. Future Work

The future work of this research is to estimate the number of CNG stations in the intercity network of the whole country as well as in the divisional city. The location of each CNG station will be determined using the layout and location theory.

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