A Model for Estimating Delay and Waiting Time of Vehicles in Gas Stations

Meead Saberi Kalaee
Undergraduate Student, Civil Engineering Department
Ferdowsi University of Mashhad, Iran

Abstract
One of the common techniques to reduce fuel consumption in transportation is traffic delay reduction. Because of the limited capacity for fueling in gas stations, formation of lines and their corresponding delays are inevitable. Proper geometric design of gas stations can significantly reduce delays due to disorderliness of vehicles in line which result in less fuel consumption and emission. This paper presents the result of a study on modeling the waiting time and delay of vehicles in such stations. This model uses adjacent lines interaction theory and time matrices to estimate waiting time and delay of vehicles. The result is proven to be satisfactory and the mean error ratios of waiting time are not more than 6.5%.

Introduction
According to the published information and statistics of Iran, energy consumption in different parts of the country has been increased significantly in recent years. Statistics show that the value of energy consumption in the country were $12.4 billion in 1992 and $15.5 billion in 1999 and will be about $35.2 billion in 2011. [1]
Structural problems in fuel consumption and not effective exploitation of the country's oil resources are the major problems in almost all economical subdistricts. For example in transportation section the average fuel consumption of a vehicle in Iran is about 11 liter per day. This number is 2.5 liter in Germany and Japan, 3.5 liter in UK, 6.5 liter in Canada and 7.3 liter in United States. [2]
Transportation section is one of the biggest consumers of energy in the country and also the largest user of oil resources. The annual energy consumption in this section was 12.5 million gallon in 1976 and 233.4 million gallon later in 2003. Available statistics show a %7 annual increase in energy consumption in transportation section in Iran. [2]
One of the common techniques to reduce fuel consumption in transportation is traffic delay reduction. The formation of long lines in highways or parking entrance gates can be good objective examples which result in fuel wasting and emission. Another example is gas stations. Because of the limited capacity for fueling in gas stations, formation of lines and their corresponding delays are inevitable. Proper geometric design of gas stations can significantly reduce delays due to disorderliness of vehicles in line which result in less fuel consumption and emission.

Classification of Waiting Times and Delay of Vehicles in Gas Stations
Almost all gas stations with different geometric designs have similar operation in vehicles direction, line formation and fueling. Each vehicle has to stay in a line in order to fuel. Usually each two continual vehicles start fueling together. So other vehicles waiting time in a line depends on fueling time of fore vehicles which is defined as fueling step time. A fueling step for a vehicle starts with entering to the fueling

platform, fueling and ends with quitting there. Vehicles total fueling time can be classified into three parts:

- fueling time in each fueling step
- waiting time to enter the fueling platform
- delay time because of disorderliness of vehicles in line

Fueling time in each step includes times for entering into the platform, preparing the vehicle to get fueled, fueling, paying the fee and at last quitting the platform. Waiting time in a line depends on the location of the vehicle in the line and fueling time of fore vehicles. Figure 1 shows how the fueling steps were numbered in this study.

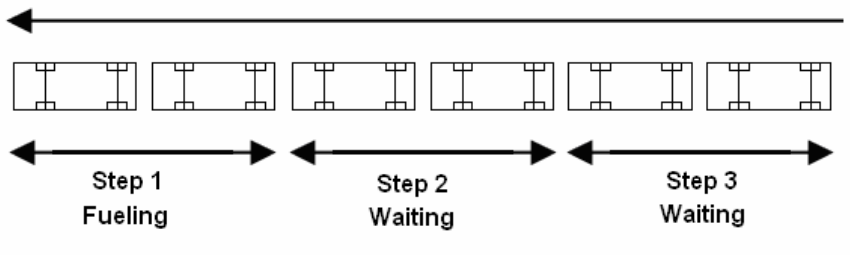

Fig 1. Numbering of the fueling steps

Adjacent Lines Interaction

Because of not proper geometric design of gas stations, adjacent lines interact each other. Delay time of a vehicle in a line depends on the location of the vehicle. Disorderliness in lines is the major cause of delay in gas stations. Studies show that the maximum delay time of waiting vehicles in the second step is equal to the fueling time of vehicles in the first step in the adjacent line. This means the disorderliness of vehicles in a line can affect waiting time of vehicles in adjacent lines. If this disorderliness continues, the delay time of vehicles will increase in an arithmetic progression.

A Model for Estimating Waiting Time

This paper presents the result of a study on modeling the waiting time and delay of vehicles in gas stations. This model uses adjacent lines interaction theory and time matrices to estimate waiting time and delay of vehicles. w_{ij} represents the waiting time of vehicles in i^{th} fueling step and j^{th} part of the line.

$$[w^*]_{n\times n} = [w]_{n\times n} + \sum_{i=2}^{n}[D_i] \qquad (1)$$

$$[w]_{n\times n} = \begin{cases} 0 & if \quad i \geq j \\ m\times(j-1) & if \quad i < j \end{cases} \qquad (2)$$

$$[D]_{n\times n} = \begin{cases} 0 & if \quad i \geq j \\ 0 & if \quad j < k \quad and \quad i < j \\ D_k & if \quad j \geq k \quad and \quad i < j \end{cases} \qquad (3)$$

$$[w^*]_{n\times n} = \begin{cases} 0 & if \quad i \geq j \\ W_{j-1} & if \quad i < j \end{cases} \qquad (4)$$

$[w^*]$: Waiting time matrix – without delay

$[w]$: Waiting time matrix – with delay

$[D_i]$: Delay matrix in ith step

n : Total number of fueling steps

k : Delayed fueling step

For example in *4* fueling steps with average fueling time of *m* and *D* seconds delay in third step, the total waiting time for each step can be calculated as below:

$$\begin{bmatrix} 0 & W1 & W2 & W3 \\ 0 & 0 & W1 & W2 \\ 0 & 0 & 0 & W1 \\ 0 & 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0 & m & 2\,m & 3\,m \\ 0 & 0 & m & 2\,m \\ 0 & 0 & 0 & m \\ 0 & 0 & 0 & 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 & D3 & D3 \\ 0 & 0 & D3 & D3 \\ 0 & 0 & 0 & D3 \\ 0 & 0 & 0 & 0 \end{bmatrix} \qquad (5)$$

Satisfactory of Waiting Time Estimation Model

This model has been tested in a case study in order to evaluate its satisfactory. In this study which has been performed in Daneshjoo Street gas station 15 continuous fueling steps with a 152 seconds delay in 9th step were observed. All delay and waiting times of vehicles were recorded. The result is proven to be satisfactory and the mean error ratios of waiting time are not more than 6.5%.

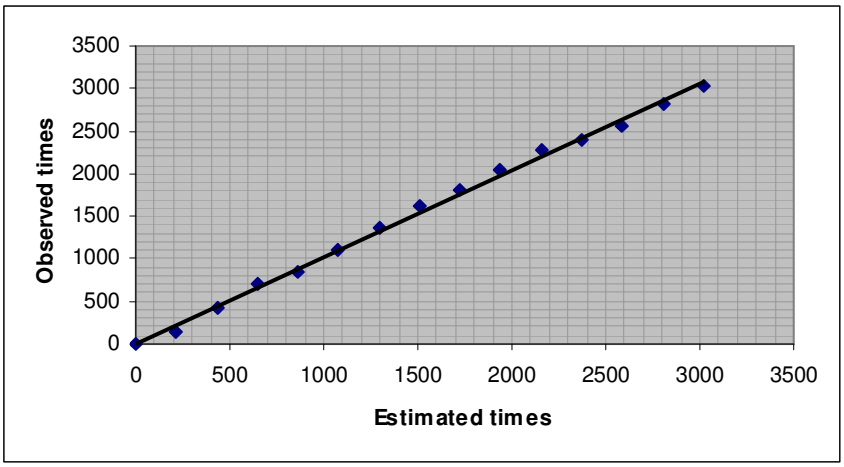

Fig 2. Correlation between estimated and observed results

Figure 2 shows the correlation between estimated and observed waiting times. The correlation coefficient is 0.9984.

Correction of Geometric Design of Gas Stations

Concerning to different types of vehicles movements and lines formation in gas stations and reviewing type maps and standards of gas stations archived by Iran National Oil Company, remarkable results were found. Current geometric design and engineering of

gas stations rather focus on how underground mechanical and electrical installations should be set, gas resources location and sufficient space for oil tankers to discharge.

Fig 3. The left hand picture belongs to Abkooh Street gas station in Mashhad, Iran. Not proper geometric design of this station engenders disorderliness in lines and made lines cross the traffic of the adjacent street. The right hand picture belongs to Daneshjoo Street gas station. A special ramp is used by vehicles to enter this station. This distinct ramp prevents lines to cross the passing traffic. Nevertheless frequent delays happen in lines because of its narrow entrance.

Therefore this study tries to offer corrections for geometric design of gas stations with a special concern to delay and waiting times of vehicles. Table 1 shows current and recommended standards for geometric design of gas stations.

Gas Station Type	Minimum Entrance Width [m]		Minimum Area [m2]	
Number of fueling platforms in the station	Current	Recommended	Current	Recommended
3	18	32.2	1335	1725
4	21	39.5	2000	2707
5	22.9	48	2500	3725

Table 1. Current and recommended standards for geometric design of different types of gas stations

Conclusions

Lines interaction in gas stations because of their not proper geometric design is one of the major factors which affect delay and waiting time of vehicles in lines. The model reported in this paper can estimate total delays of vehicles in a gas station. Through estimating delays other estimations in emission and fuel wasting can be done. In order to reduce delays of vehicles, geometric design of gas stations should be corrected. This correction can lead to less time and fuel wasting and emission.

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Meead Saberi K. is an undergraduate student at the department of civil engineering, Ferdowsi University of Mashhad, Iran. His research interests include Intelligent Transportation Systems, Transportation Safety, Traffic Simulation, Traffic Data Analysis, Statistical Analysis and Environmental Impacts of Transportation.