Assessment of the level of Demand Response based on Hydrogen Charging Stations in Korea

Choongheon Yang[1*)], Dukgeun Yun[2)], Daisik Nam[3)]

[1)*] Korea Institute of Construction Technology, 283, Goyangdae-Ro, Ilsanseo-Gu, Goyang, Gyeonggido, 10223, South Korea; email: chyang@kict.re.kr; ORCID: https://orcid.org/0000-0001-9573-6720

[2)] Korea Institute of Construction Technology, 283, Goyangdae-Ro, Ilsanseo-Gu, Goyang, Gyeonggido, 10223, South Korea; ORCID: https://orcid.org/0000-0002-1204-7282

[3)] Inha University, 3100 Inha-ro, Michuhol-gu, Incheon 22212, South Korea; email: jan.granzow@bau.thm.de; ORCID: https://orcid.org/0000-0002-5059-4826

http://doi.org/10.29227/IM-2024-02-56

Submission date: *17.04.2024.* | Review date: *13.05.2024*

Abstract

Hydrogen is an environmentally friendly energy that produces heat and electricity with high energy efficiency and does not emit harmful substances. It is already attracting global attention as a key energy for the transition to carbon neutrality. Recently, as the number of transportation facilities using hydrogen as a primary fuel has increased, it has become important to forecast demand with this in mind. In Korea, the 2019 roadmap to revitalize the hydrogen economy sets the goal of providing 67,000 hydrogen vehicles and 310 hydrogen charging stations in 2022, 850,000 hydrogen vehicles and 660 hydrogen charging stations in 2030, and 2.9 million hydrogen vehicles and 1,200 hydrogen charging stations in 2040. However, as of December 31, 2022, the number of registered hydrogen vehicles is approximately 30,000 and the number of hydrogen charging stations is 220, which does not meet the distribution target. The lack of hydrogen charging stations inconveniences hydrogen vehicle users, and hydrogen charging stations continue to experience deficits due to the lack of charging vehicles. Accordingly, in this study, based on hydrogen charging stations in Korea, the utilization rate of hydrogen charging stations and the level of demand response at charging stations were estimated by queuing theory. This is to evaluate the suitability of hydrogen charging station distribution.

Keywords: *hydrogen demand, queuing theory, hydrogn charging station. charging station location*

1. Introduction

To prevent the concentration of greenhouse gas in the atmosphere from rising, reducing carbon emissions caused by human activities and increasing absorption so that net emissions become 'zero' is called carbon neutrality. This is part of a global effect to recognize the seriousness of global warming caused by greenhouse gas and to respond to the climate crisis. The signing of the Framework Convention on Climate Change [1] and the adoption of the Kyoto Protocol [2] and the Paris Agreement [3], have led to efforts to limit the rise in the global average temperature. As a result, Korea is striving to achieve carbon neutrality by 2050. To achieve this, it is essential that all sectors, including energy, environment and ICT, work together to reduce carbon emissions. As it is virtually impossible to reduce emissions in many areas, CO_2 reduction is very important in the energy sector, which has the largest share of emissions. Energy conservation means minimizing the loss of energy efficiency caused by wasted or insufficient energy.

More recently in the energy sector, hydrogen has been touted as the key to the world's transition to carbon neutrality, as it is an environmentally friendly energy source that produces heat and electricity with high energy efficiency but does not emit harmful substances such as greenhouse gas and particulate matter. Recently, as the number of vehicles using hydrogen as their main fuel has increased, it has become important to forecast demand taking this into account. In Korea, the 2019 Roadmap for the Revitalization of the Hydrogen Economy sets targets for the supply of 6.7 million hydrogen vehicles and 310 hydrogen charging stations in 2022, 850,000 hydrogen vehicles and 660 hydrogen recharging stations in 2030, and 2.9 million hydrogen vehicles and 1,200 hydrogen recharging stations in 2040. However, as of 31 December 2022, there are approximately 30,000 registered hydrogen vehicles and 229 hydrogen recharging stations, so the supply target will not be met. Hydrogen vehicle users are inconvenienced by the lack of hydrogen charging stations, and hydrogen charging stations continue to experience shortages due to a lack of charging vehicles.

Accordingly, in this study, based on hydrogen charging stations in Korea, the utilization rate of hydrogen charging stations and the level of demand response to charging stations were evaluated using queuing theory. This was done to evaluate the suitability of hydrogen charging station distribution.

2. Literature Review

Many researches have been carried out on models and methods for forecasting hydrogen demand. In the study of Hwang et al, in order to implement a data-based hydrogen charging station demand forecasting model, different three hydrogen charging stations installed were selected, supply and demand data of hydrogen charging stations were secured, and 7 machines learning and deep learning algorithms were used. was selected to learn a model with a total of 27 types of input data (weather data + demand for hydrogen charging stations), and the model was evaluated with root mean square error (RMSE) [4]. By reviewing the global energy status and foreign energy policies, the authors analyzed the transition from fossil to non-fossil energy systems and the R&D policies of advanced countries. Finally, an R&D strategy for hydrogen energy technology was developed by analyzing the current status of energy research policies and programs in major countries [5]. The government's target values are compared with the demand forecast results. In addition, using the estimated FCEV forecasts, we forecast the demand for hydrogen for transportation and analyze the effect on emissions of CO2, the core greenhouse gas. The estimation results show that about 2.5 million units will be supplied by 2040, which is 87.4% of the government target of 2.9 million units [6]. It is adopted systems thinking and system dynamics approaches to construct a conceptual model for hydrogen energy, with a special focus on the pathways of hydrogen use, to assess the potential unintended consequences, and possible interventions; to highlight the possible growth of hydrogen energy by 2050. The results indicate that the combustion pathway may increase the risk of the adoption of hydrogen as a combustion fuel, as it produces NOx, which is a key air pollutant that causes environmental deterioration, which may limit the application of a combustion pathway if no intervention is made [7]. The development and value of a model that simulates stochastic future demand at a hydrogen filling station was addressed. This study can be used for hydrogen station requirements and operation and maintenance strategies and to assess the impact of demand variations and scenarios. This article presents the current status of hydrogen demand, the model development methods, a set of sample results. Discussion and conclusions concentrate on the value and use of the proposed model [8]. A commercially established urban district energy system located in Southampton (United Kingdom) is analyzed with the aim of exploring potential variations in its energy demand. The study proposes the use of scalable data-driven methods and probabilistic simulation to generate seasonal energy demand patterns that represent the potential short- and long-term evolution of the energy district [9].

3. Hydrogen Statiom Demand Analysis

In this study, we aim to assess the current status of charging station locations and the level of responsiveness of charging stations to current demand through buffer analysis and queuing theory using a GIS(Geographic Information System) software.

3.1 Analysis of Potential Sites According to National Charging Station Installation Regulations

At present, the installation area is limited by regulations on charging facilities such as the National land planning and utilization Act, the high-pressure gas safety management Act and the building Act in South Korea. In this study, we aim to derive areas where charging stations can be located where each regulation is applied. Due to limitations in data collection when applying to all regulations, the buffer analysis was carried out by first applying to road, education, health and housing regulations.

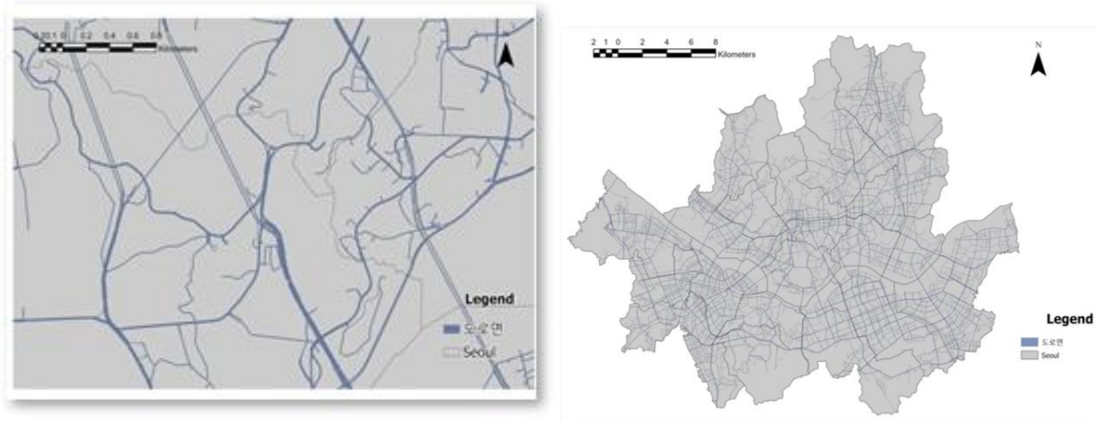
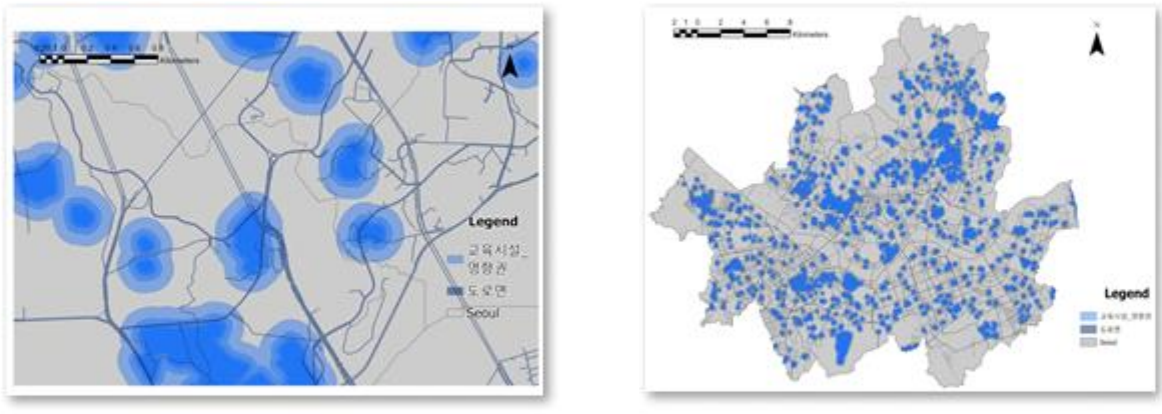


Fig. 1. Results of traffic regulation application.

Firstly, due to the nature of the road area under the road Act, hydrogen charging stations cannot be installed within 5 meters of the road boundary. Figure 1 illustrates this. Although 5 meters from the road edge is not a high restriction in terms of area, the road is the last access point to the charging station, so accessibility can be very high if users leave the road to charge.

Second, according to the education environment protection Act, hydrogen charging stations cannot be installed in absolute protection areas within 50 meters in a straight line from the school gate. In addition, areas within a straight-line distance of 200m from the relative protection area are also excluded from consideration.



(a) Example of educational regulation application (details) (b) Example of educational regulation application (Seoul)

Fig. 2. Results of educational regulation application.

Third, based on regulations on housing construction standards, and so on, medical facilities must be located at a horizontal distance of more than 50 m from hazardous materials storage and processing facilities. As a result of analyzing the area of influence of medical facilities by applying it to Seoul City, it was found that they occupy about 70% of the area, excluding green areas.

Fig. 3. Results of medical facility regulation application.

Fourth, based on regulations on housing construction standards, and so on, apartment complexes, like medical facilities, must be located at a horizontal distance of 50 m or more from hazardous materials storage and processing facilities.

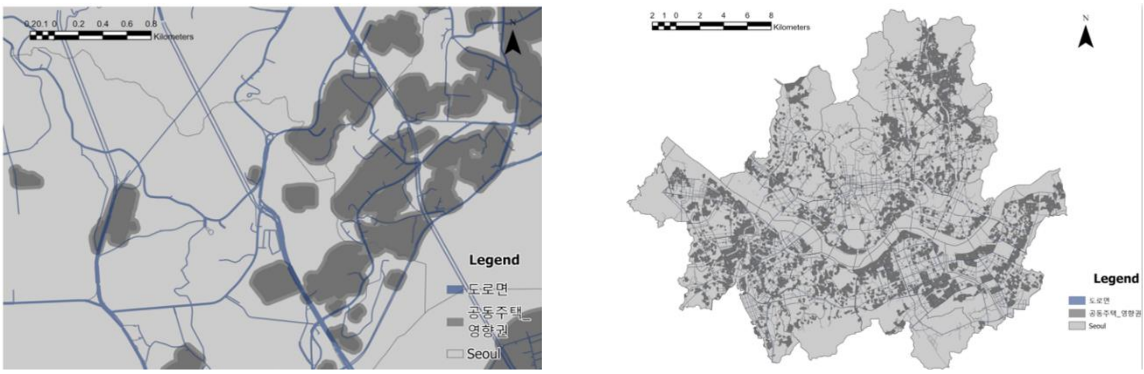
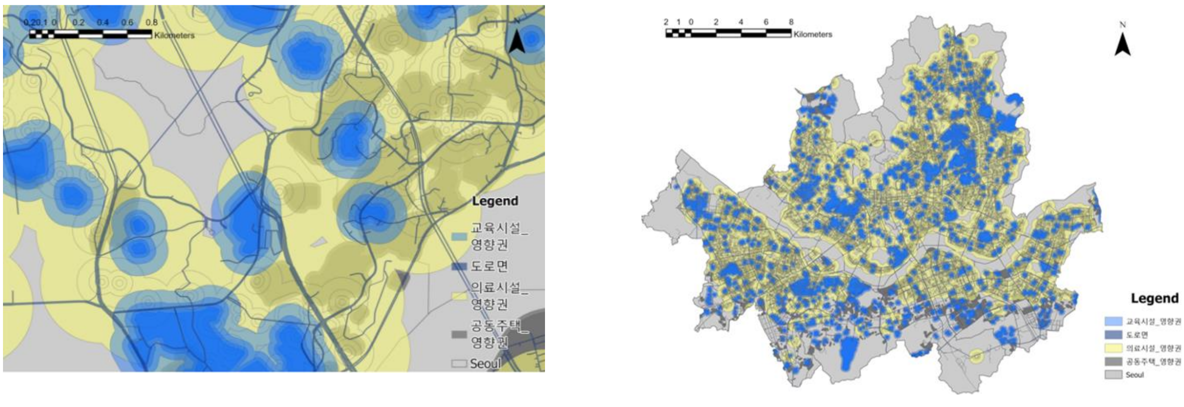


Fig. 4. Results of apartment complex regulation application.

Figure 5 shows the impact areas of roads, educational facilities, medical facilities, and apartment complexes as applied above. As a result of the buffer zone analysis, approximately 80% of Seoul's area requires only the four regulations above. In addition, most of the regulated areas shown on the map are residential or commercial areas, and it was confirmed that access to charging stations for residents and transient populations is very poor.



(a) Example of all regulation application (details)

(b) Example of all regulation application (Seoul)

Fig. 5. Results of all regulation application.

As a result of applying buffer area analysis through GIS to Seoul City, it was found that most areas are regulated areas and there is a lack of places where hydrogen charging stations can be installed. Even in areas where installation is possible, hydrogen vehicle users face difficulties due to inaccessibility. Therefore, appropriate deregulation of charging stations and strategic site selection methods are needed to ensure user accessibility.

4. Evaluation Of Queue-Based Hydrogen Charging Station Demand Response Level

In this section, the hydrogen charging station utilization rate and the charging station demand response level were evaluated using queuing theory. Through this, we aim to evaluate the suitability of the hydrogen charging station location. Queuing theory is used to efficiently control the queuing that occurs in the system and to make correct decisions. Various types of queues that exist due to services and work, such as management, industrial engineering, communication and transportation networks, are actually used.

4.1 Hydrogen Charging Station Service Level

The charging time for hydrogen vehicles at a hydrogen charging station is known to be approximately 5 to 15 minutes. However, there is no publicly available statistical data on hydrogen charging time, so the researchers made direct observations. The observation target was collected at the National Assembly hydrogen charging station in Yeouido for 3 days, and a total of 34 samples were secured. The average time to charge was 7.26 minutes and the standard deviation was 0.99 minutes. The minimum charge time was 4.2 minutes and the maximum charge time was 9.2 minutes. Figure 5 shows the observed data as a histogram.

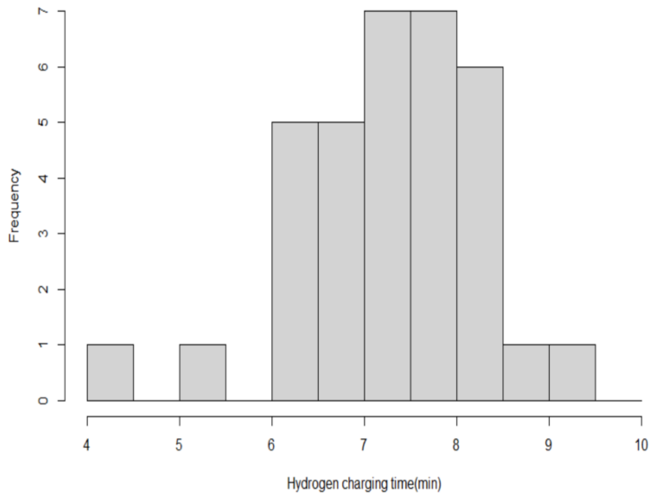


Fig. 5. Hydrogen charging service time.

4.2 Optimal rate of hydrogen station users

To determine the arrival rate of hydrogen station users, the average visit frequency of the past 30 days by time of day and day of week was used for 23 hydrogen stations for which data is available in the Hydrogen Distribution Information System. This was used to calculate the number of vehicles visiting each station per hour and per day. The results of the survey are shown in Table 1. In summary, the average number of visiting vehicles per hour was 2.48 and the standard deviation was 0.95.

Tab. 1. Charging frequency measurement results for hydrogen vehicles.

Station	Average number of charge (daily basis)	Average number of charge (time basis)
1	21	3
2	49	5
3	16	2
4	8	2
5	32	3
6	21	2
7	44	3
8	15	2
9	11	2
10	24	2
11	44	4
12	41	4
13	4	1
14	19	2
15	16	2
16	30	3
17	12	1
18	18	2
19	17	2
20	29	3
21	40	3
22	5	2
23	19	2

4.3 Basic assumptions for queue analysis

Before fully analyzing a queue, we need to make some basic assumptions for our analysis. Therefore, the arrival rate of hydrogen vehicles and the utilization rate of charging stations have been assumed.

(1) The average user arrival rate (λA) follows an exponential distribution.

(2) The average hydrogen charge service rate (λU) follows an exponential distribution.

(3) Arrival rate and service rate are independent.

In this assumption, the arrival and service rates do not arrive or serve at regular intervals. In addition, the length of the inter-arrival interval between vehicles and the vehicle boarding time are unrelated, so there is no violation of the basic assumptions of queuing theory. The placement of chargers at charging stations has been studied to define the queuing system. There is a lack of publicly available data on charger placement or charging station design, and a sampling of some charging stations did not identify any charging stations with three or more chargers installed and operating. Therefore, the possible arrangement of chargers within two units can be divided into three cases:

1) When operating one charger independently

2) Operating two chargers in series

3) Two chargers operating in parallel

Figure 6 illustrates this division. When expressed as a model of queueing theory, it can be expressed as M/M/1, serial M/M/2, and parallel M/M/3.

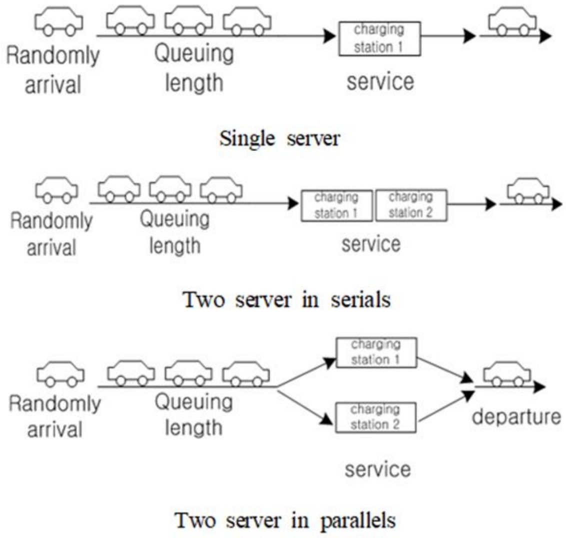
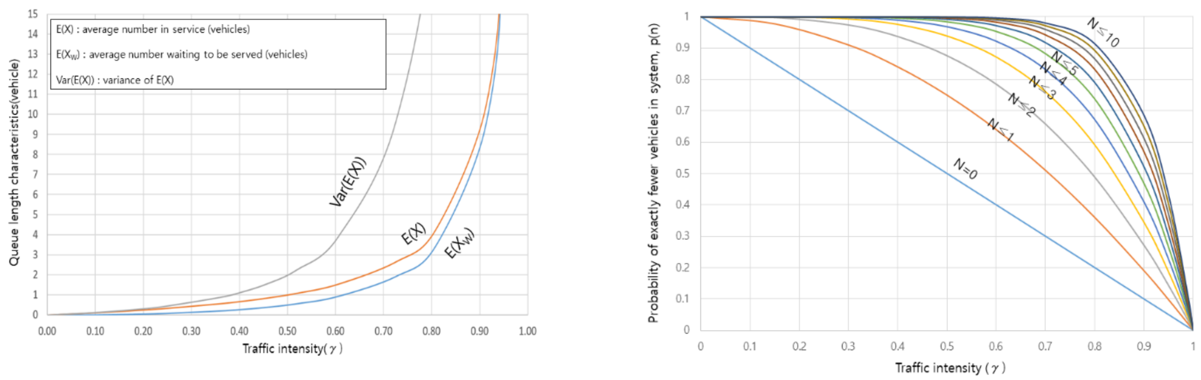


Fig. 6. Charger arrangement type of hydrogen charging station.

4.4 Queue Analysis Results

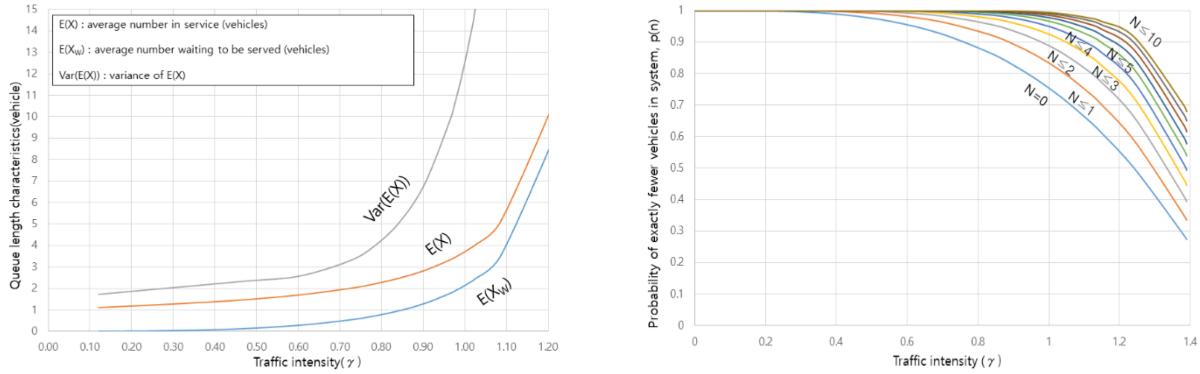
First, the analysis results of the M/M/1 system showed that when the hydrogen charging utilization rate was about 0.6 or more, that is, when more than 5 vehicles were used per hour, a queue of more than 1 vehicle occurred. It was found that when the charging utilization rate exceeds 0.8 (more than 7 vehicles per hour), the queue length in the system increases exponentially and reaches a level that cannot meet the demand for hydrogen charging. Figure 7 shows the results.



(a) M/M/1based queue length (b) Probability of waiting in the system of M/M/1

Fig. 7. Queuing theory analysis results of M/M/1.

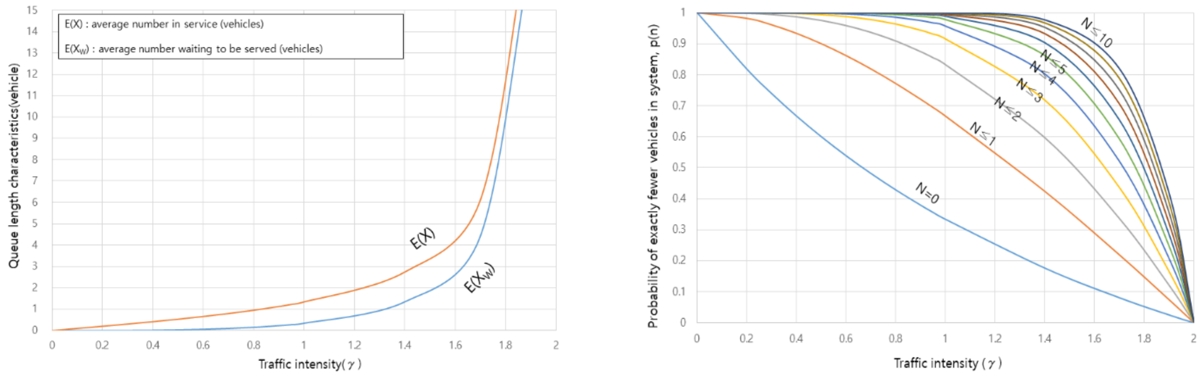
Second, looking at the queue analysis results of the M/M/2 serial system, a queue of more than one vehicle occurred when the hydrogen charging utilization rate was about 0.85 (about 7 vehicles per hour) or higher. It was found that from a hydrogen charging utilization rate of 1.2 (about 10 vehicles per hour) or higher, the queue within the system increases exponentially and reaches a level that cannot meet the demand for hydrogen charging. Figure 8 shows the results of this analysis.



(a) Queue length as a function of serial M/M/2 (b) Probability of waiting in the system of serial M/M/2

Fig. 8. Queuing theory analysis results of serial M/M/2.

Finally, by looking at the queue analysis results of the parallel M/M/2 system, a queue of more than 1 vehicle occurred when the hydrogen charging utilization rate was about 1.3 (about 10 vehicles per hour) or higher. It was found that when the hydrogen charging utilization rate exceeds about 1.7 (about 14 units per hour), the queue in the system increases exponentially and reaches a level that cannot meet the demand for hydrogen charging.



(a) Queue length as a function of serial M/M/2 (b) Probability of waiting in the system of serial M/M/2

Fig. 7. Queuing theory analysis results of serial M/M/2.

As a result of analyzing the three queuing systems above, it was confirmed that parallel M/M/2 had the highest level of hydrogen demand response, and M/M/1 had the lowest. In addition, the queue length M/M/1 measured through queue analysis is 5 cars when the maximum capacity level is 7 cars per hour, and the serial M/M/2 is the queue length is 9 cars per hour. 4 cars, parallel M/M/2 was measured to have a queue length of 4 cars at 14 cars per hour. Applying the above results to the average space of 6m when calculating the left turn lane length suggested in the Intersection Design Guidelines issued by the Ministry of Land, Infrastructure and Transport, M/M/1 is 30m, serial M/M/2 is 24m, and parallel It was analyzed that M/M/2 requires a waiting space of 24m [10].

Tab. 2. Results of calculating the length of waiting area required for hydrogen charging stations

Type	**Arrival Rate(veh/h)**	**Number of vehicles required storage(vehicle)**	**Queuing storage length(m)**
M/M/1	≤ 4	1	6
	5~6	2	12
	7	3~5	18~30
	>7	≥6	≥36
M/M2 in parallels	≤ 10	1	6
	12	2	12
	13	3	18
	14	4	24
	≥15	≥5	≥30
M/M/2 in series	≤ 7	1	6
	8	2	12
	9	3~4	18~24
	>9	≥5	≥30

5. Conclusion

We measured the level of responsiveness to hydrogen charging demand at the station by analyzing the queue according to the placement of the charger at the hydrogen charging station. When operating two chargers, it was found to be more appropriate to place them in parallel than in series. However, the placement of chargers in series or parallel must be decided considering the type of site, area and layout of other facilities. If the waiting area length is calculated based on the above results, a waiting area of 30m is required to ensure that the waiting line extends to the street and does not interfere with the traffic flow. Therefore, when designing the layout of the charging station, it is necessary to ensure a waiting area of 30m. In addition, in M/M/1, which is the lowest level among the system deployment types, a queue occurs when the hydrogen charging utilization rate is greater than 0.8 (7 units per hour). The current charging station utilization rate is 0.3 (2.48 units per hour), so there are no queues for any of the three system deployment types.

This means that all of the system deployment types have no problems responding to the current level of demand. This suggests that the current level of hydrogen refueling station provision is good. However, the reason why hydrogen vehicle users claim that there is a lack of charging stations is likely to be due to low convenience, such as accessibility to the charging station location and time of use, rather than a lack of charging stations themselves.

Acknowledgement

Research for this paper was carried out under the KICT Research Program (project no. 20240176-001, Development of technology to secure safety and acceptability for infrastructure in hydrogen city) funded by the Ministry of Science and ICT.

References

1. United Nations, United Nations Framework Convention on Climate Change (21 March 1994)
2. United Nations, Kyoto Protocol (16 February 2005)
3. United Nations, Paris Agreement (22 April 2016)
4. M.W. Hwang, Y. Ha, and S.G. Park, "Machine learning-based hydrogen charging station energy demand prediction model", J. Internet Compu. Serv. 24(2), 47-56 (2023).
5. S.H. Kang, S.J. Choi, and J.W. Kim, " Analysis of the world energy status and hydrogen energy technology R&D of foreign countries", 28(2), 216-223 (2007).
6. C.Y. Lee, D. Jeong, and J. Shin, "Forecasting hydrogen demand for transportation using the diffusion model and the CO2 reduction effect", J. of Climate Change Research, 12(5-1), 363-370 (2021).
7. T. Yusaf, M. Laimon, W.Alrefae, K.Kadirgama, H.A. Dhahad, D. Ramasamy, M.K.Kamarulzaman, and B.Yousif, " Hydrogen Energy Demand Growth Prediction and Assessment (2021–2050) Using a System Thinking and System Dynamics Approach", Appl. Sci. 12, 2022.
8. J.Kurtz, T.Bradley, E. Winkler, C. Gearhart, " Predicting demand for hydrogen station fueling", International J. of hydrogen energy 56, 32298-32310 (2020).
9. M.Manfren, K.M. Gonzalez-Carreon, A.S. Bahaj, "Probabilistic modelling of seasonal energy demand patterns in the transition from natural gas to hydrogen for an urban energy district", International J. of hydrogen energy 51, 398-411 (2024).
10. Ministry of Land, Infrastructure and Transport in Korea, At grade Intersection Design Guidelines, 2015.