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Forecasting hourly traffic volume: Incheon international airport access road

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Abstract. This paper is intended to clarify the relationship between airport access road hourly traffic and airport user trip characteristics. A mathematical model is developed in order to provide a foundation for planning airport facilities and enhancing existing services. From the results, it can be concluded that a significant relationship exists between airport operation and traffic volume in airport access roads. It was found that the proposed model has good prediction capability for traffic volume on the Incheon International Airport Expressway on an hourly basis. This model can be used to predict the number of vehicles queuing at airport entrances, intersections, or toll plazas, predicting optimum toll lane staffing, and analyzing the level of congestion on the roadway for different levels of air passenger demand in the future.

1. Introduction

Seoul metropolitan area is served by two commercial airports; Incheon International Airport (ICN) and Gimpo Airport. ICN opened on March 29, 2001, to replace the older Gimpo airport. ICN serves the majority of international passenger flights in the Seoul area, while the Gimpo airport mostly handles domestic flights with short distance shuttle flights to alternative airports in China and Japan. ICN is located on reclaimed land between the Yeongjong and Yongyoo islands, 51 kilometers from downtown Seoul, and, following its opening, more than 21 million passengers and 2 million metric tons of cargo have used this airport. In 2013, the annual number of passengers using ICN passed 40 million for the first time since its opening. Furthermore, the number of airlines providing services in ICN has increased from 47 to 84 over the past 13 years. The number of cities being served surged from 109 to 176, with the number of transfer passengers increasing from 1.63 million to 7.06 million during the same period.

As of 2013, the airport has the capacity to handle 44 million passengers yearly. Meanwhile, construction of the 2nd terminal is expected to be completed by 2017. Once the new terminal opens, it will increase total capacity by serving an additional 18 million passengers. With the new cargo terminal and apron, the 2nd terminal will ease capacity issues regarding the growing number of passengers and cargo, with its new passenger capacity increasing from 44 million to 62 million, and 4.5 million tons of cargo increasing to 5.8 million tons.

Upon the opening of ICN, access to the airport was facilitated by the newly constructed six-lane Incheon International Airport Expressway. This

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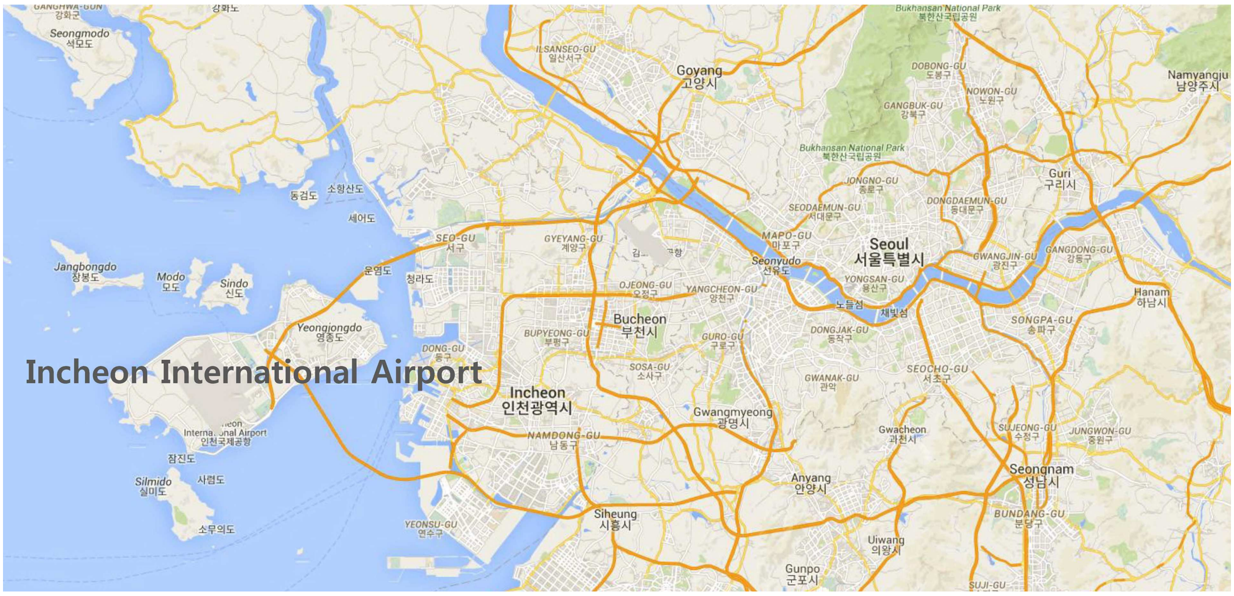

Figure 1. Incheon International Airport highway map (Source: Incheon International Airport).

expressway, connecting ICN and mainland Seoul, has been in operation since 2001. Because ICN was built between two islands, and there is a single bridge over the sea connecting ICN and the mainland, the Incheon International Airport Expressway was the only access road to the airport, excluding a small number of ferries, until opening the Incheon Bridge in October 2009 (Figure 1).

By its nature, the toll plaza in ICN access roads can become a major congestion bottleneck that can impede vehicular movement. A number of toll lanes are operational during peak hours. Conversely, during off peak periods, opportunities exist to maximize the efficiency of the toll operation by determining the optimum lane staffing requirements needed to meet an acceptable service standard [1]. Recognizing that most traffic is airport-bound, which significantly varies over time, it would be helpful to develop an analytical approach that could be used to select the most cost effective strategy for facilities in ICN access roads.

2. Research objectives

Airports are one of the largest generators of people and goods traffic in metropolitan areas. From the perspective of a city's overall transport network, trip generation of a major airport is usually second only to that of the city's central business district [2]. When airport capacity is addressed, most people consider the number of aircraft takeoffs and landings that runways can possibly handle, the number of arrival and departure flights that gates and ground facilities can handle, or the number of passengers that terminal concourses, hold rooms, or ticket counters can process. However, there is another element in any airport whose operation governs airport capacity and dominates passenger perception of the entire airport operating system. This is the airport ground transportation system, especially the terminal roadway and curbside area [3]. Flight passengers, and anyone who accompanies them have to use some mode of ground transportation to access or leave the airport terminal. All passengers, their baggage, companions, ground service personnel, pilots and crew members all have to use this common area to continue their journeys. To improve roadway traffic operation on the airport access road, it is important to develop a useful analytical tool that helps airport planners, engineers and operators to analyze and evaluate airport access road traffic.

For most traffic engineering studies, traffic flow is usually analyzed and evaluated on an hourly basis for design and planning. However, few studies have been performed that estimate the number of ground passenger trips made to an airport as a function of originating passengers by time of day. The objective of this paper is to develop and validate a mathematical model which forecasts hourly traffic volume using airport operation data by time of day. To develop this model, it was required to determine if, and to what degree, the hourly traffic volume of the Incheon International Airport Expressway is correlated with airport operation data. The developed model will aid in the following analyses:

1. Predicting the number of vehicles queuing at airport entrance intersections and the toll plaza by time of day;
2. Predicting optimum toll lane staffing for different levels of flight schedule on an hourly basis;
3. Evaluating different toll lane operation strategies;

4. Analyzing the level of congestion on the roadway for different levels of air passenger demand in the future.

3. Literature review

Airport ground transportation systems have received increasing attention from airport authorities and regional transportation agencies [4]. A number of studies have documented various subjects, including transit services, travel mode choices, curbside design, and terminal parking operations, to mitigate congestion in the airport system. Regarding ground transportation at the airport, Shapiro et al. provided policy guidance, rules of thumb, data, and analytical techniques related to airport access in the "Intermodal Ground Access to Airports: A Planning Guide" [5]. Using the guide as a starting point, Mahmassani et al. expanded the set of solution options to consider airport access in its strategic regional context, and, further, addresses specific issues encountered at Texas airports in America [6]. Shapiro and Katzman presented highlights from the planning guide and provided detailed discussion of vehicle trip relationships and airport trip generation, curbside configurations, parking requirements and mode access to US airports [7]. Mahmassani et al. summarized the findings of the literature review and discussed the applicability of ground access planning to four major airports in Texas [6]. In this report, previous articles and reports were grouped into five main categories: At-airport issues, demand side, entire airport system, network, and rail access. Hoel and Shriner described the elements that comprise airport access. They developed a methodology for identifying and evaluating existing landside access performance and proposed improvements from a passenger perspective [8].

To predict landside demand, numerous models have been applied. Many have tried to evaluate passenger airport choices or passenger mode choices traveling to the airport. Others have tried to predict landside traffic to solve and mitigate curbside congestion. Airport land access models have collected and analyzed the vehicle arrival pattern, and have fitted a statistical distribution, such as Poisson distribution or exponential distribution, to generate vehicular traffic for the model input [6]. However, few studies have been performed that estimate the number of ground passenger trips made to an airport as a function of originating passengers by time of day [5]. Also, existing tools that have been used thus far in airport ground access system analyses are either focused on curbside parking or mode choice. Therefore, as airport ground access systems are becoming more congested, a good analytical tool is needed to help better plan, design and manage the airport access road. For predicting traffic volume in airport access roads information regarding roadway operations, such as toll plaza design, land staffing and traffic management, should be provided.

4. Model development

Incheon International Airport was selected as the target airport for the model, because the airport has limited access roads to the mainland from where all air passengers travel. This provides a very good environment for developing a model that can fully reflect the relationship between air passenger distribution and real traffic operation at the airport access road, without other outside factors affecting the results. Since Incheon International Airport Expressway was the only access road to the airport, excluding a small number of ferries, until opening the Incheon Bridge, traffic data before the opening of the Incheon Bridge was used for the analysis. The traffic information collected includes: inbound and outbound traffic volume on the Incheon International Airport Expressway for 24 hours, and an origin/destination and trip purpose survey carried out at the Incheon International Airport Expressway toll plaza. The collected traffic data were used to validate the model. Some other crucial data for the model, such as airline flight operation data on those days when traffic data were collected, passenger arrival and departure time distribution, and transportation mode split, were acquired from the Incheon International Airport Corporation. The following step describes the proposed model for this study.

Step 1. Generating air passengers on an hourly basis
One should multiply the flight seat capacity by the load factor (the number of passengers on board vs. the number of seats on the flight) and subtract the number of transfer passengers to estimate the number of origin/destination passengers for each flight. If passenger arrival and departure distribution data by time is available, this step is not preceded.

Step 2. Modal split and party size distribution
One should use transportation mode split information to assign each airline passenger a transportation mode, such as automobile, taxi, bus, etc., and use passenger party size distribution to group passengers of the same transportation mode. This information can be obtained by survey.

Step 3. Trips generated by enplaning passengers
One should apply passenger arrival time distribution, prior to the flight scheduled departure time, to assign each enplaning passenger party an arrival time at the airport. He/she should create a vehicle for each pas-

senger party that uses private transportation modes, and sign an arrival time to each vehicle based on the passenger party's arrival time at the airport.

Step 4. Trips generated by deplaning passengers
One should apply passenger departure time distribution after the flight to assign each deplaning passenger party a departure time at the airport.

Step 5. Trips generated by greeters
One should apply greeters per passenger rate, and their arrival time distribution to assign each greeter party an arrival time at the airport. He/she should create a vehicle for each greeter's party that uses private automobiles to come to the airport, and assign an arrival time to each vehicle, based on greeters arrival time distribution at the airport, to pick up their passengers. One assumes that greeters are using the same vehicle after they meet their passengers at the airport.

Step 6. Trips generated by well-wishers
One should apply well-wishers per passenger rate, and their departing time distribution to assign each well-wisher party a departing time at the airport. He/she should create a vehicle for each well-wisher party that uses private transportation modes, and assigns a departing time to each vehicle, based on their departing time distribution, after sending off their passengers at the airport. One assumes that well-wishers are using same vehicle when they come to the airport.

Step 7. Predicting traffic volume of the airport access road by time of day
One should apply vehicles generated from Step 3 through Step 6 to the inbound and outbound traffic flow of the airport access road. In the model, it is assumed that mode choice and time distributions for departing/arriving at the airport did not vary by the time of day. They can be determined based on survey data. Depending on availability, data from all time periods can be pooled to derive mode choice and departing/arriving time distributions. No specific mode choice distributions were identified for peak or non-peak hours.

5. Results and model validation

Model validation shows how reliably people can use the proposed simulation model to analyze a real-world system. In other words, model validation is a procedure that helps determine if the proposed simulation model can replicate real world operations of the target system, so that its results can be used for decision-making purposes with confidence. For the purpose of model validation, traffic volumes derived from the model were compared to the actual traffic volume collected from the Incheon International Airport Expressway by time of day. Also, correlation between the model and actual flow was checked by time of day. To statistically prove the results, a correlation test between the model and actual traffic volume was performed for 4-day traffic data. The correlation coefficient, ρ_{ij}, between two random variables, X_i and X_j, is defined by:

$$\rho_{ij} = \frac{C_{ij}}{\sqrt{\rho_i^2 \rho_j^2}}, \tag{1}$$

where, C_{ij} is the covariance between X_i and X_j, and ρ_i and ρ_j are the variance of X_i and X_j.

The correlation coefficient is used as a measure of the dependence between two random variables, say X_i and X_j. The value of the correlation coefficient is between -1 to 1. If ρ_{ij} is close to +1, then X_i and X_j are highly positively correlated. On the other hand, if ρ_{ij} is close to -1, then X_i and X_j are highly negatively correlated. For the purpose of validating the dependence between the model and the actual traffic data, the results from the model were treated as the outcomes of one random variable, and the actual traffic data as the outcomes of another random variable. The correlation coefficients between the model and the actual traffic volume for the 4-day data from the Incheon International Airport Expressway were calculated and listed in Table 1.

In Table 1, the correlation coefficient between the model and the actual traffic data at the Incheon International Airport Expressway shows that they are highly associated. For traffic volume on day 3, the correlation coefficient between the model and the actual data is low (although a correlation coefficient of 0.874/0.907 still shows a high correlation), due to the fact that the small beach on Yeongjong island attracts people during the weekends of the summer months. People come to Yeongjong Island on Saturday from the mainland and go back on Sunday afternoon. Evidence supporting this phenomenon can be identified by looking at the total traffic volume in each direction, because outbound traffic (to the mainland) volume (33,439) is 1,505 more than inbound traffic (31,934) on Sunday (Table 2). Figure 2 also explains the excessive afternoon outbound traffic volume in detail.

On the other hand, the differences between in-

Table 1. Correlation coefficient between the model and the actual traffic data.

	Day 1, weekday	Day 2, weekday	Day 3, Sunday	Day 4, weekday
To ICN	0.932	0.919	0.874	0.911
From ICN	0.922	0.905	0.907	0.968

Table 2. Differences between inbound traffic and outbound traffic (number of vehicles).

	Day 1, weekday	Day 2, weekday	Day 3, Sunday	Day 4, weekday
To ICN (A)	30,442	24,749	31,934	25,006
From ICN (B)	29,882	24,217	33,439	25,728
A-B	560	532	-1,505	-722
% (A-B)/B	1.84	2.15	4.50	2.81

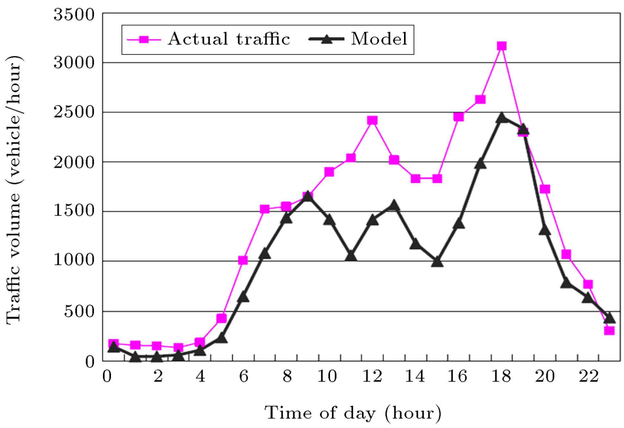

Figure 2. Model results vs. actual traffic volume (day 3 - Sunday, from ICN).

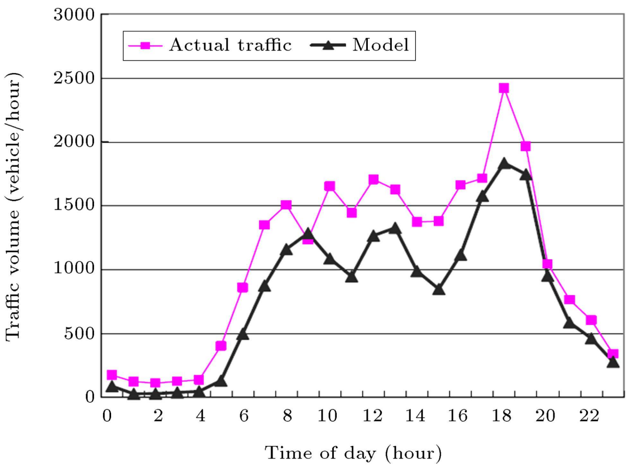

Figure 3. Model results vs. actual traffic volume (day 4 - weekday, from ICN).

bound and outbound volume on the 3 other weekdays are very small compared to Sunday (Table 2), and the difference between model volume and actual traffic volume in weekday traffic data is well dispersed over 24 hours (Figure 3). Figure 3 shows the actual traffic volume is more than the model volume for every hour. These relatively low values are probably because of the following reasons:

1. Traffic of airport employees was not modeled. ICN is staffed 24 hours a day with various types of worker. Although many employees live in Yeongjong new town inside the island, and many living outside the island commute by mass transportation systems (commuter bus), a number of people still commute using their own vehicles;
2. Traffic of the airport freight terminal was not modeled. Traffic related to airport freight is not sensitive to departure and arrival times, like air passengers, so, it is difficult to model, and this traffic accounts for just 1.8% of total traffic;
3. Tourists of Yeongjong Island were not modeled. This traffic is evident at weekends;
4. Trips of Yeongjong new town residents to the mainland were not modeled.

6. Discussion

Based on the origin/destination and trip purpose survey conducted at Incheon International Airport Expressway, the toll plaza shows that this traffic accounts for 25.9% of total traffic (Table 3). Table 4 also shows that 77.5% of vehicles using the Incheon International Airport Expressway are either traveling to or from the ICN terminal. This result is in full accordance with the difference between actual traffic volume and model volume. Figure 4 shows that model volumes are 17.10 to 29.19% lower than actual traffic volume. Although there are differences between model results and actual data, if the above reasons are considered, the proposed model traces actual traffic flow well. Significantly, the correlation coefficients are all above 0.874 for four-day hourly traffic volume, and over 0.90, except Sundays, from the airport (Table 1). Because traffic flow is usually analyzed and evaluated on an hourly basis for

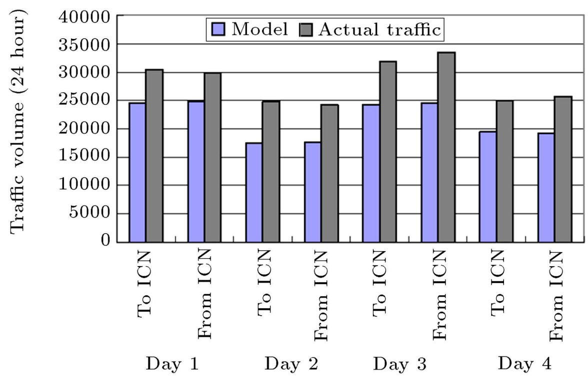

Figure 4. Model results vs. actual traffic volume.

Table 3. Trip purpose distribution of Incheon International Airport Expressway users.

Trip purpose	Airport related (excluding airport employee)	Work	Pleasure	Others
%	74.1	19.4	1.8	4.7

Table 4. Origin or destination in Yeongjong island.

Origin or destination in Yeongjong island	Airport passenger terminal	Airport employee parking or freight terminal	Yeongjong newtown or costal area
%	77.5	19.4	5.0

engineering design and planning, it can be concluded that the proposed model will assist airport operators and analysts in performing analyses on their airport roadway traffic operations.

7. Conclusions

In an effort to customize a methodological approach for ICN access road traffic, it is important to understand the relationship between traffic volume and airport user trip characteristics. An analytical model was proposed in order to provide a foundation for planning airport facilities and enhancing existing services. From the results, it can be concluded that significant relationships exist between airport operation and traffic volume in airport access roads. However, some factors were not considered; for example, the model did not include airport employee traffic and freight cargo. It may be possible to derive a simple and systematic model to predict employee commuting behavior and freight movement by time of day. Also, the model did not include Yeongjong Island tourist traffic and the traffic of Yeongjong new town residents traveling to the mainland, which were substantial on weekends.

In conclusion, the model validation results, based on comparisons of actual traffic data and traffic volume derived from the model, show that the proposed model possesses the ability to predict operations of an actual system. Nevertheless, employee commuting traffic, freight traffic and non-airport related traffic need to be further investigated. The model shows that traffic volume is highly correlated to airport operational data on an hourly basis. This model can be used to (1) predict the number of vehicles queuing at airport entrance intersections and the toll plaza by time of day; (2) predict optimum toll lane staffing for different levels of flight schedule on an hourly basis; (3) evaluate different toll lane operation strategies; and (4) analyze the level of congestion on the roadway for different levels of air passenger demand in the future.

The methodology in this model is flexible and may accommodate airports with a wide range, if enough data for local conditions are provided. Furthermore, this evaluation process requires no special training. This model can be applied to engineering, and traffic operation and planning fields. In real-world applications, the model may need to be modified to cope with local operational situations, such as passenger ground transportation mode choice, and arrival/departure distributions. Although the model was developed with an emphasis on an airport roadway, the same logic and model can be applied to similar places, such as for access roads of bus or transit stations and seaports. In planning and design applications, the model can be used for analysis, if the proposed access roadway and toll plaza are able to accommodate anticipated future demand levels by time of day.

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Conflict of interests

The authors declare that there is no conflict of interest regarding the publication of this article.

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Biographies

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