A Model of the Elasticity of Railway Fare and Travel Time of General Trains

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Abstract: General trains, characterized by high accessibility, are heavily influenced by competing transportation methods, railroad policies, and environmental change. Thus, the development of a direct demand estimation model that can comprehensively reflect external environmental factors that impact passenger demand is required. This study has selected external determining factors that influence the demand for each train line based on the Saemaul Line, a line that exemplifies the general train lines in Korea, and followed by the construction of a direct demand estimation model based on the gravity model. This study analyzes the influence of the determining factors of railway fare and travel time. The results of the elasticity analysis on railway fare and travel time indicate that general train passengers are more sensitive to railway fares unlike the passengers of high-speed trains who emphasize the value of time. The analysis results can be used as basic data for line-specific train operation planning.

Keywords: transportation planning; transport policy; passenger demand; demand estimation model

1. BACKGROUND

This study uses a time series model, which is a model often applied when estimating short-term passenger demand for general trains. As the time series model only uses historic passenger volume data for estimations, there are limitations to the explanation of external environmental changes such as the introduction of new lines or updates to train operating schedules. Specifically, general trains that have higher accessibility compared to mobility are heavily influenced by competing transportation methods, railroad policies, and environmental change. Thus, the development of a direct demand estimation model that can comprehensively reflect external environmental factors that impact passenger demand is called for.

Direct demand estimation models are based on theories of consumer behavior in the field of economics. Related models include the Quandt-Baumol Model (conductivity model), the McLynn Model, and the Competition Model of Logistics. Among these models, the Quandt-Baumol model considers the regional population, average income, industrial character of the origin and travel zones, minimum or relative travel time, travel cost, and the departure frequency of transportation modes as the determining factors. The Competition Model of Logistics includes population, income, employment levels, and service characteristics as determining factors. Kim and Jeong (2010) constructed a direct demand estimation model for railway passenger demand and considered the determining factors to be various socioeconomic indices such as population, distance, the number of industry workers, the number of cars, and road extensions. Jeong and Kim (2012) cited the Honam Line as an example when estimating the demand for general trains and proposed population, inter-regional distances, and the number of cars as socioeconomic indices. Moreover, the authors argued that when cities grow larger, the accessibility of train stations declines and the area of a city should be included in the model. Among the external factors influencing passenger demand, Jeong et al. (2007) emphasized the importance of demand elasticity between railway fares and train operating hours.

Prior to the introduction of the Korea Train eXpress (KTX), the Saemaul train was the leader in interregional passenger transport and a leading mode of metropolitan transportation. However, with the value of time constantly increasing for Korean citizens, passenger demand for the KTX is also increasing while the Saemaul Train is experiencing declining demand. In this context, the analysis of factors influencing passenger demand for the Saemaul train can play an important role in strategically developing an operating plan for the Saemaul train. Therefore, this study selects external determining factors influencing passenger demand of train lines referencing the five main lines of the Saemaul train including the Gyeongbu Line, Honam Line, Jeolla Line, Janghang Line, and Jungang Line. This study constructs a direct demand estimation model based on the gravity model and analyzes the influence of railway fare and travel time.

2. ANALYZED DATA AND DATA CHARACTERISTICS

The data used in this study are based on passenger volume data available from data warehouse (DW) of KORAIL. Moreover, the basic data of the Annual Railway Statistics use the meta-view data from "[National Railroad] Passenger-Operating Month-Departing Station." However, this study has also included the meta-view data from "[National Railroad] Passenger-Days of Operation-Additional Fare (Departing Station)" including daily analysis and monthly fares.

2.1 Passenger Volume Trends in Trunk Lines

Trunk-line trains can be divided into KTX and general train lines, and general train lines can be divided into the Saemaul train, Mugunghwa train, and the commuter train. With increasing service areas, KTX has shown average annual growth of 8.3% in the past five years (2010~2014); the opening of the second section of the Gyeongbu high-speed railway (November 2010), completion of the first section of the double-tracked Gyeongchun Line (December 2010), and the opening of the double-tracked Jeolla Line (October 2011) has contributed to this rapidly increasing passenger volume. Despite the significant decrease in trips by the Saemaul train with its operable age nearing its end, the introduction of the Nuri Line (June 2009) and the sizeable decrease in general train fares from June 2008 have led to an increase in short-distance passengers and an average annual increase of 2.3%.

Table 1. Passenger volume by year

(Unit: thousand passengers)

Year	KTX	General Train				Total
		Saemaul	Mugunghwa	Commuter	Subtotal	

2010	41,349	10,925	58,565	1,255	70,745	112,094
2011	50,309	10,206	60,510	744	71,460	121,769
2012	52,362	9,380	63,333	742	73,455	125,817
2013	54,744	9,036	67,163	1,090	77,289	132,033
2014	56,917	9,862	66,958	704	77,524	134,441
Growth (%)	8.3	-2.5	3.4	-13.5	2.3	4.6

Actual passenger volume by distance indicates that in the case of KTX, short-range (less than 100 km) and long-range (more than 301 km) trips are on the rise; medium-range (101 km~300 km) trips appear to be on the decline. For general trains, short-range (less than 100 km) trips are on the rise while medium-range (101 km~300 km) and long-range (more than 300 km) trips are on the decline. Annual distance on rail per capita for KTX has slightly decreased from 265.6 km in 2010 to 261.3 km in 2014. Similarly, for general trains, there has been a decline from 113.6 km in 2010 to 106.1 km in 2014.

Table 2. Passenger volume by distance

(Unit: thousand passengers)

Year	KTX			General Train		
	Less than 100 km	101 km ~300 km	Over 301 km	Less than 100 km	101 km ~300 km	Over 301 km
2010	10.7	61.5	41.1	116.9	63.5	13.4
2011	15.1	67.2	55.6	116.4	66.8	12.5
2012	16.1	68.9	58.0	122.6	66.3	11.8
2013	18.2	72.3	59.0	134.3	65.5	11.4
2014	20.0	75.0	60.0	132.9	66.4	11.1
Growth (%)	16.9	5.1	9.9	3.3	1.1	-4.6

2.2 Saemaul Train – Actual Passenger Volume

Actual passenger volume for the Saemaul train, calculated by line from the statistical review of average differences of actual passengers transported by line, year-over-year, from 2013 to 2014, indicates that the average changes in the following lines were significant: Gyeongbu (increase), Honam (increase), Jeolla (increase), and Janghang (decrease).

Table 3. Summary statistics of passengers transported by line, Saemaul train

Type			N	Average	Standard Deviation	Min	Max	Coef. of variation	t-value
Gyeongbu	Total	2013	365	11,621	3,256	4,320	19,764	28.0	-4.658
		2014	365	12,899	4,106	7,745	23,992	31.8	
	Weekdays (Mon-Thu)	2013	209	9,416	1,869	6,994	19,764	19.8	-3.768
		2014	209	10,230	2,591	7,745	22,454	25.3	
	Weekends (Fri-Sun)	2013	156	14,576	2,204	4,320	18,773	15.1	-6.579
		2014	156	16,474	2,850	10,339	23,992	17.3	
Honam	Total	2013	365	3,314	1,348	966	8,258	40.7	-4.775
		2014	365	3,852	1,680	1,318	9,799	43.6	

	Weekdays	2013	209	2,525	957	966	8,258	37.9	-3.395
	(Mon-Thu)	2014	209	2,863	1,075	1,318	9,799	37.5	
	Weekends	2013	156	4,370	1,037	1,472	7,214	23.7	-5.749
	(Fri-Sun)	2014	156	5,176	1,412	1,524	8,605	27.3	
Jeolla	Total	2013	365	1,486	549	442	3,485	36.9	-8.760
		2014	365	1,955	862	796	4,596	44.1	
	Weekdays	2013	209	1,175	395	442	3,485	33.6	-6.366
	(Mon-Thu)	2014	209	1,505	635	796	4,153	42.2	
	Weekends	2013	156	1,903	439	1,013	3,204	23.1	-9.395
	(Fri-Sun)	2014	156	2,558	752	1,254	4,596	29.4	
Janghang	Total	2013	365	6,461	1,720	3,873	11,038	26.6	3.439
		2014	365	6,069	1,333	3,847	9,394	21.9	
	Weekdays	2013	209	5,320	958	3,873	9,823	18.0	1.576
	(Mon-Thu)	2014	209	5,184	805	3,847	9,059	15.5	
	Weekends	2013	156	7,990	1,270	5,002	11,038	15.9	5.865
	(Fri-Sun)	2014	156	7,256	911	5,296	9,394	12.5	
Jungang	Total	2013	365	1,538	953	315	4,263	62.0	-0.291
		2014	365	1,557	821	467	3,880	52.7	
	Weekdays	2013	209	1,158	698	315	3,330	60.3	0.816
	(Mon-Thu)	2014	209	1,109	503	467	3,657	45.3	
	Weekends	2013	156	2,047	1,013	464	4,263	49.5	-1.073
	(Fri-Sun)	2014	156	2,157	782	727	3,880	36.3	

3. ANALYSIS OF RAILWAY FARE ELASTICITY AND TRAVEL TIME USING A DIRECT DEMAND ESTIMATION MODEL

This study uses a direct demand estimation model constructed for train lines (Gyeongbu, Honam, Jeolla, Jungang, Janghang) to analyze the demand elasticity of railway fares and travel time. Demand elasticity explains the rate of change in the dependent variable relating to the rate of change in the independent variable. This shows the influence of a specific independent variable on the dependent variable and forms the basis of policy structuring and management strategies. Elasticity refers to the price elasticity of demand and denotes the rate of change in demand that relates to the rate of change in price. In other words, if the demand for a good, q, is a function of p ($q = f(p)$), it can be denoted as below.

$$\epsilon = \left|\lim_{\Delta p=0} \frac{\Delta q/p}{\Delta p/p}\right| = \left|\frac{dq}{dp} \times \frac{p}{q}\right| \tag{1}$$

Equation 1 refers to a scenario where the dependent variable is not sensitive to a change in the independent variable and is, thus, inelastic; $\varepsilon = 1$ is a unit-elastic scenario where the rate of change of the independent variable is equal to that of the dependent variable; $\varepsilon > 1$ refers to a case where the dependent variable responds sensitively to changes in independent variables and denotes elasticity.

3.1 Estimating the Direct Demand Estimation Model

1) Setting model variables

General trains are characterized by multiple stops that tend to occur within the same city. Therefore, variables need to be set with different regional spheres. This study sets zones on the si and gun level by line and uses the gravity model to develop a double logarithmic regression by applying the natural log to the square of the selected variable between two regions. A correlation analysis is conducted to derive variables with high explaining power among the selected variables. The results indicate that collinearity exists in the socioeconomic indicators for population, GRDP, number of workers and city area, railway fare, railway operating hours, and travel distance among the railway service supply indices. Due to this collinearity, four models were constructed based on railway fare and train operating hours through stepwise inputs and selected variables with a high contribution and an appropriate model using the partial correlation coefficient, *t*-value, and R^2 values. This study concludes that the selected variables are statistically significant, and the direct demand estimation model with the highest model *R*-square value is selected as the final study model.

Table 4. Data construction for the direct demand estimation model

Type		Content	Note
Dependent variable		Transported passengers between regions (O/D) by train type and line, 2014	Actual passenger volume by Korail
Independent variable	Socioeconomic indicator	Population, GRDP, number of workers, city area, number of registered vehicles/population, highway extension/total road extension	Statistics Korea (National Statistics Portal)
	Service supply indicator (Policy aspects)	Railway fare, train operating hours, operating frequency and operating distance	Korail Railway Supply Data
	Influence of individual transportation modes	Vehicle distance, vehicle operating hours, operating costs	Korea Expressway Corporation, Ministry of Security and Public Administration (fare calculation standards)
	Other	Distance Dummy	Korail inter-station distance (O/D)

Note: For the population variable, the economically active population is provided as an indicator that includes both employed and unemployed persons over 15 years of age. This study uses the number of workers that show the economically active population as the final variables because this represents the actual size.

2) Results of the direct demand estimation model

① Gyeongbu Line

Both railway fare and travel time were selected as valid variables within the 95% significance probability; however, the explaining power of the railway fare was higher. Analysis of the direct demand estimation model with railway fare as a base led to the final variables of train operating frequency, city area, railway fare, and the number of registered variables/population. The variable with the most influence on passenger volume was train operating frequency.

② Honam Line

Both railway fare and train operating hours had low correlation with passenger volume, and the results were not significant. Therefore, they were not selected for model construction. Among the socioeconomic indicators, city area, train operating frequency, highway extension/total road extension, and the number of registered vehicles/population were selected as final variables. The variable with the highest influence on passenger volume was train operating frequency.

③ Jeolla Line

Similar to the Honam Line, both railway fare and train operating hours had low correlation with passenger volume with non-significant results and were not selected for model construction. The number of workers, operating frequency, highway extension/total road extension, and the short-distance dummy were selected as final variables.

④ Jungang Line

City area, highway extension/total road extension, and the short-distance dummy were selected as final variables within 95% significance probability. Railway fare had a low correlation with passenger volume and, therefore, was not selected at the time of model construction.

⑤ Janghang Line

Between railway fare and travel time, the fare was selected as a valid variable within the 95% significance probability. However, the coefficient of determination value was 0.207 and presented a 20% explaining power in estimating O/D passenger volume, which shows low explanatory power compared to other lines. For the Janghang Line, passenger characteristics are different compared to other lines that are used for commuter and tourist traffic. Therefore, the currently selected variables do not adequately reflect the passenger distribution of the Janghang Line, leading to low model reliability.

Table 5. Analysis results of the Saemaul direct demand estimation model

	Model	Unstandardized coefficient		Standardized coefficient	Significance probability	Collinearity	
		B	Standard Error	Beta		Tolerance	VIF
Gyeongbu Line	(Constant)	19.218	7.638		0.013		
	Train operating frequency	1.211	0.135	0.446	0.000	0.744	1.344
	City Area	0.563	0.090	0.404	0.000	0.446	2.244
	Railway Fare	-0.746	0.144	-0.238	0.000	0.878	1.139
	Number of vehicles/population	-2.385	0.811	-0.184	0.004	0.473	2.116
	R-square		0.725				
	Adjusted R-square		0.717				
	Model	Unstandardized coefficient		Standardized coefficient	Significance probability	Collinearity	
		B	Standard error	Beta		Tolerance	B
Honam Line	(Constant)	7.756	4.111		0.060		
	City Area	0.545	0.042	0.421	0.000	0.503	1.986
	Operating frequency	2.066	0.092	0.569	0.000	0.824	1.213
	Highway extension/total road extension	-0.127	0.027	-0.135	0.000	0.644	1.552
	Number of vehicles/population	-1.764	0.491	-0.132	0.000	0.396	2.524
	R-square		0.862				
	Adjusted R-square		0.860				
Jeolla Line	Model	Unstandardized coefficient		Standardized coefficient	Significance probability	Collinearity	
		B	Standard Error	Beta		Tolerance	B
	(Constant)	-4.926	0.787		0.000		

	Number of workers	0.487	0.032	0.660	0.000	0.875	1.143
	Operating frequency	2.318	0.231	0.440	0.000	0.851	1.176
	Highway extension/total road extension	-0.072	0.033	-0.093	0.034	0.879	1.138
	Short-distance dummy	0.566	0.144	0.161	0.000	0.974	1.027
	R-square		0.774				
	Adjusted R-square		0.767				
	Model	Unstandardized coefficient		Standardized coefficient	Significance probability	Collinearity	
		B	Standard error	Beta		Tolerance	B
	(Constant)	-2.846	1.605		0.084		
Jungang Line	City area	0.607	0.061	0.800	0.000	0.599	1.669
	Highway extension/total road extension	-0.242	0.087	-0.226	0.008	0.577	1.733
	Short-distance dummy	0.799	0.183	0.285	0.000	0.905	1.106
	R-Square		0.854				
	Adjusted R-square		0.843				
	Model	Unstandardized coefficient		Standardized coefficient	Significance probability	Collinearity	
		B	Standard Error	Beta		Tolerance	B
Janghang Line	(Constant)	10.119	4.086		0.016		
	Railway fare	-1.325	0.397	-0.440	0.002	0.859	1.164
	GRDP	0.347	0.124	0.368	0.007	0.859	1.164
	R-square		0.207				
	Adjusted R-square		0.178				

3.2 Analysis of Railway Fare Elasticity and Travel Time

For the Honam, Jeolla, and Janghang Lines of the Saemaul train, the variables of railway fare and travel time were not significant within a 95% confidence interval in a model developed with all railway passengers. This is because if the total service area is analyzed, the variable characteristics of travel time and railway, which are distance functions, are not appropriately reflected in the model. To resolve the issue of the significance of the railway fare and travel time variable, a strength analysis on railway fare and travel time is conducted by reflecting the travel characteristics derived in the reliability analysis. Therefore, this study has constructed separate distribution models for short distances (less than 100 km) and medium to long distances (more than 100 km) for the Honam, Jeolla, and Janghang lines of the Saemaul train to consider the distance-specific travel characteristics. The results of these models indicate that the railway fare and travel time variables were significant for both the short-distance and medium-to long-distance models for the Honam Line and the medium-to-long-distance model for the Jeolla Line. However, for the Janghang Line, railway fare was selected as a significant variable in the model for total service area as well as for the short-distance (less than 100 km) and medium-to-long-distance model (more than 100 km) while travel time was not significant. For the Janghang Line, the explaining power of the model was weak. Thus, the analyses of elasticity and the relative strength of travel time and railway fare were meaningless. However, on all five trunk lines of the Saemaul train (Gyeongbu, Honam, Jeolla, Janghang, and Jungang), railway fare was more influential than travel time. These results indicate that passengers of the general train were more sensitive to railway fare unlike the high-speed railway (KTX) passengers with high time value. Moreover, for the Honam and Jeolla lines of the Saemaul train, the elasticity value of railway fare and travel time were positive, indicating that increasing railway fares and travel times still leads to increasing passenger volume. This study concludes that the current passenger demand is higher than current train supply leading to no resistance to railway fares and travel time in train use.

Table 6. Results of Elasticity Analysis

Model		Travel time			Railway Fare		
		Coef.	Standard error	Significance probability	Coef.	Standard error	Significance probability
Gyeongbu	(Constant)	14.061	7.610	0.067	19.218	7.638	0.013
	Travel time or railway fare	-0.551	0.127	0.000	-0.746	0.144	0.000
	Operating frequency	1.216	0.139	0.000	1.211	0.135	0.000
	Vehicles/population	-2.281	0.832	0.007	-2.385	0.811	0.004
	City area	0.552	0.092	0.000	0.563	0.090	0.000
	R-square		0.744			0.725	
	Adjusted R-square		0.704			0.717	
Honam Short Distance	(Constant)	47.615	6.232	0.000	43.308	7.783	0.000
	Travel time or railway _fare	0.758	0.180	0.000	0.976	0.458	0.036
	Operating frequency	2.524	0.215	0.000	2.704	0.223	0.000
	Vehicles/population	-6.187	0.824	0.000	-6.421	0.872	0.000
	R-square		0.763			0.733	
	Adjusted R-square		0.756			0.725	
Honam Medium and Long Distance	(Constant)	38.822	4.631	0.000	35.895	5.406	0.000
	Travel time or railway _fare	0.517	0.186	0.006	0.518	0.193	0.008
	Operating frequency	2.259	0.124	0.000	2.275	0.126	0.000
	Vehicles/population	-4.881	0.578	0.000	-4.831	0.591	0.000
	Highway extension/total extension	-0.083	0.036	0.023	-0.086	0.036	0.019
	R-square		0.833			0.832	
	Adjusted R-square		0.828			0.828	
Jeolla Medium and Long Distance	Travel time or railway _fare	0.857	0.354	0.018	0.744	0.365	0.045
	Operating frequency	3.610	0.432	0.000	3.605	0.437	0.000
	Highway extension/total extension	-0.144	0.061	0.021	-0.149	0.062	0.018
	R-square		0.480			0.471	
	Adjusted R-square		0.463			0.453	
Jungang	Travel time or railway fare	-0.688	0.139	0.000	-0.971	0.171	0.000
	Highway extension/total extension	-0.234	0.083	0.007	-0.314	0.081	0.000
	City area	0.623	0.058	0.000	0.624	0.055	0.000
	R-square		0.867			0.882	
	Adjusted R-square		0.856			0.872	
Janghang	(Constant)	3.247	3.849	0.403	10.119	4.086	0.016
	Travel time or railway fare	-0.129	0.220	0.560	-1.325	0.397	0.002
	GRDP	0.204	0.128	0.117	0.347	0.124	0.007
	R-square		0.048			0.207	
	Adjusted R-square		0.012			0.178	

4. CONCLUSION

This study selected line-specific influential variables for the five trunk lines (Gyeongbu, Honam, Jeolla, Janghang, and Jungang) of the Saemaul train and constructed a direct demand estimation model based on the gravity model. The selected dependent variable was set as the passenger volume between stations (O/D) for each train and line; collinearity existed between the socioeconomic indicators of population, GRDP, number of workers, and city area, and correlations existed between travel distance, railway fare, and train operating hours with all of these variables related to distance. One of these independent variables was selected to construct the direct demand estimation model. Moreover, to improve the goodness of fit of the direct demand estimation model, distance variables deduced from the analysis of passenger characteristics using reliability theory were subsequently reflected in the reconstruction of the direct demand estimation model.

The results of the direct demand estimation model indicated that the value of the coefficient of determination (R^2) was more than 0.75 for most lines except for the Janghang Line, which indicated an explaining power level of 75%. Through the stepwise input method by train and line type, the direct demand estimation model based on each railway fare and travel time were used to analyze the influences of railway fare and travel time. The calculation of travel fare and travel time mechanisms involved functions of distance. Because collinearity exists between fare and travel time, a common variable was formed to construct the model, and the comparative influence was analyzed by comparing the coefficient values of models including railway fare and travel time variables and the coefficient of determination values (R^2).

The analysis results of railway fare and travel time indicated that on the five trunk lines of the Saemaul train (Gyeongbu, Honam, Jeolla, Janghang and Jungang), travel fare was found to be more influential than travel time. This corresponded to the observation that passengers of the general train are more sensitive to railway fare unlike passengers of high-speed railway trains (KTX) who had high time values. Moreover, the analysis indicated that the Honam and Jeolla lines of the Saemaul train had no resistance towards railway fare and travel time. Thus, it is expected that the results presented in this study from the demand change estimation model influenced by railway policies, environmental changes, and the analyses of strength could be used as basic data for railroad operation planning for each line.

While time series models are suitable for short-term estimation, they are based on past passenger results. Therefore, it is difficult to forecast demand following policy changes such as new lines or changes in operating frequency of train operations. Future research should focus on econometric models that reflect such characteristics. Moreover, transport capacity calculated from train types does not include potential passenger demand. Data from reservation information should also be used to additionally engage short and medium-term demand forecasts in the research.

Moreover, in constructing direct demand estimation models, other transportation modes such as long-distance buses also constitute choices for users and, thus, reflect railway demand. Additional research is required that considers other modes of transportation. Finally, for the Janghang Line, the construction of a direct demand estimation model could not reflect the transport characteristics of the Janghang Line with the currently selected variables. Therefore, additional variables should be considered that can reflect the transport characteristics.

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