Dynamic Analyses for Passenger Volume of Domestic Airline and High Speed Rail

Shih-Ching Lo

Abstract—Discrete choice model is the most used methodology for studying traveler's mode choice and demand. However, to calibrate the discrete choice model needs to have plenty of questionnaire survey. In this study, an aggregative model is proposed. The historical data of passenger volumes for high speed rail and domestic civil aviation are employed to calibrate and validate the model. In this study, different models are compared so as to propose the best one. From the results, systematic equations forecast better than single equation do. Models with the external variable, which is oil price, are better than models based on closed system assumption.

Keywords—forecasting, passenger volume, dynamic competition model, external variable, oil price

I. INTRODUCTION

FREEWAY coach, railway and domestic airline provide the intercity transportation of the western corridor in Taiwan before 2007. Each mode has its advantages and disadvantages according to the operational condition and service level. Taiwan High-Speed Rail (THSR) starts its service and joins the competition in the corridor on January 5, 2007. Buckeye [1] considered that intercity distance range of 100~400 miles high-speed rail and air carriers can both serve the passengers, whereas Kanafani and Youssef [2] considered the intercity distance range of 220~620 miles. In 2005, Lin et al. [3] estimated that approximately 50% of the air trips, 20% of Taiwan Rail Administration (TRA) trips, and 15% of freeway coach trips in Taiwan's western corridor would be replaced by THSR. A before-and-after comparison investigates passengers for the modal splits on Taiwan's western corridor regarding THSR's operations, 67.2% of air passengers, 47.6% of TRA passengers and 32.5% freeway coach travelers would change their mode of travel to THSR [4]. The results show that the three original modes of intercity transport are significantly affected by THSR, especially the air travel market. The impact of THSR on air market is much larger than the estimation of related studies [5]-[7]. Because of under estimation of the impact of THSR, airlines did not set up strategies to compete with THSR. Therefore, a robust forecasting model is necessary for transportation service operators so as to set up proper strategies or find out their niches to survive the keen competition.

Generally, regression method is the most used forecasting techniques. However, the predicted ability depends on the regression function and variables.

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Sometimes it is hardly to explain how the independent variables influence the dependent variables by the function. Time series analysis, which is also a common used method, might have the same problem. To analyze modal choice, discrete choice model is used mostly. By inquiring revealed and stated preference data, a Logit model or Probit model is built for analyzing modal split [8]-[12]. However, discrete choice model involve questionnaire survey, which takes time and money. If the external environment varies largely, such as financial tsunami in 2008, the prediction may also have large bias. Recently, Shyr and Hung [13] present a game theory based model to predict the competition between airline and THSR. They calibrate the payoff functions and solve the Nash equilibrium by maximizing payoff functions with respect to fare rates and flight frequency after the operation of THSR. They found that domestic airlines should unify as an alliance and cut their daily flights by 50% to maintain profitability.

In this study, we develop a macroscopic model to predict the passenger volume of domestic airline and THSR in the western corridor of Taiwan. To describe the competitive relationship between airline and THSR, the model is in the form of dynamic system equations. The basic model is developed based on the assumption that the two travel modes are in a closed system. That is, the external environment is unchanged. However, the social-economical environment changes with time. Therefore, a further model, which considers oil price as the external influence, is proposed. Oil price influences the level of price, economic, purchase ability and choice of travel mode. From the result, the model, which considers oil price, has better predicted ability than the closed system model. The remaining content of this paper is organized as follows. In Sec. 2, the background of domestic airlines and THSR are introduced briefly. Dynamic competitive model is proposed and numerical results are presented in Sec. 3. Finally, the conclusion is drawn in Sec. 4.

II. DOMESTIC AIRLINE AND THSR IN TAIWAN

Since the Taiwan government carried out the deregulation policy, which is so-called "sky opening" policy, in 1987. The aviation market in Taiwan had considerably prospered. The aviation market had grown greatly and reached its highest record in 1997. However, the number of passengers taking western airline had started to decline since 1998. Figure 1(a) illustrates the declining trend. One of the reasons is the improvement of highway systems and the deregulation of freeway coach. Although the operation of THSR is another reason of recession of domestic civil aviation industry, in fact,

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Taiwan's domestic airlines were facing a cash crunch before the high-speed rail service opened. Expecting the rapid opening of direct flights between Taiwan and China, airlines have made considerable investments in new planes during that time. Direct flights have, however, yet to materialize, and this preparedness has turned into a major financial burden. Soaring oil prices, industrial migration out of Taiwan and lackluster economic development on the island have also combined to reduce revenues. As a result, the domestic air travel market has shrunk and the THSR service is just another blow. Now, only the Mandarin Airlines, a subsidiary of Taiwan's China Airlines, still runs flights between Taipei and Kaohsiung, which once the nation's most lucrative domestic route that was also operated by three other local airlines, Uni Air, TransAsia Airways and Far Eastern Air Transport.
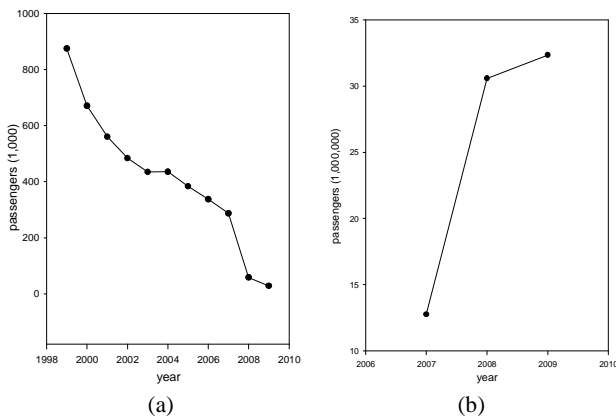

Fig. 1 Annual passenger volume of (a) domestic civil aviation and (b) THSR service in the western corridor of Taiwan

Taiwan High Speed Rail (abbreviated to THSR or HSR) is a high-speed rail line that runs approximately 345 km (214 mi) along the west coast of Taiwan from the national capital of Taipei to the southern city of Kaohsiung. Services began on January 5, 2007, using trains with a top speed of 300 km/h (186 mph), which offer journey times from Taipei to Kaohsiung as short as 96 minutes. In comparison, trains operating on the conventional Western Line of the Taiwan Railway Administration, take over four hours for the same journey. Tickets are more expensive than on normal trains or express buses, but cheaper than those for airplanes. Most intermediate stations on the line lie outside the cities served, with rapid transit connections constructed only after the opening of the line. Figure 1 (b) shows the annual passenger volumes from 2007 to 2009. The passenger volume grows from only 40,000 passengers a day to over 100,000 passengers a day in 2010. The original estimates foresaw a daily ridership of 180,000 passengers a day. Generally, about 140 train runs per day in average. A maximum 210 train runs is possible. The frequency was reduced with the onset of financial tsunami in 2008. A Taipei-Kaohsiung ticket on THSR costs NT$1,490 (US$45) is more expensive than TRA's NT$845 (US$25) and freeway coach's NT$500 (US$15), but it is cheaper than the fare of airplane, which costs 1,750 (US$53). Although the line haul

travel time of airplane is less than it of THSR, the total travel time of THSR is less than it of airplane. It is because the THSR trains usually serve city centers, whereas airports are typically located on the urban fringe by necessity. Therefore, THSR poses a severe threat to domestic western civil aviation services.

III. DYNAMIC COMPETITION MODEL

Dynamic competition model is extended from the population model. The simplest population model considered the growth rate of population is proportional to the population. If $N(t)$ is the function of population and t is time. Let α be the proportional constant. Then, we have $dN(t)/dt = \alpha N(t)$. The model can be solved analytically if the initial condition is given. The solution is $N(t) = N_0 e^{\alpha(t-t_0)}$, where t_0 is the initial time and N_0 is the initial population. According to empirical studies, the model can only to apply to short-term forecasting because when t increases N increases exponentially. The result is unreasonable and unrealistic. In real world, the growth of population is also proportional to the capacity of the system, that is, $dN(t)/dt \propto (M - N(t))$, where M is the capacity of system and is a constant. Combine the capacity restriction to the previous model, the analytical model is obtained by separation of variables. It is in the logistic form, which is given by

$$N(t) = M \left/ \left[1 + \left(\frac{M - N_0}{N_0} \right) e^{-\alpha M t} \right] \right. . \tag{1}$$

Under the close system assumption, Eq. (1) can be represented by a general form, which is $dN(t)/dt = F(N, t)$. $F(N, t)$ is the growth function. If two species of population are considered, the model is consisted by two equations with interaction terms, such as $dN_1(t)/dt = F_1(N_1, N_2, t)$ and $dN_2(t)/dt = F_2(N_1, N_2, t)$, where N_1 and N_2 are two species, F_1 and F_2 are growth functions of N_1 and N_2, respectively. The most famous model in this form is the Lotka-Volterra (LV) model [14]-[16], the model is given by

$$dN_1(t)/dt = a_1 N_1(t) + b_1 N_1^2(t) + c_1 N_1(t) N_2(t) , \tag{2}$$

$$dN_2(t)/dt = a_2 N_2(t) + b_2 N_2^2(t) + c_2 N_1(t) N_2(t) , \tag{3}$$

where a_1、a_2、b_1、b_2、c_1 and c_2 are coefficients. The multi-mode form of LV model is illustrated in Table 1 for the case of two species. Although there are five types of modes, note that there are two possible predator-prey interactions (depending on which species is the predator or prey) in predator-prey mode and two possible states (depending on which species is the stronger of the two) in amensalism model.

Bass model [17]-[18] is also a most used model for analyzing competition of two species or products. However, it is a parsimonious one which does not consider the competition factor in the market. Fisher and Pry [19] developed a simple substitution model based on the assumption that a new

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technology would displace an older established technology. However, the weakness of the Fisher and Pry model does not show their competition. Norton and Bass [20] took the Bass model as its core driver and incorporated the Fisher and Pry model to demonstrate the substitution effect. It can be used to forecast technological market growth or decline. Among these, the mathematical Lokta-Voterra model was used in many papers and it could well explore the diffusion phenomenon and reciprocal competition of two species [21]-[25]. Furthermore, equations of the system are not restricted to two. If there are three or four species, the system can be extended to three or four equations.

TABLE I
THE RELATIONSHIP ACCORDING TO THE SIGNS OF c_1 AND c_2

coefficient		Type	Explanation
c_1	c_2		
–	–	Pure competition	Both species suffer from each other's existence.
+	–	Predator-prey	One of them serves as direct food (N_2) to the other (N_1).
+	+	Mutualism	It is the case of symbiosis or a win-win situation.
–	0	Amensalism	One (N_1) suffers from the existence of the other (N_2), who is impervious to what is happening.
0	0	Neutralism	There is no interaction

In this study, Eq. (2) – (3) is the basic model and the passenger volume of airlines (N_1) and THSR(N_2) are the variables. In addition, different forecasting models are considered so as to compare the results. Models considered herein are given as follows:

(1) Single equation without oil price and interaction between airline and THSR: Eqs (4) and (5) show the model of airline and THSR. The two equations are employed to forecast passenger volume separately.

(2) Single equation with oil price but without interaction between airline and THSR: Eqs (6) and (7) show the model of airline and THSR, where $oil(t)$ denotes the external variable – oil price. The two equations are employed to forecast passenger volume separately.

(3) LV model without oil price: Eqs (2) and (3) are used to forecast passenger volume at the same time.

(4) LV model with oil price: Eqs (8) and (9) are used to forecast passenger volume at the same time.

$$dN_1(t)/dt = a_1N_1(t) + b_1N_1^2(t) \ , \qquad (4)$$

$$dN_2(t)/dt = a_2N_2(t) + b_2N_2^2(t) \ , \qquad (5)$$

$$dN_1(t)/dt = a_1N_1(t) + b_1N_1^2(t) + d_1oil(t) \ , \qquad (6)$$

$$dN_2(t)/dt = a_2N_2(t) + b_2N_2^2(t) + d_2oil(t) \ , \qquad (7)$$

$$dN_1(t)/dt = a_1N_1(t) + b_1N_1^2(t) + c_1N_1(t)N_2(t) + d_1oil(t) \ , \qquad (8)$$

$$dN_2(t)/dt = a_2N_2(t) + b_2N_2^2(t) + c_2N_1(t)N_2(t) + d_2oil(t) \ , \qquad (9)$$

Oil price is considered as the external effect because it not only influences the operating cost of airlines but also influences modal choice of travelers. In addition, oil price may also influence the inflation and influence the transportation demand indirectly. Therefore, we consider oil price is a good external variable. In our model, oil price is considered as the external input.

Figures 2 to 5 illustrate the comparison between actual and predicted data. To obtain the models, we calibrate coefficients by historical data firstly. Then, the models can be used to forecast. Table II is the R-square value of each equation. Obviously, single equation cannot forecast the passenger volume of airline well. The results of systematic models are better. Table III gives the absolute percentage error. From the results, models with oil price are better than models without oil price. According to the R-square value of each equation, the LV model with oil price should be the best model. However, the result of Fig. 3(b) seems to be better than the result of Fig. 5(b). Therefore, a combined model, which is consisted of Eq. (7) and (8), is proposed. Figure 6 shows the results, which are better than the four kinds of models presented above.
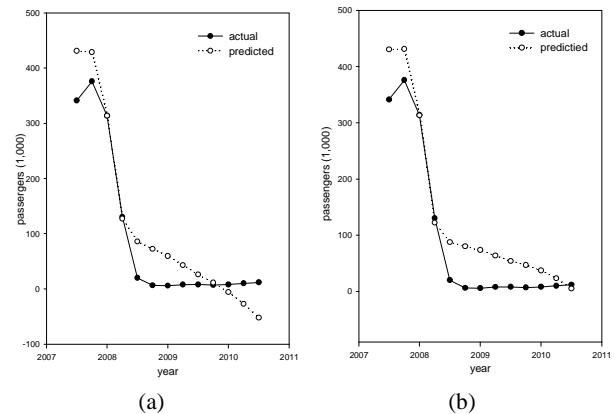

(a)   (b)

Fig. 2 Actual and predicted passenger volume of domestic civil aviation by (a) Eq. (4) and (b) Eq. (6)
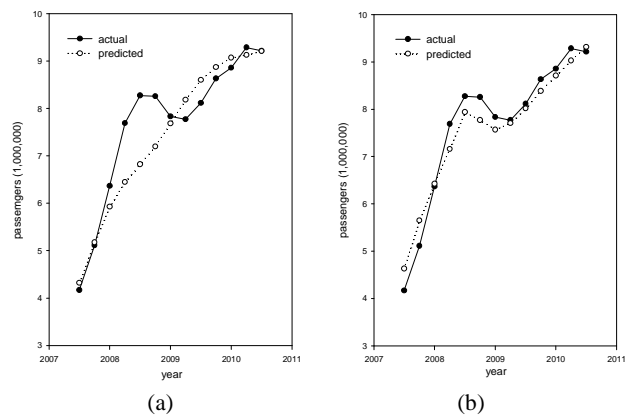

(a)   (b)

Fig. 3 Actual and predicted passenger volume of THSR by (a) Eq. (5) and (b) Eq. (7)

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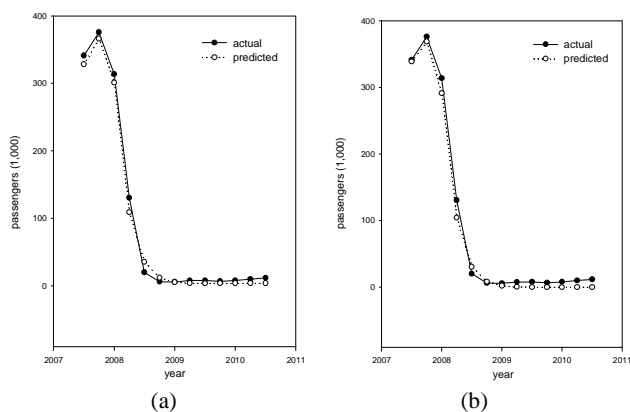Vol:6, No:1, 2012

Fig. 4 Actual and predicted passenger volume of domestic civil aviation by systematic models (a) without oil price and (b) with oil price.
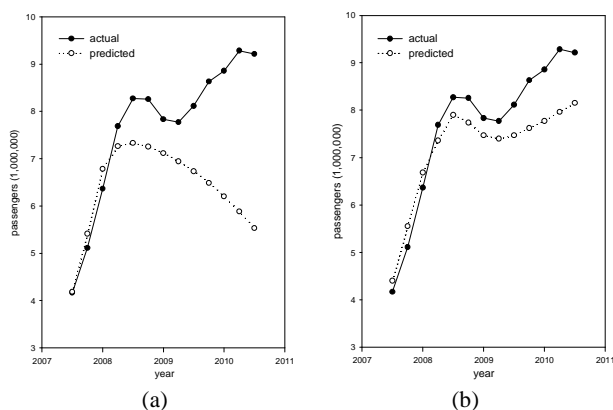

Fig. 5 Actual and predicted passenger volume of THSR by systematic models (a) without oil price and (b) with oil price
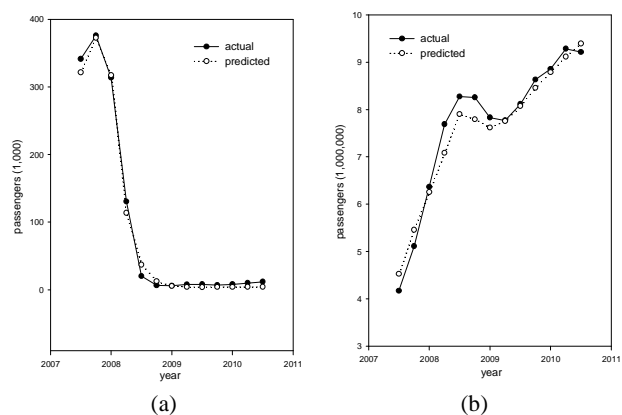

Fig. 6 Actual and predicted passenger volume of (a) domestic civil aviation and (b) by combined systematic models (Eq. (7) and (8)).

TABLE II
R-SQUARE VALUE OF PROPOSED EQUATIONS

Equation	R^2 of airline	Equation	R^2 of THSR
(2)	0.88	(3)	0.66
(4)	0.66	(5)	0.25
(6)	0.67	(7)	0.66
(8)	0.89	(9)	0.79

TABLE III
ABSOLUTE PERCENTAGE ERROR VALUE OF PROPOSED MODELS

Model	Mode	Max (%)	MAPE (%)	Min(%)
Eq.(4)	airline	1045.19	321.05	0
Eq.(5)	THSR	17.58	6.03	0.6
Eq.(6)	airline	1171.68	359.91	0.18
Eq.(7)	THSR	11.12	4.08	0.86
LV w/o oil price	airline	99.99	58.91	0.8
	THSR	39.99	16.17	0.38
LV with oil price	airline	89.74	40.99	2.54
	THSR	14.26	7.8	4.23
combined	airline	97.24	39.84	0.89
	THSR	8.63	3.47	0.2
* prediction of passenger volume has negative value.				
LV w/o oil price model: Eqs (2) and (3)				
LV with oil price model: Eqs (8) and (9)				
combined model: Eqs (7) and (8)				

The values and signs of the coefficients are given in Table IV. The signs of coefficients are consistent of the two models. From the signs of c_i, when the volume of THSR increases, the volume of airline increases, vice versa. This means domestic civil aviation and THSR are mutualism. It does not agree with the common sense. It may be caused by the consideration of external variable, oil price. The volume of THSR and the volume of airline increase with oil price. Although the oil price influences the operating cost of airline and may reduce the demand of airline. The oil price also influences the usage of cars and buses. Therefore, when the oil price increases, transportation demand may transfer to public transportation. That is, the volume of airlines and THSR increases.

TABLE IV
COEFFICIENTS OF SYSTEMATIC EQUATIONS

Model	Mode	Eq.	a_i	b_i	c_i	d_i
LV with oil price	Airline	(8)	-4.68	9.26×10^{-6}	2.45×10^{-7}	354.21
	THSR	(9)	-4.68	2.32×10^{-8}	4.93×10^{-7}	96678.22
combined	Airline	(8)	-4.68	9.26×10^{-6}	2.45×10^{-7}	354.21
	THSR	(7)	-0.52	4.05×10^{-8}	0	60393.29

IV. CONCLUSION

In this study, dynamic competitive models for forecasting passenger volumes of domestic civil aviation and THSR are proposed. According to the results, systematic equations forecast better than single equations do. Models with the external variable, which is oil price, are better than models based on closed system assumption. We find that the model consists of the highest R-square value may not present the most accurate result. A calibration method of calibrating coefficients of the systematic equation so as to obtain the best forecasting should be studied and left for further researches.

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