AN ESTIMATION SYSTEM OF TRANSFER TIME AT RAILWAY STATION WITH THE HELP OF COMPUTER AIDED DESIGN AND COMPUTER GRAPHICS

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Abstract: While there may be several alternative routes to go from an origin station to a destination station, railway passengers select one preferred route by considering route-related factors such as line-haul time, fare, congestion, impedance of transfers at stations and so on. In the Tokyo Metropolitan Area (hereinafter TMA), transfer facilities at stations have especially become an important factor, as a result of the increase in transfer opportunity due to the development of the railway network. This study aims to do the following: (1) to model the transfer behavior of passengers and estimate the transfer time at an interchange station, (2) to apply Computer Aided Design (hereinafter CAD) and Computer Graphics (hereinafter CG) to an estimation system, (3) to show the effect brought about by the introduction of station facilities such as; automatic ticket gates, stairs, escalators, etc., on the transfer time and (4) to suggest a planning process for new railway station projects. The study concludes that CAD and CG play an important role in evaluating the railway planning and design of transfer facilities at railway stations.

Key Words: Railway Planning, Transfer Service, Computer Aided Design, Computer Graphics

1. INTRODUCTION

The alternative routes of railway passengers in going from their origins to their destinations in the TMA have steadily increased as a result of rapid developments in the railway network. The decision to use a particular route is made on the basis of not only line-haul time and fare but also the ease of the transfer. It has been reported that over 80 % of passengers in the TMA must transfer during a normal commute and the average number of transfers per passenger is approximately 0.85 times[1)]. It is known however, that there are a lot of vertical transfers in an interchange station particularly in very large stations (e.g., Tokyo Station, Ueno Station, etc.). In other words transfer facilities (i.e., stairs, elevators, escalators, etc.) have become very important for passengers. Further, the former Ministry of Transport in Japan has indicated in the 18th verdict of transportation policy-making advisory board, published in January 2000[2)] that improvement and development of transfer services were necessary.

In the field of railway planning, there had been recent studies that focused on the details of transfer behavior at interchange stations and railway route choice (e.g., UCHIYAMA, H. *et al*[3], OSHIMA, Y. *et al*[4),5)], IIDA, K. *et al*[6)], YAI, T. *et al*[7,8),9),10)] etc.). In a large number of studies done in the past, the transfer time has consistently been treated as a constant. HIBINO, N.[11)] has suggested an estimation system for real and variable transfer time depending on degree of congestion as well as station design in order to measure the level of services at interchange stations. The proposed system involves the calibration of a railway route choice model and detailed railway network assignment analysis. It is conceivable that the railway route choice model and the railway network assignment model can become more precise by using the transfer data that the proposed system provides. The system is envisioned to be one of the sub-systems in the Railway Planning Supporting System for the TMA that the authors have developed[12),13)].

This study applies CAD and CG to the estimation system. Through the application of the CAD and the CG to the system, (1) the transfer time at a station may be estimated more precisely, (2) the transfer time at new stations that are in the planning stages can be also estimated, as well as existing stations that can actually be surveyed, (3) the transfer behavior of passengers at stations can be displayed visually, and (4) comparisons between alternative designs of proposed railway stations (i.e., with/without automatic ticket gates, stairs, escalators and so on) can be readily made. In other words, the study is to focus on the difference in transfer time based on the design of transfer facilities and the congestion at stations in order to evaluate railway services.

2. CASE STUDY

This paper estimates transfer behavior at Nagareyama Shin-shigaichi Station as a case study. The station is now planned as an interchange station where a new railway line (Joban Shin Line) crosses an existing line (Tobu Noda Line). The Joban Shin Line has been planned in order to enlarge the railway network in the northeast side of the TMA, to develop the regional area along the line, and to decrease the congestion of existing lines. The line is scheduled to operate from Akihabara Station to Tsukuba Station in 2005. It is predicted that a lot of passengers who go toward the central from northeast area will use the new line and the new interchange station. Figure 1 shows the geographic location of the case study area while Figure 2 shows the design of the station. The platform of the Tobu Noda Line is on the first floor, the concourse is on the second floor, and the platform of the Joban Shin Line is on the third floor. The station has 4 platforms, 2 latches, 8 stairs, and 8 escalators. In this study, the word "concourse" means the open flat area where passengers can walk for transfer, and the word "latch" means the area where the automatic ticket gates are located. The arrows shown in Figure 2 are the transfer routes that will be used by most passengers in the station from the platform of the Tobu Noda Line towards Kashiwa Station to the platform of the Joban Shin Line towards Akihabara Station. This study tries to estimate the transfer time along the arrows. Table 1 shows the forecasted data of the frequency of trains and the number of the passengers that will disembark a train during the peak hour.

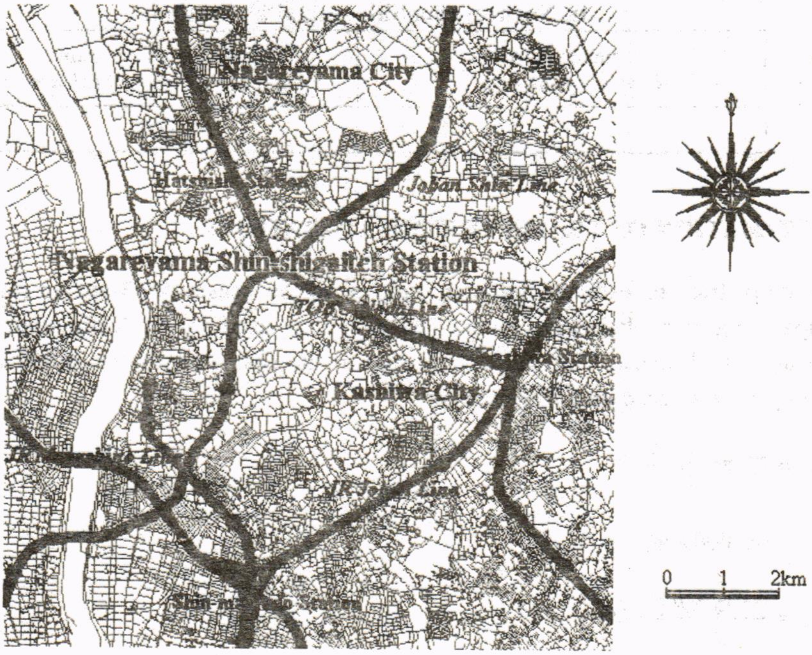

Figure 1. Geographic Location Nagareyama Shin-shigaitch Station

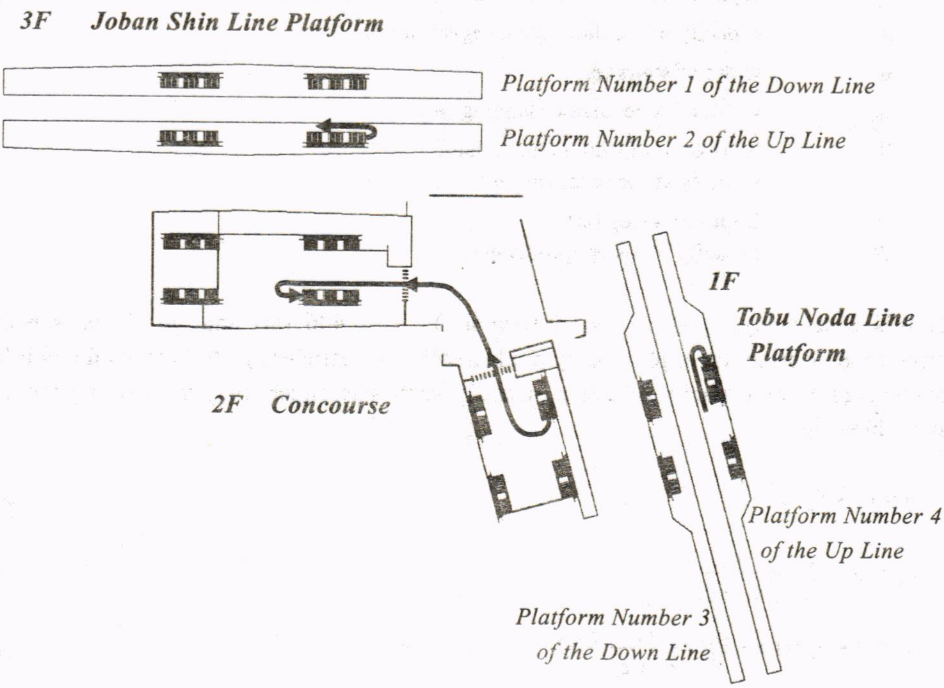

Figure 2. Design of Nagareyama Shin-shigaitch Station

Table 1. Data of Tobu Noda Line during Peak Commuting Periods in Nagareyama Shin-shigaitch Statiom

Frequency of trains (*trains / peak hour*)	Passengers from train (*passengers / train / peak hour*)
12	10,000

3. ESTIMATION OF TRANSFER TIME AT STATIONS

The study tries to estimate transfer time in various cases for transfer routes and to compare between alternative plans. The equations used for the estimation of transfer time are listed below. The parameters used in the case study were estimated from the existing papers based on actual surveys[1), 11)].

$$c_s = 2{,}500 \times w_s \tag{1}$$

$$c_{level} = 3{,}000 \times w_{level} \tag{2}$$

$$c_e = \frac{\eta \times v_e \times p}{d} \times 3{,}600 \tag{3}$$

where

c_s : capacity of stairs (*passengers/hour*)
c_{level} : capacity of concourse or landing (*passengers/hour*)
c_e : capacity of escalator (*passengers/hour*)
w_s : width of stairs (m)
w_{level} : width of concourse or landing (m)
η : Efficiency of riding on escalator
v_e : velocity at escalator (m/sec)
d : Depth of a step (m)
p : capacity of a step (*passengers*)

In this case study, η =0.75, v_e =30 (m/min), d =0.406 (m) and p =2 (*passengers*) were adopted from paper previously published[11)]. The efficiency "η " means that while 2 passengers is the capacity of a step, actually some passengers may miss riding the next available step.

$$n = n_s + n_e \tag{4}$$

$$n_s = (n-50) \times \frac{c_s}{c_s + c_e} \tag{5}$$

$$n_e = n - n_s = (n-50) \times \frac{c_e}{c_s + c_e} + 50 \tag{6}$$

where

n : number of passengers who use a vertical transfer facility per a train (*passengers/train*)
n_s : number of passengers who select stairs (*passengers/train*)
n_e : number of passengers who select escalator (*passengers/train*)

$$v_{s-up} = -0.9649 \times con_s + 1.761 = -0.9649 \times \frac{n_s}{c_s} + 1.761 \quad (7)$$

$$v_{s-down} = -1.045 \times con_s + 1.883 = -1.045 \times \frac{n_s}{c_s} + 1.883 \quad (8)$$

$$v_{level} = -2.814 \times con_{level} + 1.141 = -2.814 \times \frac{n_{level}}{c_{level}} + 1.141 \quad (9)$$

$$v_{latch} = v_{level} \times 0.9 = -2.533 \times \frac{n_{level}}{c_{level}} + 1.027 \quad (10)$$

$$v^0_{s-up} = 0.606 \ , \quad v^0_{s-down} = 0.643 \ , \quad v^0_{level} = 1.207$$

where

v_{s-up} : velocity of going up at stairs at the peak (*step/sec*)
v_{s-down} : velocity of going down at stairs at the peak (*step/sec*)
v_{level} : velocity of walking on concourse or landings at the peak (*m/sec*)
v_{latch} : velocity of passing through automatic ticket gates (*m/sec*)
v^0_{s-up} : velocity of going up at stairs at the off-peak (*m/sec*)
v^0_{s-down} : velocity of going down at stairs at the off-peak (*m/sec*)
v^0_{level} : velocity of walking on concourse or landings at the off-peak (*m/sec*)
con_s : factor of congestions at stairs
con_{level} : factor of congestions at concourse or landings
n_{level} : number of passengers who walks on concourse or landings per a train (*passengers/train*)

$$t_{s-wait} = 136.57 \times con_s + 4.273 = 136.57 \times \frac{n_s}{c_s} + 4.273 \quad (11)$$

$$t_{e-wait} = 136.57 \times con_e + 4.273 = 136.57 \times \frac{n_e}{c_e} + 4.273 \quad (12)$$

where

t_{s-wait} : waiting time in front of stairs (*sec*)
t_{e-wait} : waiting time in front of escalator (*sec*)

$$T = \sum t_i = \sum \frac{d_j}{v_j} + t_{k-wait} \quad (13)$$

where

T	: transfer time (*sec*)	d_j	: distance of *j* (*m*)
t_i	: transfer time at *i* (*sec*)	v_j	: velocity at *j* (*m/sec*)
t_{k-wait}	: waiting time in front of *k* (*sec*)	*i, j, k*	: transfer facilities

Three scenarios were considered in estimating transfer time. The first is the case where passengers use stairs only. The second is the case where passengers select an escalator and stand on the escalator. This case is called "Escalator (1)" in the paper. The last is the case where passengers select an escalator and walk up on the escalator. This case is called "Escalator (2)".

Table 2. Estimated Transfer Time at Peak Hour

		Tobu Noda Line					
		1F				*2F*	
		platform	wait	up	landing	concourse	latch
Stairs	velocity (*m/sec*)	1.024	0.000	1.738	1.024	1.047	0.942
	distance (*m*)	25.489	0.000	31.000	1.500	25.458	1.500
	time (*sec*)	24.898	7.543	17.838	1.465	24.311	1.592
Escalator (1)	velocity (*m/sec*)	1.024	0.000	0.500	0.000	1.047	0.942
	distance (*m*)	27.003	0.000	9.820	0.000	26.173	1.500
	time (*sec*)	26.377	10.561	19.640	0.000	24.993	1.592
Escalator (2) •	velocity (*m/sec*)	1.024	0.000	0.750	0.000	1.047	0.942
	distance (*m*)	27.003	0.000	9.800	0.000	26.173	1.500
	time (*sec*)	26.377	10.561	13.067	0.000	24.993	1.592

					Joban Shin Line			total
		2F					*3F*	
		concourse	latch	concourse	wait	up	level	platform	
Stairs	velocity (*m/sec*)	1.047	0.942	1.047	0.000	1.738	1.024	1.024	
	distance (*m*)	48.923	1.500	38.043	0.000	39.000	3.000	32.786	248.20
	time (*sec*)	46.718	1.592	36.328	0.000	22.441	2.930	32.025	**219.68**
Escalator (1)	velocity (*m/sec*)	1.047	0.942	1.047	0.000	0.500	1.047	1.024	
	distance (*m*)	48.923	1.500	39.050	0.000	10.980	3.720	34.886	205.86
	time (*sec*)	46.718	1.592	37.290	0.000	21.960	3.552	34.077	**228.35**
Escalator (2) •	velocity (*m/sec*)	1.047	0.942	1.047	0.000	0.750	1.047	1.024	
	distance (*m*)	48.923	1.500	39.050	0.000	10.980	3.720	34.886	205.86
	time (*sec*)	46.718	1.592	37.290	0.000	14.640	3.552	34.077	**214.46**

Table 3. Comparison of the Peak with the Off-peak

	Stairs	Escalator	
		(1)	(2)
Off-peak	187.6	191.8	176.2
Peak	219.7	228.4	214.5
(Peak)-(Off-Peak)	32.1	36.6	38.3

(*seconds*)

The result summarized in Table 2 show that the difference in the type (and usage) of transfer facilities affect the transfer time itself. Table 3 shows the estimated result of transfer time during peak and the off-peak hours which confirms that transfer time depends on congestion. This goes to show that the transfer time should not simply be estimated using time proportional to the distance because some form of impedance is introduced by the congestion along the way.

In order to measure the performance of transfer facilities, alternative designs are compared through three simulation analyses. The following three cases were applied: (1) with or without escalator, (2) the number of vertical transfer facilities (here a set of stairs and an escalator is counted as a unit), (3) the velocity of escalators from 30 (*m/min*) to 40 (*m/min*) or 60 (*m/min*). It should be noted, however, that the velocity of escalators is currently regulated under 30 (*m/min*) by the Fire Defense Law in Japan.

Table 4. Performance of Escalator at the Peak and the Off-peak

	Off-peak			Peak		
	Stairs	Escalator		Stairs	Escalator	
		(1)	(2)		(1)	(2)
Stairs and Escalator	187.6	191.8	176.2	219.7	228.4	214.5
Stairs only	187.6			222.5		

(*seconds*)

Table 5. Change in Total Transfer Time by the Number of Units

Number of Units of Vertical Transfer Facilities	Peak		
	Stairs	Escalator	
		(1)	(2)
1	231.9	239.9	226.0
2	219.7	228.4	214.5
3	216.0	224.9	211.0

(*seconds*)

Table 6. The Amount of Time Saving by the Number of Units

Number of Units of Vertical Transfer Facilities	Peak		
	Stairs	Escalator	
		(1)	(2)
1 → 2	12.3	11.5	11.5
2 → 3	3.7	3.5	3.5

(*seconds*)

Table 4 shows the transfer time with or without escalator during peak and the off-peak periods. From the viewpoint of the transfer time, the existence of an escalator does not bring about much higher time saving. The provision of escalator, however, may have another advantage with regards to safety, barrier free for aged and disable passengers, passenger flow control and so on.

Table 5 and Table 6 show the results of the second simulation analysis. Table 5 gives the tendency that makes the transfer time shorter with the increase of the number of units. The difference in the number of units is shown in Table 6. From the viewpoint of the amount of time savings, the difference in the number of units, 1→2 performs much better than 2→3. It is suggested therefore, that the station be equipped with two units of vertical transfer facilities that would result in an adequate and effective number of facilities.

Table 7. Total Transfer Time and Velocity of Escalator

Velocity of Escalators (*m/min*)	Off-Peak (*sec*)	Peak (*sec*)
30	191.8	228.4
40	181.4	217.4
60	171.0	206.2

Table 8. Performance of Velocity of Escalator

Velocity of Escalators (*m/min*)	Difference (*sec*)	
	Off-Peak	Peak
30 → 40	10.4	11.0
30 → 60	20.8	22.2

The results of the third simulation analysis are shown in Table 7 and Table 8 which show that the velocity of escalator has great effects on transfer time. If the velocity changes from the legal speed to some higher speed like the subway in Moscow [14)], more savings in transfer time could be achieved compared to the savings generated by the increase in the number of units described in Table 5 and Table 6.

4. APPLICATION OF CAD AND CG [15), 16)]

It is very important that transfer behavior is explained in studies of route choice and network assignment mentioned above. In short, it is necessary that the transfer time depending on the transfer distance and the degree of congestion are estimated. In this study, the distance is measured using CAD. The study produced a 3D design map of Nagareyama Shin-shigaitch Station, based on existing 1/500 scale drawings and plans. On the other hand, it is well known that the application of CG is useful in comparing alternative scenarios. In order to show the performance of automatic ticket gates, stairs, escalators and so on, the study developed a new system based on CG concepts. The new system is composed of a PC running WINDOWS 98 as its hardware core, and Auto CAD 2000 as the CAD software and Shade Professional R4 as the CG software. Figure 3 shows the displays with help of the CAD and the CG software. Figure 4 shows the transfer routes that are adopted by the analysis. Figure 5 shows the example of the CG animations.

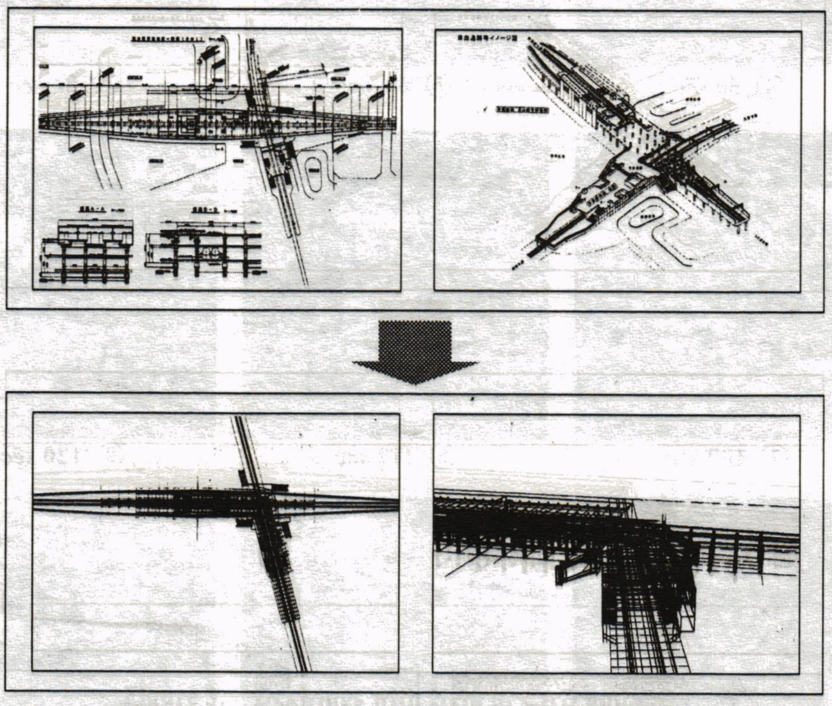

Figure 3. Drawings with Help of CAD and CG

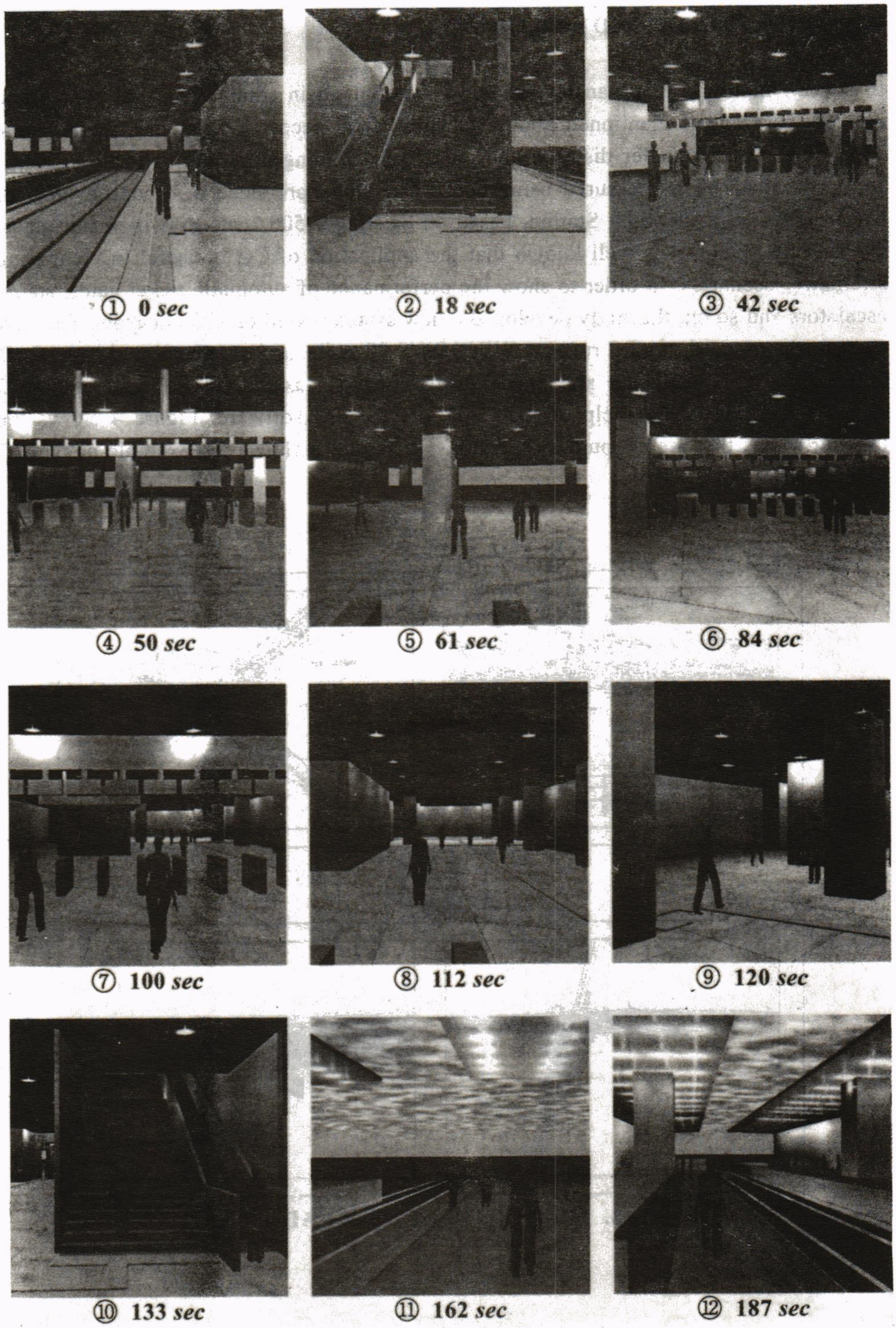

Figure 5. CG Animations

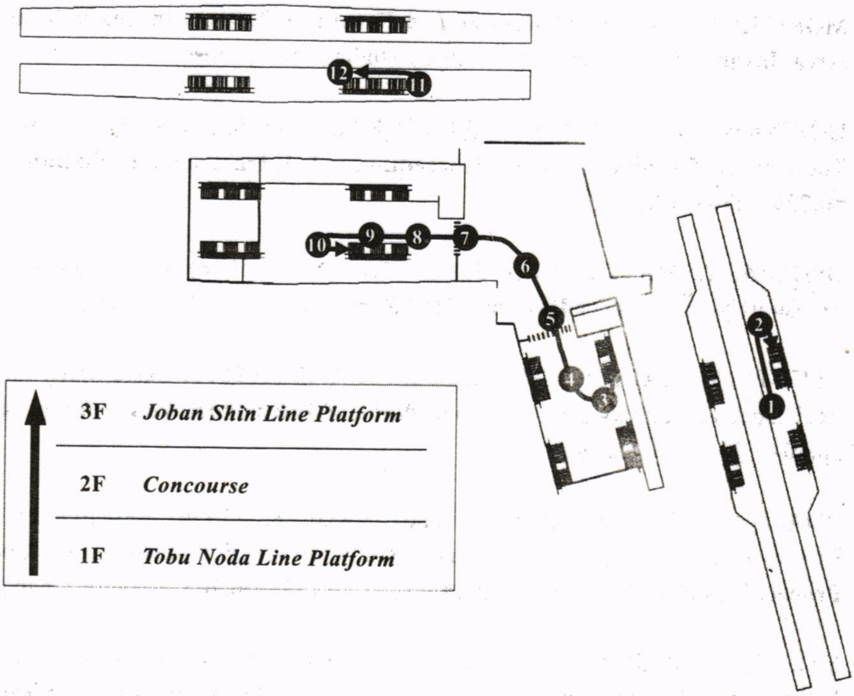

Figure 4. Transfer Route from Tobu Noda Line to Joban Shin Line

5. CONCLUSION

This study focuses on the transfer behavior of railway passengers and estimates transfer time at interchange stations depending on the location of the transfer facilities, the number of the units, and congestion brought about by passenger flow. The study demonstrates that factors such as the location, the number of the units and the congestion impact heavily on the transfer time. The study proposes a new estimation system of transfer time with the help of CAD and CG as follows: (1) the transfer time is estimated in detail, (2) the transfer behavior of passengers at stations is displayed and analyzed visually, and (3) comparisons between alternative designs of proposed railway stations (with respect to transfer facilities) are made. The study finally concludes that the proposed system can play an important role in evaluating the design of transfer facilities at railway stations in particular and railway planning in general.

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