Rail Rapid Transit Operational Assessment: a Case Study of the Airport Rail Link Bangkok, Thailand

Rajitha GUNATHILAKE [a], Surachet PRAVINVONGVUTH [b]

[a,b] *Graduate School of Transportation Engineering, Asian Institute of Technology, Pathumthani, 12120, Thailand*
[a] *E-mail: rajitha19909@gmail.com*
[b] *E-mail: spravinvongvuth@ait.asia (Corresponding Author)*

Abstract: Rail rapid transit has gained a lot of interest in Eastern Asia. Operations of a transit system play an important role in attracting passengers and receiving good reputations from public. To understand how well the system operates, an assessment is required. This paper summarizes key operational assessment from a practical point of view, given data availability and interests of practitioners. A case study was developed by using real world data from the Airport Rail Link (ARL) which is a commuter rail in Bangkok, Thailand. Operational indices cover the transit line operations, transit travel characteristics, transit line capacity, and schedule of service. Various tables, graphical displays, and key indices are illustrated as a practical example to assess the operations of a rail rapid transit system. The methodology used in this study can be applied to other rail rapid transit systems to assess their performances or to compare with another.

Keywords: Rail rapid transit, Operational assessment, Transit operations, Urban railway

1. INTRODUCTION

1.1 General Background

As a city gets bigger and more urbanized, it is more likely to develop a rail rapid transit system (Roth *et al*., 2012). Recently, many cities in the Eastern Asia have made large investments in establishing transit networks. A rail rapid transit system is not only a service to transport passengers to their destinations, it is more like a social service to reduce individual uses of private cars and hence reduce traffic congestions. It can be viewed as an investment alternative to road capacity expansion, but with higher capacity, less land acquisition, and less environmental impacts. It is stated in the literature that a rail rapid transit is considered to be the most energy efficient mode compared to other modes of mass transit (Newman and Kenworthy, 1999), but of course with sufficient ridership.

Transit ridership highly depends on its operations. It is important to assess how well the system operates to ensure that it can handle the demand while maintain an acceptable level of performance (Gercek *et al*., 2004). An assessment refers to a periodic process of gathering data and analyzing them in such a way that the resulting information can be used to determine whether the system is effectively operated and the extent to which it is achieving its stated objectives. Thus, a well-defined assessment should be compiled as an ongoing management and learning tool to improve a transit system.

There are many methods and indicators to assess a transit system in the literature; however, one might carefully apply to their problems due to data availability and complexity. If the analysis is too complicate, the decision makers cannot digest or even misinterpret the results.

This paper summarizes key operational assessment from a practical point of view, given data availability and interests of practitioners. A case study was developed by using real world data from the Airport Rail Link (ARL), which is a commuter rail in Bangkok, Thailand.

1.2 Bangkok ARL (Airport Rail Link)

The Airport Rail Link (ARL) was opened to the public since August 23, 2010. It is owned by the State Railway of Thailand (SRT) and operated by the SRT Electrified Train company (SRTET). ARL solely runs on a 28.5-kilometer double-track railway, from Phaya Thai (PTH) station in the center of Bangkok to the Suvarnabhumi (SVB) Airport station in the eastern part of Bangkok. The main purpose of developing ARL was to serve the airport passengers both inbound and outbound to shorten their travel times. Furthermore, many residents in the eastern part of Bangkok as well as the airport staff can use it for commuting.

ARL was developed as a system which was consisted of two Express Lines (which one line runs nonstop between the Makkasan (MAS) station and the Suvarnabhumi (SVB) station and the other line runs nonstop between Phaya Thai (PTH) station and the Suvarnabhumi (SVB) station) and the City Line, a commuter line that serves all the eight stations along the line as follows. The ARL route is shown in Figure 1.

(1) PTH - Phaya Thai (Terminal)
(2) RPR - Ratchaprarop
(3) MAS - Makkasan
(4) RKH - Ramkhamhaeng
(5) HUM - Hua Mak
(6) BTC - Ban Thap Chang
(7) LKB - Lat Krabang
(8) SVB - Suvarnabhumi (Terminal)

Figure 1. Airport rail link (ARL) route

Since September 2014, all the Express Lines were suspended due to the shortage of rolling stock availability. Until now, the City Line is the only line in operations. As a result, the assessment in this study is limited to the City Line. The ARL rolling stock consists of 9 sets of Seimens Desiro ll trains built in Krefeld, Germany. 4 trains – 4 cars (red color) were used for the two Express Line services while 5 trains – 3 cars (blue color) were used for the City Line service. As the Express Lines are currently under suspension, all the trains are now being used for the City Line service of which a train departs every 12 minutes during peak hours and 15 minutes during the off-peak and on weekends. The service time is every day from 6:00 to midnight.

1.3 Literature Review

"Attributes, "measures" or "indicators" which are referred as quantitative and qualitative elements of transportation system performance are plenty. At a fundamental level, transportation is defined as "the movement of a number of objects over a distance during an elapsed interval of time" (Vuchic, 2007). "Objects" are referred to be goods, persons, vehicles, units of vehicle capacity or trains consisting of several vehicles. The ratios of those three elements define basic performance attributes of transportation system when a number of objects are transported over a single path. Some of the basic attributes commonly used are speed, slowness, density, spacing, frequency, and headway.

When different kinds of decisions regarding transit planning, management and finance have to be taken, performance indicators play a major role. All the performance indicators are calculated as a ratio of two operating statistics for service inputs, service outputs and service consumption. The most common service effectiveness indicators are "passenger boarding per revenue vehicle mile" or passenger boarding per revenue vehicle hour" (Lena *et al*., 1994).

Many researchers have done evaluations for rapid transit systems throughout the world. It has been considered in turn the role of ITS (Intelligent Transportation Systems) technology in influencing the operational efficiency, technical performance and cost issues associated with BRT for the evaluation of performance and impacts of (BRT) Bus Rapid Transit implementation in Beijing (Deng and Nelson, 2013).

At the same time it has examined the possibilities of using the data from smart card based transit fare scheme which was introduced in Seoul (Jang, 2004). The easily obtained data as mentioned in the paper was transfer data as the on and off boarding information was include in the data set. Consequently the critical transfer points have been found and transfer patterns between two zones have been analyzed.

The Analytical Hierarchy Process (AHP) which is a multiple criteria decision support system has been used for the analysis of the three proposed rail transit networks in Istanbul transportation system (Haluk *et al*., 2004). Through the analysis, decision makers have developed a combination of most closely competing two alternatives which is now under construction

2. METHODOLOGY

2.1 Identification of operational indices

The operational indices which aid to evaluate the ARL were referred to Vuchic (2005). The indices which covered the basic transit line operations, transit travel characteristics, transit line capacity were initially identified and listed with all the required parameters in order to request for the relevant data sets. Once the data was collected twenty indices were picked from the list which could be calculated using the available real world data. All the indices are discussed in the Analysis and Results section.

2.2 Data Collection

The secondary data which was directly collected from the ARL depot was used for the entire analysis.

2.2.1 Passenger data

Passenger count of the ARL is done at the exit of each station. When the token or the value card is tapped at the exit gate, it reads all the information like where it was previously tapped (which determines the origin) and it is proceeded to automatically count the detailed passenger volumes.

The passenger data used in this study is the detailed passenger volumes which is the number of passengers exited at each station provided separately for each entry station for every hour from January 1 to December 31, 2014. For the analysis, the annual data was averaged where necessary using MATLAB software.

2.2.2 Speed and travel time data

The trains of the ARL run according to a preprogrammed timetable and a speed profile. Therefore, the train's arrival and departure times are accurate to the provided second unless the station standing times are more than thirty seconds (the typical station dwell time) due to overcrowdings. The ARL maintains two scheduled time tables which consist of departure and arrival at each station, for weekdays and weekends separately.

2.3 In Depth Assessment

The analysis was performed primarily based on the deterministic equations and concepts from Vuchic (2005). Numerical results were computed under different scenarios. Passenger volume and travel time analysis were also carried out focusing on the graphical presentation. In order to consider temporal variations, some selected relationships were analyzed further for peak and off-peak, weekdays and weekends, and each month.

3. ANALYSIS AND RESULTS

3.1 Basic Operating Elements

3.1.1 Transit units and fleet size

Transit unit (TU) is defined as a set of n vehicles travelling physically coupled together. Transit units are referred to collectively as *fleet* and the total number of transit units needed for operation of a line is referred to fleet size.

The numerical analysis for transit units and fleet size was conducted for weekdays and weekends separately as the usage of transit units on weekdays and weekends are different according to the schedule.

The fleet size N_f of the ARL was calculated using Equation 1 where N is the number of transit units required for regular service (determined by the peak hour operation), N_r is the number of transit units on reserve and N_m is the number of transit units on maintenance.

$$N_f = N + N_r + N_m \quad (1)$$

The utilization of the fleet was measured using the utilization factor φ from Equation 2. The results shows the percent of fleet available for service.

$$\varphi = \frac{N + N_r}{N_f} \quad (2)$$

The fleet size of the ARL is nine where six TUs are in regular service in weekdays and four TUs are on weekends. The percent of fleet available was found to be 89% on weekdays and 67% on weekends.

3.1.2 Headway and frequency

Transportation can be basically defined as the movement of *u* objects over a distance *s* during some interval of time *t*. The time interval between the moments two successive TUs pass a fixed point on a transit line in the same direction is the *headway h*. At the same time the number of Tus passing a point on a transit line in one direction during one hour (or some other time interval) is the *frequency of service f* (Vuchic, 1981). The Airport rail link operates daily from 6:00 to 24:00. On weekdays during the peak hours (6:00-9:00 and 17:00-20.00), the scheduled headway is 12minutes/TU while on weekends and off-peak of weekdays the scheduled headway is 15 minutes/TU.

Thus, using Equation 3, the operating frequency on peak hours of weekdays was calculated as 5 TU/h and the operating frequency of weekends and on off-peak hours of weekdays was 4TU/h.

$$f = \frac{60}{h} \quad (3)$$

Where,

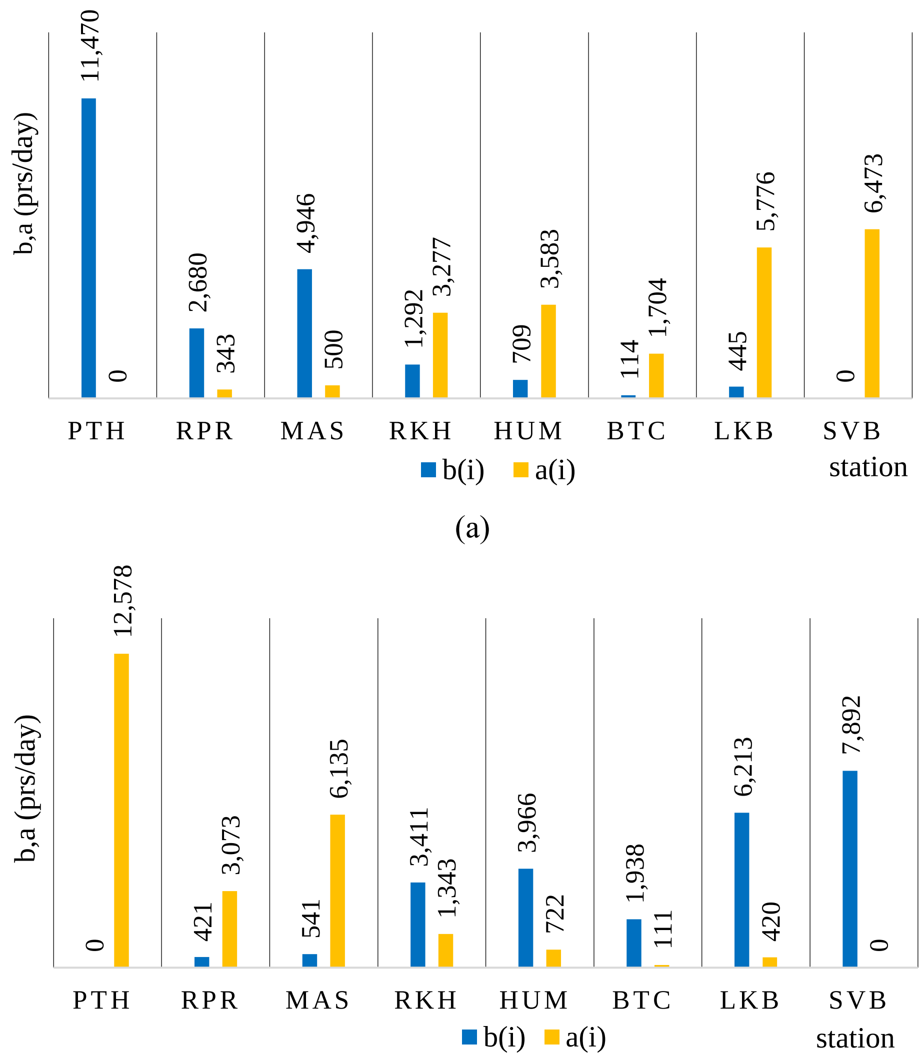
f : operating frequency,
h : headway.

3.2 Usage of Service: Passenger Volume

3.2.1 Boarding and alighting at stations

Apart from the terminal stations, when the inter stations are taken into consideration, the maximum number of boarding takes place at MAS while traveling outbound, and at LKB while traveling inbound. On the other hand, the maximum number of alighting takes place at LTB while traveling outbound, and at MAS while traveling inbound (Figure 2 (a) and (b)).

When the total number of passengers traveled along the line for both inbound and outbound are considered, there are 21,656 persons/day traveling outbound while 24,382 persons/day traveling inbound on a typical working day. Thus, the outbound and inbound passengers are almost equal.



(b)

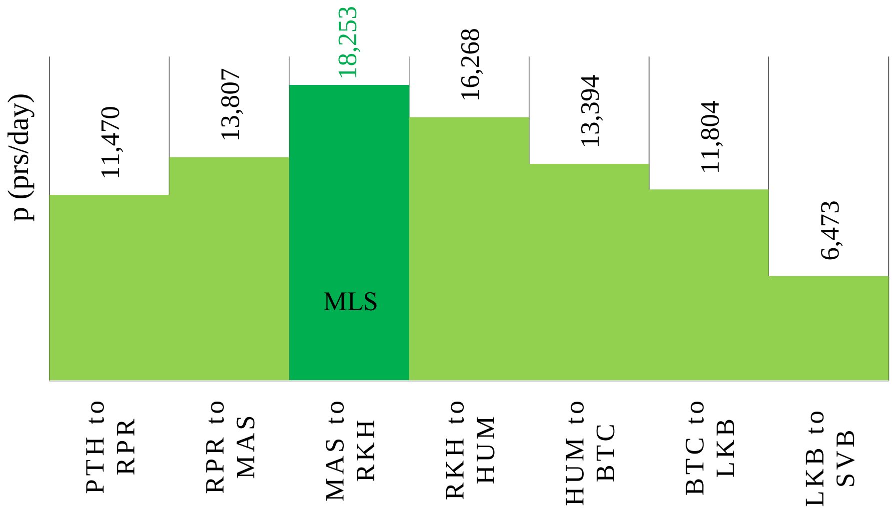
Figure 2. Passenger boarding and alighting at each station, (a) outbound and (b) inbound

3.2.2 Maximum load section

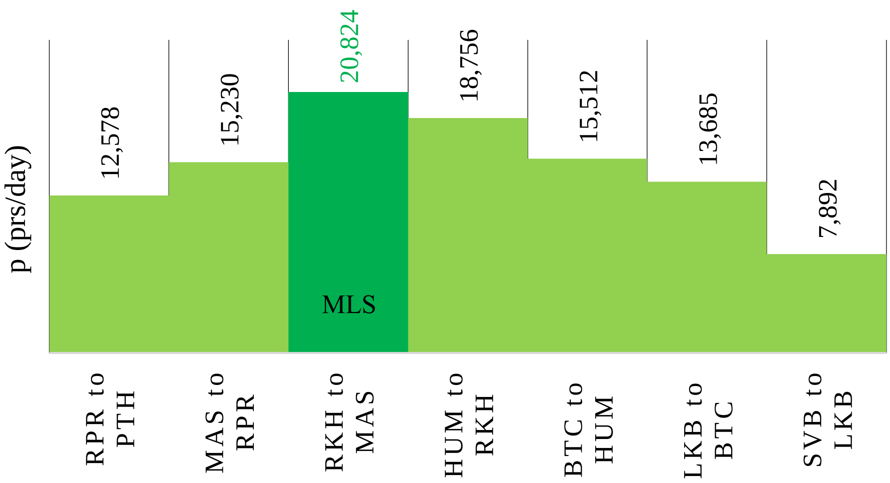
The section on which the maximum passenger volume, P_{max} is found, is called the Maximum Load Section (MLS). The daily passenger volume on a given section k was plotted using Equation 4 for both inbound and outbound separately using the averaged data of 2014.

The MLS of the ARL lies between MAS and RKH for both outbound and inbound directions, with the maximum passenger volume P_{max} of 18,253 prs/day and 20,824 prs/day respectively for a typical working day, as shown in Figure 3.

$$P_k = B_k - A_k = \sum_{i=1}^{k} b_i - \sum_{i=2}^{k} a_i \tag{4}$$



(a)



(b)

Figure 3. Passenger volumes transported along the line, (a) outbound and (b) inbound

3.3 Capacity, Work and Utilization

City Line trains are of 5 trains – 3 cars (blue color) with a capacity of 745 spaces/TU. The added trains (trains which were used for the Express Lines and now being used for City Line) are of 4 trains – 4 cars (red color) with a capacity of 500 spaces/TU. Usually the City Line trains are used for the regular service and the added trains are used for the short run trains. On weekdays during morning peak, five extra trips are made from HUM to PTH and two extra trips are made during the evening peak from PTH to SVB per day.

Line capacity C, was calculated using Equation 5, where C_v is the vehicle capacity, n is the number of cars per TU and h_{min} is the minimum headway.

$$C = C_v \times c = C_v \times n \times f_{max} = \frac{60 \times C_v \times n}{h_{min}} \quad (5)$$

Moreover, the capacity utilization coefficient, which is also known as the load factor α, was determined using Equation 6 where P is the utilized capacity. Since the load factor is used in transportation planning and scheduling, the maximum number of passengers per hour that are actually transported along the line is used as the utilized capacity.

$$\alpha = \frac{P}{C} \tag{6}$$

The offered capacity of the ARL varies for outbound and inbound as mentioned above. Figure 4 show how the passenger volume, offered line capacity, and load factor varies along the line for outbound and inbound. According to the figure the load factor peaks between MAS and RKH for both outbound and inbound.

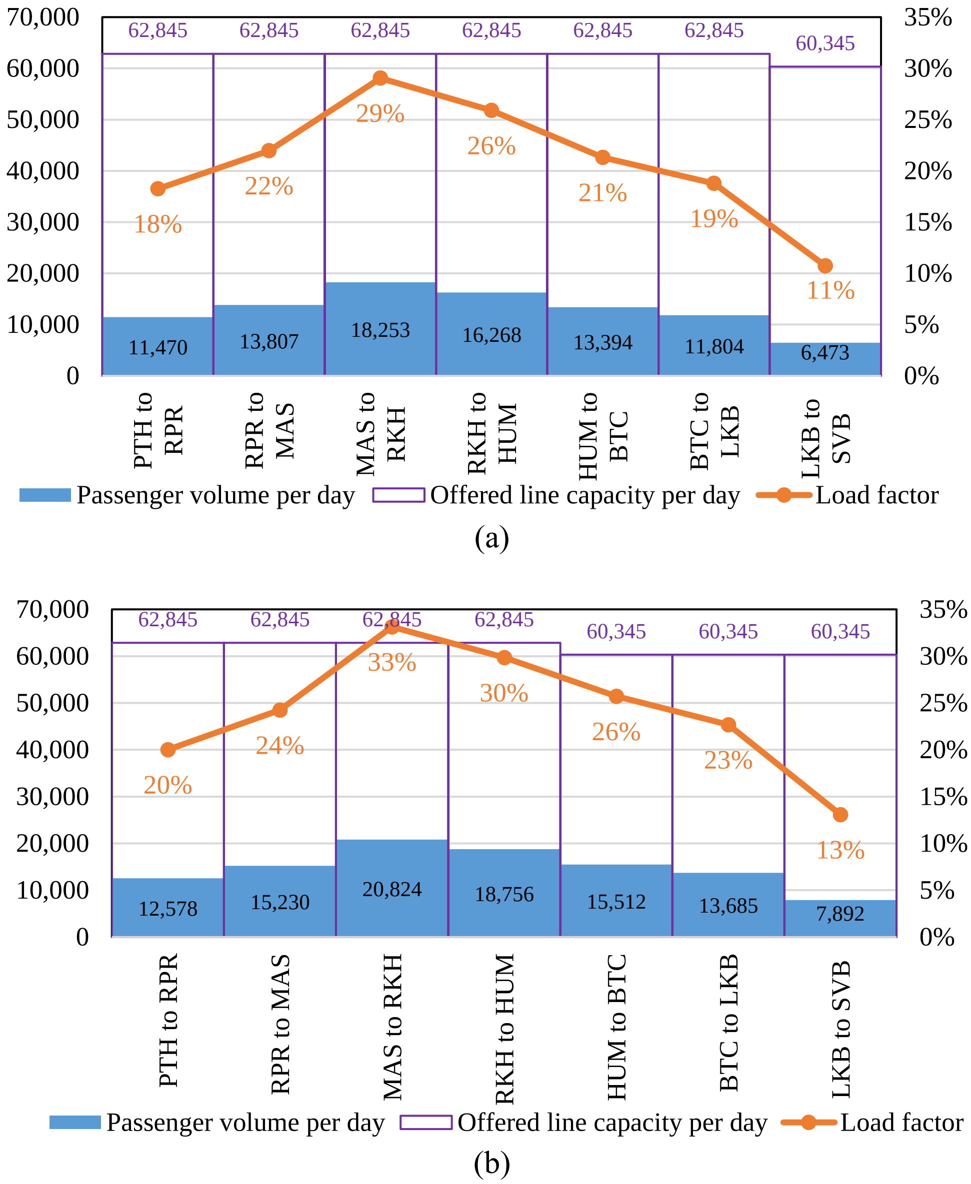


Figure 4. Line capacity, passenger volume and load factor, (a) outbound and (b) inbound

The offered work w_0 when the TUs operate on the entire length L of the line, was calculated using Equation 7.

$$w_0 = C \times L = f \times n \times C_v \times L \tag{7}$$

Furthermore, the utilized work (w_p) in terms of passenger-km travelled on the line, for a passenger volume of p_i on any section i of the line for a length of that section S_i, was obtained from Equation 8.

$$w_p = \sum_i p_i S_i \tag{8}$$

The ratio of utilized to offered work which is the work utilization coefficient ($\bar{\alpha}$) was then calculated using Equation 9.This represents the average utilization of offered capacity along the line, or the average value load of the load factor weighted by the passenger volume.

$$\bar{\alpha} = \frac{w_p}{w_o} = \frac{\sum_i p_i . S_i}{C.L} \tag{9}$$

The work utilization coefficients $\bar{\alpha}$ for weekday outbound and inbound, and weekend outbound and inbound were found to be 25%, 28%, 22% and 25% respectively. Thus, the offered capacity is mostly utilized while traveling inbound on weekdays.

3.4 Travel Time and Speed

The following analysis is based on the scheduled time table of the Airport Rail Link. The scheduled station to station travel times T_{si} and operating (or travel) time T_o from PTH to SVB or either way were calculated using Equations 10 and 11, respectively.

$$T_{si} = t_{ri} + t_{si} \tag{10}$$

$$T_o = \sum_i (t_{ri} + t_{si}) \tag{11}$$

Where,

t_{ri} : running time at any spacing *i,*

t_{si} : station standing time at any spacing *i.*

The typical dwell time at each station for both boarding and alighting was considered to be 30 seconds. The operating travel time T_o of the ARL was calculated to be 1602 seconds (26 minutes and 42 seconds). Terminal time at PTH station $t_t^{'}$ and the terminal time at SVB station $t_t^{''}$ are approximately three minutes. Thus, the total terminal time as a percent of operating time on the line(γ) according to Equation 12 is 11%.

$$\gamma = \frac{t_t' + t_t''}{2T_o} \times 100\% \tag{12}$$

Substituting the above values to Equation 13, the cycle time T of the ARL was found to be 60 minutes.

$$T = T_o' + T_o'' + t_t' + t_t'' = 2(T_o + t_t) \tag{13}$$

All the calculated travel times are shown graphically on the time-distance diagram of TU travel in Figure 5.

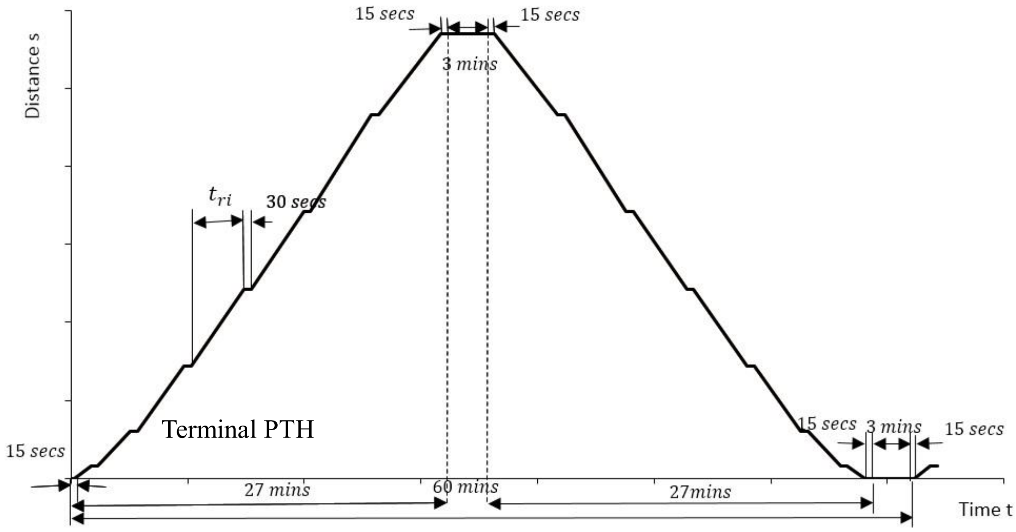


Figure 5. Travel times on the transit line

The station to station running speed V_{ri} which is the average speed a TU achieves while travelling from one station to the succeeding station was calculated using Equation 14. As both inbound and outbound travelling take same time period to travel each station spacing, the station to station speed is same for both inbound and outbound. Usually the running speed is analyzed for individual spacing between stations S_i, rather than as an average for line. Hence, the calculations were done for each spacing between two adjacent stations.

$$V_{ri} = \frac{60S_i}{t_{ri}} \tag{14}$$

Station-to-station speed V_{si} which is the average speed a TU travels between moments while traveling between two adjacent stations including running time and one station dwell time for each spacing S_i was calculated from Equation 15.

$$V_{si} = \frac{60S_i}{t_{ri} + t_{si}} = \frac{60S_i}{T_{si}} \tag{15}$$

Operating speed or travel speed V_o of a transit line is one of the basic offered transit service performance elements, as it is the speed of travel offered to public. It is obtained by averaging the station to station speeds. Thus, V_o is the average speed of a TU that travels along a transit line with *j* spacing (or on a section of it).

$$V_o = \frac{\sum_{i=1}^{j} S_i}{\sum_{i=1}^{j} T_{si}} = \frac{60L}{T_o} = \frac{120L}{T_o' + T_o''} \tag{16}$$

Operating speed calculated using Equation 16 which is the speed of travel offered to public of the ARL is 63km/h.

Cycle speed V_c which is the average speed of a TU for a complete round trip on a line can be obtained using Equation 17. The calculated result of the cycle speed is 57 km/h.

$$V_c = \frac{60.2L}{T} = \frac{120L}{T} \quad (17)$$

3.5 Transit Travel Characteristics

3.5.1 Average passenger trip length and volume

The average distance the passengers travel on a line, which is the average passenger trip length l_{av} can be simply obtained by dividing the total passenger-km from the number of passengers (Equation 18).

$$l_{av} = \frac{\sum_{i=1}^{n} p_i l_i}{\sum_{i=1}^{n} b_i} = \frac{1}{p_t}\sum_{i=1}^{n} p_i l_i \quad (18)$$

By dividing the total passenger-km on the line by its length L the average passenger volume is obtained (Equation 19).

$$P_{av} = \frac{\sum_{i=1}^{n} p_i l_i}{L} \quad (19)$$

The average passenger trip length for both outbound and inbound is approximately 17 kilometers and average volume which is carried by the train is 13,000 persons/day for outbound and 15,000 persons/day for inbound.

3.5.2 Coefficient of flow variation

The ratio of the maximum volume, P_{max} (on MLS) and the average volume P_{av} is the coefficient of flow variations η_f, which expresses the degree to which passenger volume peaks along the line as shown in Equation 20.

$$\eta_f = \frac{P_{max}}{P_{av}} = \frac{LP_{max}}{\sum_{i=1}^{n} p_i l_i} \quad (20)$$

The lowest possible value is 1.0 where there is a constant passenger load along the entire length. The greater the value of η_f means the average load factor is low. In such cases, adjustments of offered service to passenger volume are desirable. For ARL, the coefficient of flow variation for both outbound and inbound was calculated to be 1.4 for weekdays and 1.3 for weekends.

3.5.3 Trip patterns

The following analysis was done in order to identify the most utilized trip pattern for outbound and inbound out of the 28 trip patterns (PTH to RPR, PTH to MAS, etc.) that the ARL provides. As shown in Table 1, it is confirmed that ARL is predominantly used to travel from PTH to SVB and SVB to PTH. 14.05% of the outbound users travel from PTH to SVB while 15.46% of the inbound ARL users travel from SVB to PTH.

Table 1. Trip patterns for a typical working day, (a) outbound and (b) inbound

(a)

Entry/Exit	PTH	RPR	MAS	RKH	HUM	BTC	LKB	SVB
PTH		1.58%	1.45%	9.75%	9.79%	3.95%	12.40%	14.05%
RPR			0.86%	2.30%	1.75%	0.87%	3.31%	3.28%
MAS				3.08%	4.46%	2.36%	7.24%	5.70%
RKH					0.54%	0.46%	2.28%	2.68%
HUM						0.23%	1.24%	1.80%
BTC							0.20%	0.32%
LKB								2.05%
SVB								

(b)

Entry/Exit	PTH	RPR	MAS	RKH	HUM	BTC	LKB	SVB
PTH								
RPR	1.73%							
MAS	1.39%	0.82%						
RKH	8.36%	2.30%	3.33%					
HUM	9.16%	1.94%	4.75%	0.41%				
BTC	3.79%	0.95%	2.65%	0.39%	0.17%			
LKB	11.69%	3.17%	7.43%	1.99%	1.03%	0.16%		
SVB	15.46%	3.42%	7.00%	2.71%	1.76%	0.30%	1.72%	

Since the outbound travel peaks during the evening hours and inbound travel peaks during the morning hours, the trip pattern analysis was done separately for outbound and inbound. Trips between 17:00 to 20:00 were considered for outbound analysis and trips between 7:00 to 10:00 were considered for the inbound analysis as the peak periods.

Table 2. Trip patterns during peak periods, (a) Outbound PM peak period and (b) inbound AM peak period

(a)

Entry/Exit	PTH	RPR	MAS	RKH	HUM	BTC	LKB	SVB
PTH								
RPR	0.81%							
MAS	0.72%	0.51%						
RKH	8.98%	2.82%	4.08%					
HUM	11.85%	2.76%	7.56%	0.42%				
BTC	6.30%	1.64%	5.21%	0.65%	0.18%			
LKB	13.69%	4.12%	10.66%	2.21%	0.90%	0.09%		
SVB	6.31%	1.90%	2.93%	1.06%	0.72%	0.14%	0.80%	

(b)

Entry/Exit	PTH	RPR	MAS	RKH	HUM	BTC	LKB	SVB
PTH		1.28%	1.28%	10.49%	12.33%	5.51%	13.69%	9.02%
RPR			0.88%	2.62%	2.18%	1.18%	3.17%	2.13%
MAS				3.62%	6.33%	3.60%	8.70%	3.46%
RKH					0.69%	0.66%	2.46%	1.25%
HUM						0.27%	1.26%	0.80%
BTC							0.17%	0.13%
LKB								0.85%
SVB								

During the morning peak the maximum number of trips is from LKB to PTH and during the evening peak the maximum number of trip is from PTH to LKB (Table 2). Consequently, a couple of short run express trips are recommended to operate from LKB to PTH during am peak and from PTH to LKB during pm peak in order to reduce the congestion during peak periods.

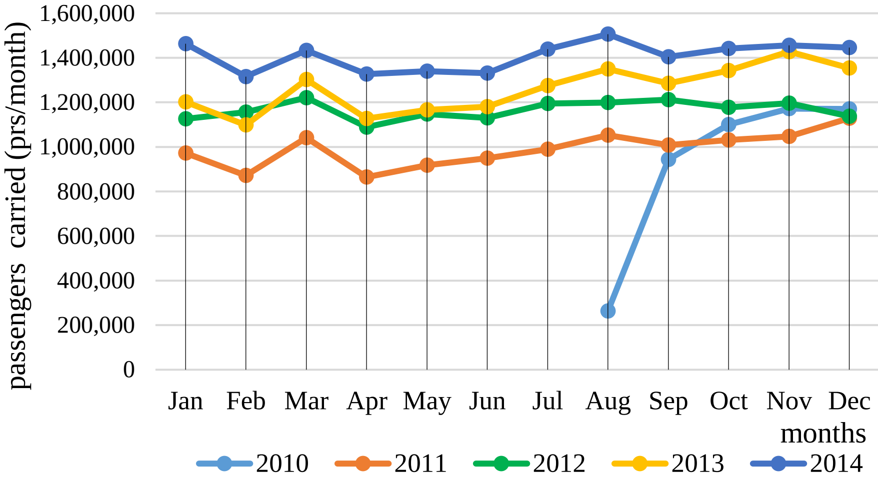
3.6 Temporal Variations of Transit Travel

3.6.1 Annual monthly variation

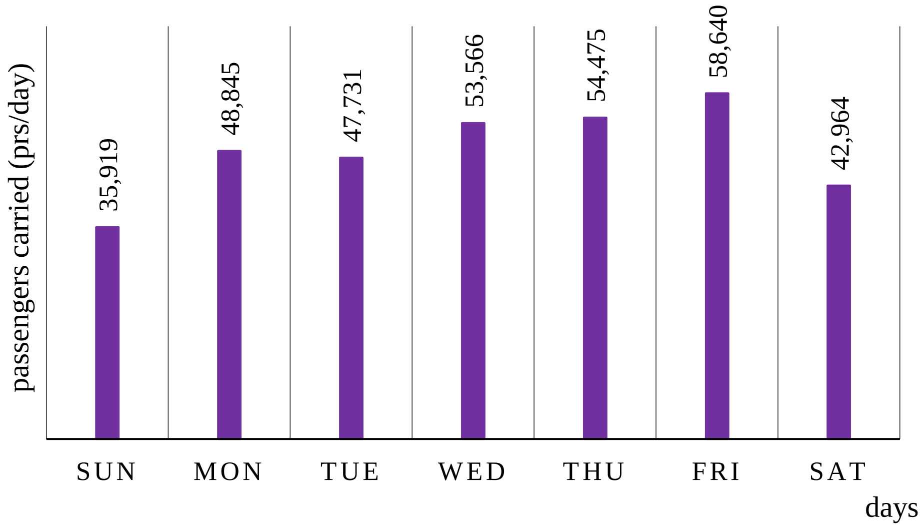
The deviations of the passengers carried along the line for each month using separate trend lines for the years since the initiation of the line is shown in Figure 6 (a). The usage of ARL seems to be steadily increasing annually but with a slight increment from 2012 to 2013. The variation of the trend line for each year follows almost the same pattern. For each year, there is a considerable drop in February and April in every year.

3.6.2 Daily variation

The line is mostly being used on weekdays than on weekends as shown in the Figure 6 (b). Moreover, on Fridays, the line carries the maximum number of passengers when compared with the rest of the days.



(a)

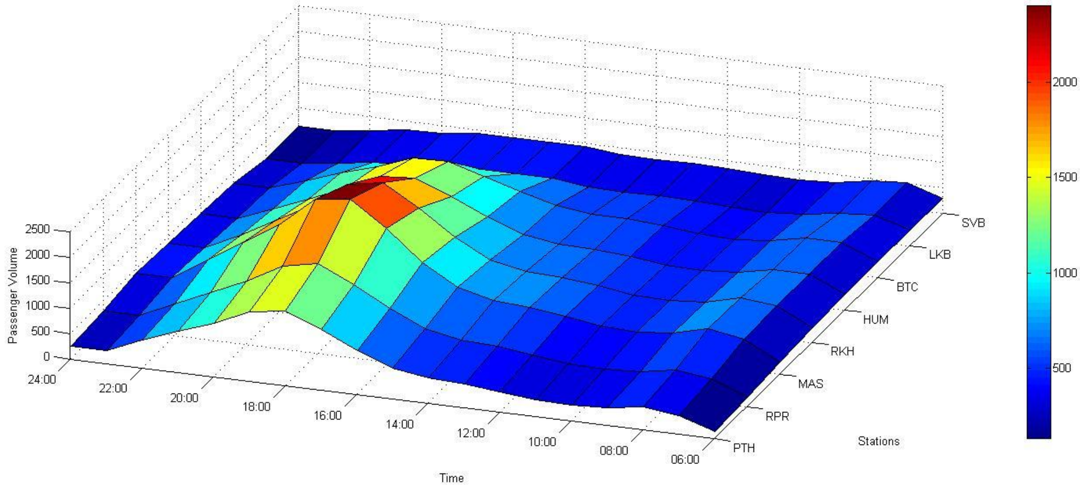


(b)

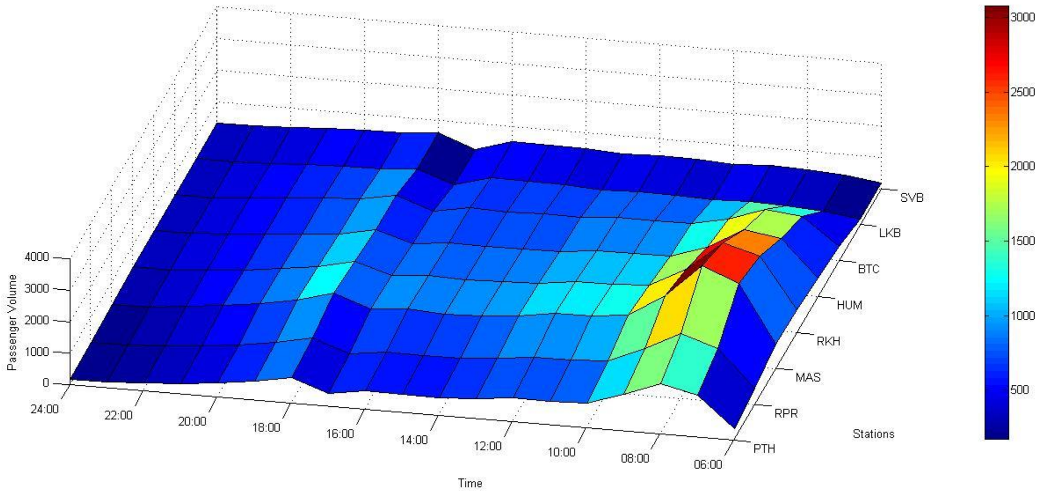
Figure 6. Temporal variations, (a) monthly variation and (b) daily variation

3.6.3 Hourly variation

The passenger volumes along each section during each hour are presented with distance and time in a three dimensional plot, as shown in Figure 7. From the figure, it is clear that the maximum passenger volume travels from MAS to RKH during 18:00-19:00 while traveling outbound and from MAS to RKH during 8:00-9:00 while traveling inbound.



(a)



(b)

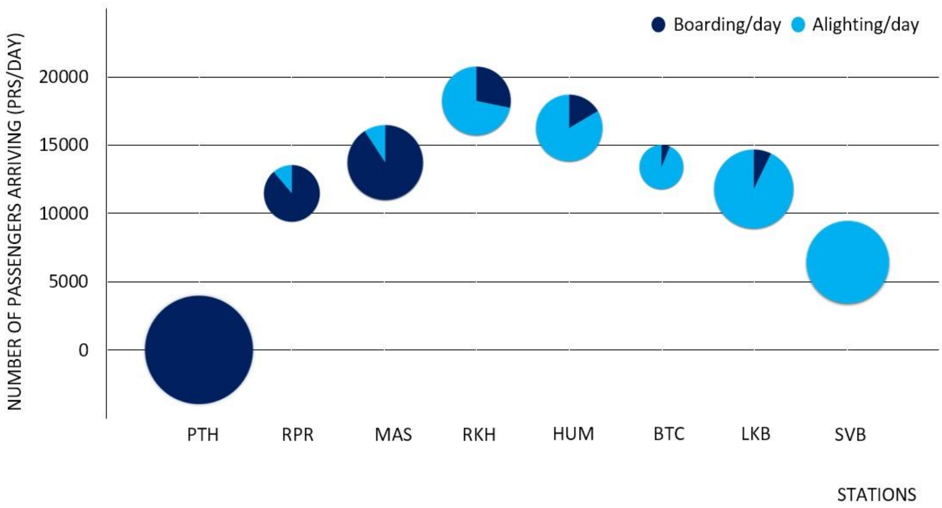
Figure 7. Three-dimensional presentation of passenger volume distribution in distance and time along the line, (a) outbound and (b) inbound

3.7 Transit stations

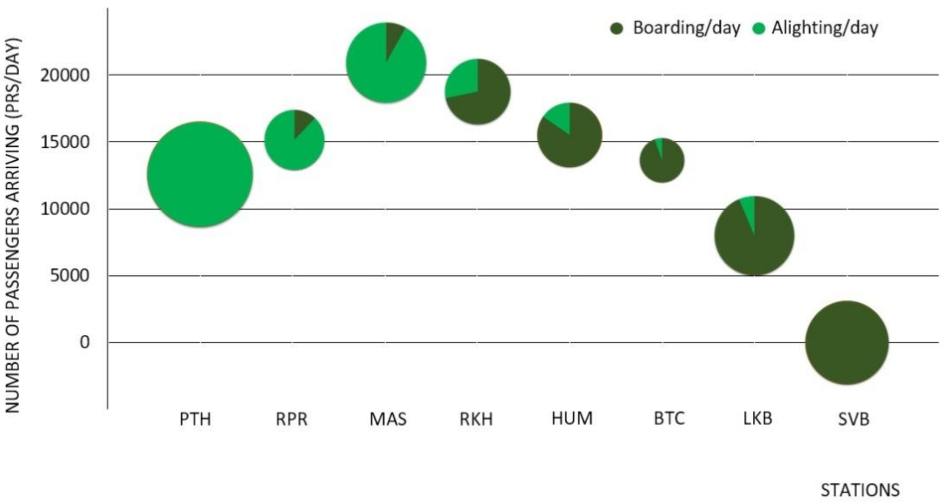
3.7.1 Passenger counts at stations

The following results are based on the data automatically collected at each station exit via magnetic tokens (for non-member) and smart cards (for members). Figure 8 shows the boarding and alighting separately for outbound and inbound. The size of circles represent the number of passenger boarding and alighting at each station, which the *y*-axis indicates the number of passengers arriving with the train at each station. According to the ARL staff, this figure is very useful to them. It contains a lot of important information in one plot.

The maximum number of boarding and alighting, which is 24,048 transactions per day, take place at the PTH station. The second of 14,365 transactions per day takes place at the SVB station. This is consistent with the fact that PTH is the busiest station. Among the non-terminal stations, the LKB station is the busiest with the 12,854 transactions per day.



(a)



(b)

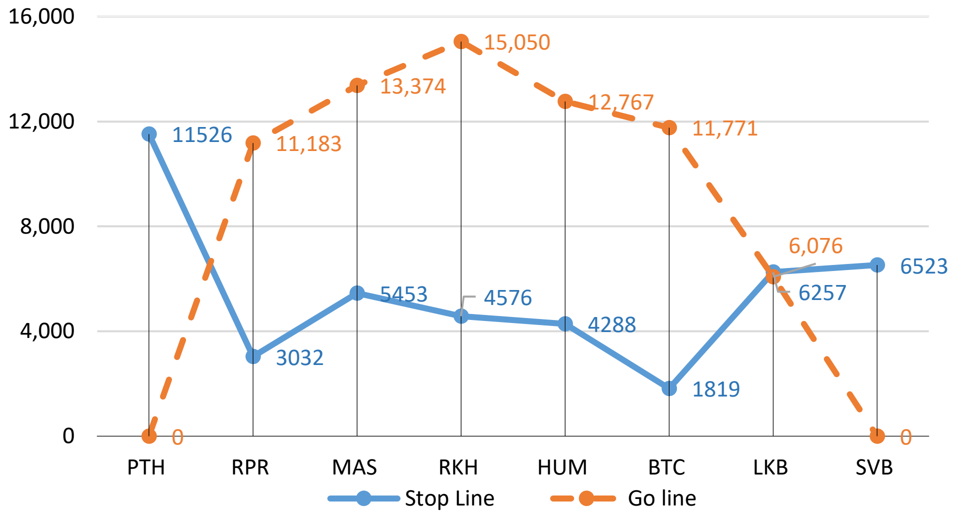
Figure 8. Passenger count at stations for a typical working day: boarding and alighting, (a) outbound and (b) inbound

3.7.2 Application of theoretical analysis to station planning

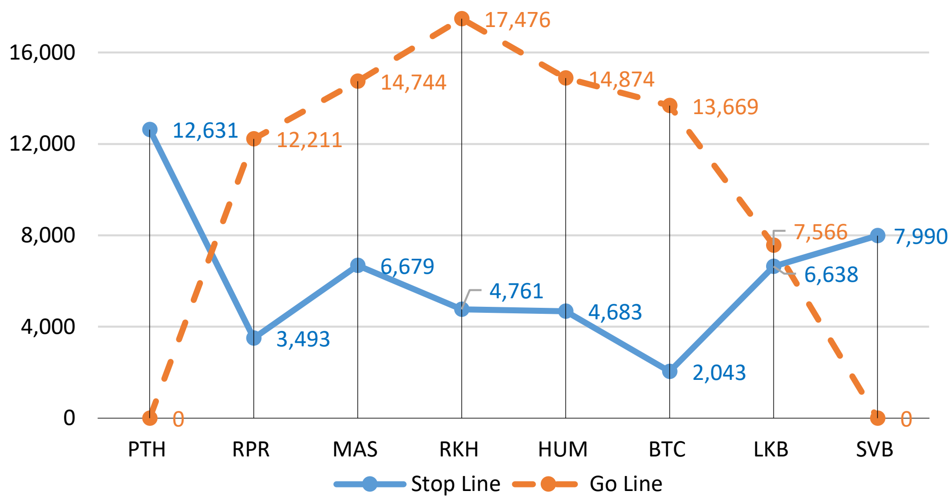
By adding up the functions $b(s)$ and $a(s)$, the persons wanting to board or alight are computed. By reducing the alighting function $a(s)$, from the passenger volume function $p(s)$, passengers on trains travelling along the section who do not want to stop are computed.

The "Stop Line" represents the number of persons who want to have a station, the function of $(b_i + a_i)$. Whereas the "Go Line" represents the number of persons who do not want to be delayed at a station, the function of $(p_{i-1} - a_i)$.

Each station is more important for persons who board and alight than for those who only lose about one minute by stopping. Thus, the Stop value has a greater relative weight than the Go value. Accordingly, only stations where the Stop value much lower than the Go value can be considered to be eliminated. Therefore, as illustrated in Figure 9, the BTC and RPR stations could be considered to be eliminated (if needed). However, it is important to note that there are many other factors that should be considered before eliminating any station.



(a)



(b)

Figure 9. “Stop line” and “Go line” , (a) outbound and (b) inbound

4. CONCLUSSIONS AND RECOMONDATIONS

This paper illustrates a practical way to assess operational performances of rail rapid transit by using a real world data set from the Airport Rail Link (ARL) in Thailand as an example. An array of deterministic equations, which covers several practical aspects for operational assessment including the basic transit line operations, transit travel characteristics, transit line capacity, and schedule of service, is presented. Various analyses based on graphical presentations of transit operations are carried out including the passenger volume analysis which combines more than 370,000 trip data to a single plot.

The ARL runs on an elevated structure throughout a distance of 28.5 kilometers. The average passenger trip length is 17.3 kilometers for both outbound and inbound. The maximum load section of ARL lies between MAS and RKH stations for both outbound and inbound with the maximum passenger volume carried along the line being 18,253 persons per day for outbound and 20,824 persons per day for inbound (Figure 3). As illustrated in Figure 5, it takes approximately 27 minutes to travel from one terminal to the other, including station standing times for passenger boarding and alighting. The typical station standing time is 30 seconds and the terminal time is 3 minutes. Thus, the cycle time (time to travel in one cycle) is about 1 hour with an average cycle speed of 57 kilometers per hour.

The primary reason that the ARL was created is to serve airport travelers. The numerical results support its mission on the daily basis. However, it is interesting to point out that during the peak periods there are many non-airport travelers and the trains are very crowded, which is not convenient for airport travelers. The analysis shown in this paper was provided to the ARL officers to help them get a better picture of their operational performances and come up with some possible strategies to improve their services. Last but not least, the readers can use this paper as an example to assess the operational performances of their transit systems or to compare various systems.

REFERENCES

Deng, T., Nelson, J.D. (2013). Bus Rapid Transit implementation in Beijing: An evaluation of performance and impacts. *Research in Transportation Economics*, 108-113.

Gercek, H., Karpak, B., Kilincaslan, T. (2004). A multiple criteria approach for the evaluation of the rail transit networks in Istanbul. *Transportation*, 31, 203–228.

Haluk, G., Karpak, B., Kilincaslan, T. (2004). A multiple criteria approch for the evaluation of the rail transit networks in Istanbul. *Kluwer Academic Publisher*, 203-228.

Jang, W. (2010). Travel time and transfer analysis using transit smart card data. *Transportation Research Record*, 2144, 142-149.

Lena, L.L., Li, J.L., Wachs, M. (1994). *Comprehensive Transit Performance Indicators.* Los Angeles, CA: University of California Transportation Center.

Newman, P., Kenworthy, J. (1999). *Sustainability and Cities.* Washington: Island Press the center for resource economics.

Vuchic, V.R. (1981). *Urban Public Transportation Systems.* Prentice Hall.

Roth, C., Kang, S.M., Batty, M., Barthelemy, M. (2012). A long-time limit for world subway networks. *Journal of the Royal Society Interface*, 1-11.

Vuchic, V.R. (2005). *Urban Transit Operations, Planning and Economics.* Canada: John Wiley and Sons.

Vuchic, V.R. (2007). *Urban Transit Systems and Technology.* New Jersey: John Wiley and Sons.