An Investigation on Urban Circle Rail Transit: A Case Study on the Alignment of Mass Rapid Transit 3 (Circle Line)

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Abstract. Mass Rapid Transit (MRT) is one of the important components of the Greater Kuala Lumpur (KL) development plan. It consists of three line-systems and would be finally operated by Klang valley public transport system. These three lines are aligned on the concept of wheel and spoke pattern that encompasses two north-south radial lines as well as a circular line (also known as ring line) circulating around KL and enclosing the central business district. However, fixing the locations of the stations has become an issue. The aim of the paper is to find out the optimal alignment for the ring line with respect to the total passenger benefit. A numerical-analytical model has been used to determine the optimum radius for the proposed ring line in a city. Passenger route choice for many-to-many, origin-destination (OD) pairs is analysed using radial-only rail network and rail network with ring lines of varying radii. The route choice takes into consideration three separate options including a) direct access to destination, b) taking only radial lines, and c) taking a combination of radial and ring lines. Several important parameters such as access cost, ride cost, and transfer penalty, are the main aspects to evaluate the optimality of the ring line. Microsoft Excel has been used to run the cost-benefit optimization model with the aim of obtaining an optimal radius of ring line. Results show that the net benefit of presenting a circle line in the KL by manipulating the passenger's cost for each OD pair. Finally, the optimum alignment of MRT circle line in KL has been proposed.

1. Introduction

Kuala Lumpur (KL), the capital city of Malaysia, is one of the fastest-growing cities in Asia. The inherent problem faced by such rapidly growing cities is increased level of traffic volume and traffic delays. Historically, KL has been a large exporter of tin minerals to United Kingdom (UK). To minimize the transportation time to the nearest port, the very first rail route from KL to Bukit Kuda (near Klang) was built by British engineers and operations commenced on September 15th 1886. The transportation facilities in KL have since been constantly improving [1]. The rail transit system in Klang valley dramatically evolved in the late 20th century, when the routes were electrified, and currently it is operating 8 different lines spanning over 375.5km. The evolution timeline of Klang Valley Integrated Transit System (KVITS) are shown in Figure 1. In tune with this evolution, three more lines are being proposed to be built by 2025, which would be an ambitious enhancement and would definitely complement the efforts to ease off the traffic congestion problem of KL. The rail transportation development is not keeping pace with the land property development in KL, hence, making many places unreachable by train. This leads to increased use of private cars, clogging roads and overriding public transportation [2]. Kuala Lumpur has been a frontline profit earner from the rapid economic growth. Increasing incomes are another key force to the escalating car ownership Likewise, as stated by Ministry of Transport Malaysia Official Portal [3], the upsurge in population as well as LRT commuters, there is a drastic spike in the demand to enhance the public transportation capacity, particularly rail transportation, in KL. Thus, instead of roads, more rail lines should be constructed keeping in view the convenience and benefit of the passengers

1.1. Mass Rapid Transit in Malaysia

Mass Rapid Transit (MRT) is a major segment of development plan in Greater Kuala Lumpur [4]. It is proposed to have three lines, arranged in the wheel and spoke pattern, encompassing two north-south radial lines as well as one circle line (also known as ring line) circulating around KL. After completion, MRT system would be operated as part of Klang Valley public transport system. This project would excessively enhance the capacity of the existing Klang Valley Integrated Transit System (KVITS) by integrating with the current rail network, which would alleviate the traffic congestion problem in Greater KL.

1.2. Klang Valley Transportation Connectivity

Although, significant improvement has been done in rail transportation, however, when it comes to KVITS, Klang Valley is trailing behind. Problem with traffic congestion in KL has kept on rising probably due to inadequate rail connectivity and increase in population and car ownership. In case of road system, a purely radial road network would cause people to travel along the radial roads that pass through central business district (CBD) to reach a destination away from it. This would clearly lead to unwanted vehicle load in passages, extra travel time, and high transfer of vehicle load at CBD. To address this problem, government has built several ring roads that brought suburban areas in KL together as well as to lower down the vehicles transfer loads in CBD. However, problem with traffic congestion still remains unsolved due to the increased car ownerships in KL. Building ring roads does not actually seem to provide an effective solution. On account of these reasons, it may be concluded that beside building new roads, efforts would have to be made on the development of rail transport to actually mitigate the long-unsolved traffic congestion issue. All the existing and proposed rail lines in Klang Valley are considered to be radial lines. Therefore, it will again cause the same problem as is inherent in the purely radial roads network [5].

1.3. Circle Rail Line

Referring to the solutions that other countries have adopted, circle line seems to be an ideal solution to the problems that mentioned earlier. A circle line can help to improve the connectivity along with diminishing the network vulnerability, given that alternative routes are provided to all destinations. Moreover, the network connectivity, operational efficiency and directness can be benefitted from the circle line and these have been confirmed by several studies [6,7,8]. The attempts to come out with a solution to the problem of rail transit, planning may be traced back to circa [9]. This planning of the transit network has been practised in different type of modes to generate a configuration of optimal transit network. Numerous studies have been undertaken on the planning of rail transit [10,11,12], are indirectly applicable to circle line.

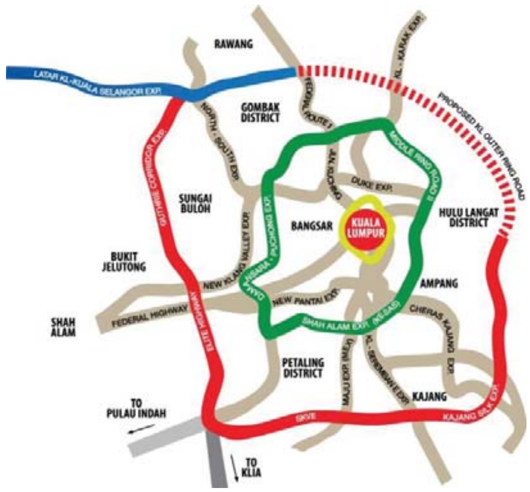

Figure 1. Existing and proposed ring roads around Kuala Lumpur City Centre [4]

2. Methodology

2.1. Passenger Route Choice

The minimum passenger cost of each origin-destination (OD) pair plays an important role in determining the total passenger benefit. It is determined by considering routes of different passengers of each OD pair that gives the lowest passenger cost to access the destination from origin. KVITS is simplified to be made of two types of lines, which are radial line and circle line. For radial-line-only network, passengers can either head to a destination either taking the same line without having to transfer, or possibly have to change to another radial line at CBD. There are some assumptions made in this paper.

List of different alternative paths of any OD pairs in the circle-radial network model are as below:

a) Access directly from origin to destination without using rail network.
b) Take only radial line;
c) Take circle line (radial line may also be used);

A deterministic route choice was adopted to evaluate the passenger cost for various paths for each OD pair. Cost of each alternative passenger route choice for each OD pair has to be calculated, and the one with the minimum passenger cost was used in determining total passenger cost. Passenger cost for the alternative routes has been classified into:

$D\ (Direct\ alternative)$ (1)

$\gamma_a D_o + \gamma_R D_R + \xi_{RL} k H_{RL} \gamma_w + (\xi_{RL} - 1)\,\gamma_T + \gamma_a D_d$ (Radial Line) (2)

$\gamma_a D_o + \gamma_R D_R + \xi_{RL} k H_{RL} \gamma_w + \xi_{RN} k H_{RN} \gamma_w + \ (\xi_{RL} + \xi_{RN} - 1)\,\gamma_T + \gamma_a D_d$ (Circle Line) (3)

2.2. Total Passenger Benefit of Circle Rail Line

Total passenger cost for radial line only network and the total passenger cost with circle line network (R) are computed depending on the minimum passenger cost and the travel demand of each OD pair. The equations for total passenger cost are:

$$C_{RL} = \ \Sigma_{i,j}^{N}(PC_{\min i,j} * OD_{i.j}) \quad (4)$$

$$C_{CL} = \ \Sigma_{i,j}^{N}(PC(R)_{\min i,j} * \ \mathrm{OD}_{i.j}) \quad (5)$$

Where C_{RL} is total passenger cost for radial line network only; C_{CL} is total passenger cost for circle line network only; $PC_{\min i,j}$ is the minimum cost of passenger from zone i to j for network with radial line only; $PC(R)_{\min i,j}$ is the cost of train rides per kilometre per passenger (RM/km/passenger) and $OD_{i.j}$ the cost of train rides per kilometre per passenger (RM/km/passenger).

$$\text{Total Passenger Benefit } (R) = C_{RL} - C_{CL} \quad (6)$$

From equation 6, it is noticeable that total passenger benefit is a function of radius, implying the total passenger benefit changes as the radius of circle line changes. All the unit cost values that were used in the cost benefit analysis are shown in Table 1.

Table 1. Summary table of all unit cost values for KL.

Parameters	Unit Cost (Malaysian Ringgit (MR))
Access cost, γ_a	RM2.17/km/passenger
Ride cost, γ_R	RM1.00/km/passenger
Wait cost, γ_w	RM0.58/min/passenger
Transfer disutility, γ_T	RM1.91/transfer/passenger
Train headway, H_{RL} & H_{RN}	KTM – 22.5 mins STAR and PUTRA LRT – 5.3 mins Monorail – 6 mins MRT – 7 mins
Wait time factor, k	0.5

3. Result and Discussion

3.1. Total passenger benefit

The total passenger benefit from the circle line in terms of cost with respect to the radius of the circle line centred at CBD is as shown in Figure 2. The higher the cost, the more cost-beneficial it is for the passengers to have a circle line at such radius. It is interesting to see that as the radius goes further away from CBD to a certain distance, more passengers will get benefit from the circle line. It is also found out that the passengers benefitted from small radius of circle line are significantly lesser despite higher population density near CBD. This is simply due to the circle line at such small values of radius would only give better coverage to a small bunch of people inside and outside of the small circumferential line. As KL is experiencing an economic boom, it is believed that the growth in population and the development of land property will lead to a more feasible circle line with a higher total passenger benefit. Values in the analysis have shown that the total passenger cost for radial line only network is always higher as compared to the rail network with single ring line. This indicates that having a circle line in a rail network will deliver more advantages to the passengers in overall. The core reason behind this was attributable to the absent of circle rail line connecting suburban areas which causes unnecessary distance travelled, rail transferred at the CBD. However, after conducting the analysis, it is found that at a radial distance of 6km from CBD, the circle line appeared to be most favourable for passengers.

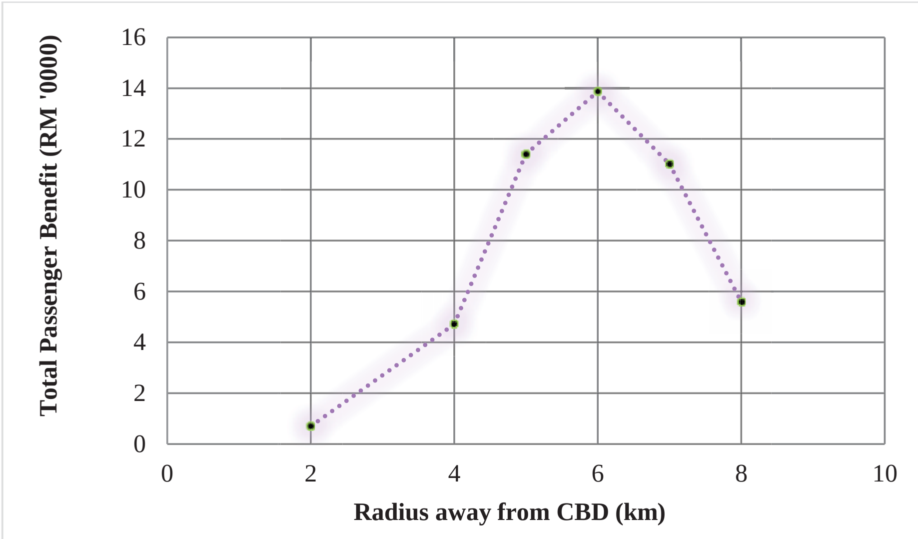

Figure 2. Total passenger benefit against radius away from CBD

3.2. Effect of Access Cost

A sensitivity analysis has also been done to study the effect of access cost on the optimality of the circle line in KL. By fixing all other unit cost values, different unit values of access cost have been input into the same model. As predicted, the higher the access cost, the larger the total passenger benefit for a circle line to be constructed, as shown in Figure 3. When the access cost is high compared to the ride cost, passenger will tend to travel to their destination by train where possible. Circle line in the case is used as a substitution for the passengers who previously chose to access directly to radial line or to the destination. Inversely, when the access cost is equal to ride cost (GammaA = 1), passenger will unquestionably choose to access directly to destination instead of taking trains. This explains the relatively flat line found in the graph when GammaA is equal to 1, which literally indicate building a circle line does not bring much benefit to the passengers. In spite of the changes in access cost, the optimum alignment for circle line still remains at 6km from CBD.

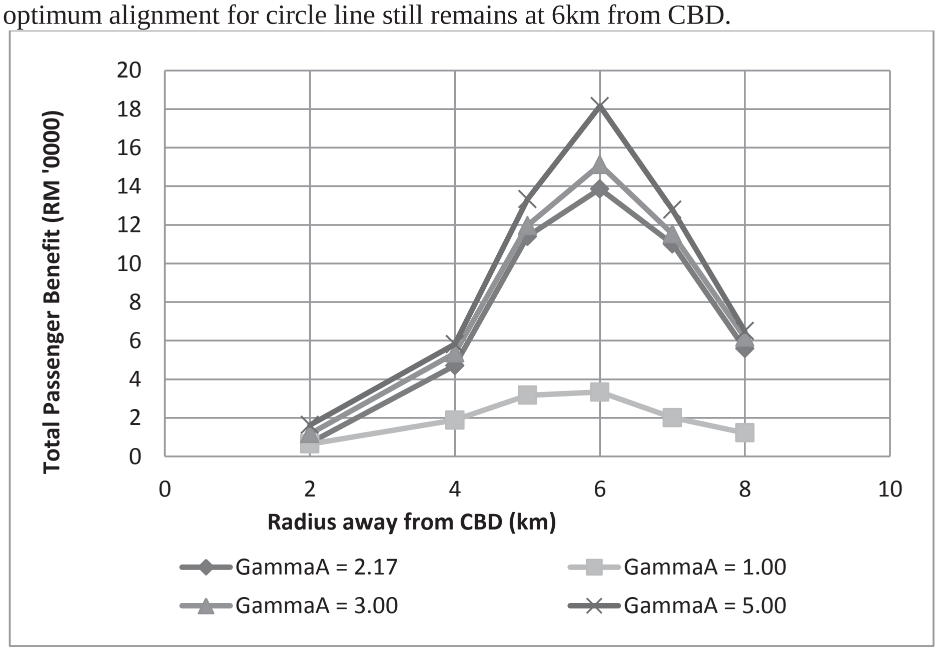

Figure 3. Total Passenger benefit against radius away from CBD (access cost factor)

3.3. Effect of Ride Cost

Another sensitivity analysis has been done by assuming all other unit costs to be constant, then finding the changes of the alignment optimality for circle line by manipulating the ride cost. The unit access cost, in this case, is fixed to be at Ringgit Malaysia 2.17/km/passenger; subsequently it is observed that the nearer the ride cost to the access cost, the lesser the benefit of introducing a circle line in general, as shown in Figure 4. In this scenario where the ride cost increases till the same value as the access cost, passengers will obviously choose to access directly to the destination and save the cost incurred in the wait time and transfer disutility. Accordingly, ride cost also plays a deterministic factor in finding the optimality radius of a circle line. If there is reduction in ride cost, access cost to their nearest train station would be the only concern for a passenger. The figure has shown that the reduction in ride cost will make circle line more feasible and efficient. Nevertheless, due to the comparatively lower number of zones used in the analysis, the total passenger cost is therefore not showing a substantial rise when the access cost is being varied.

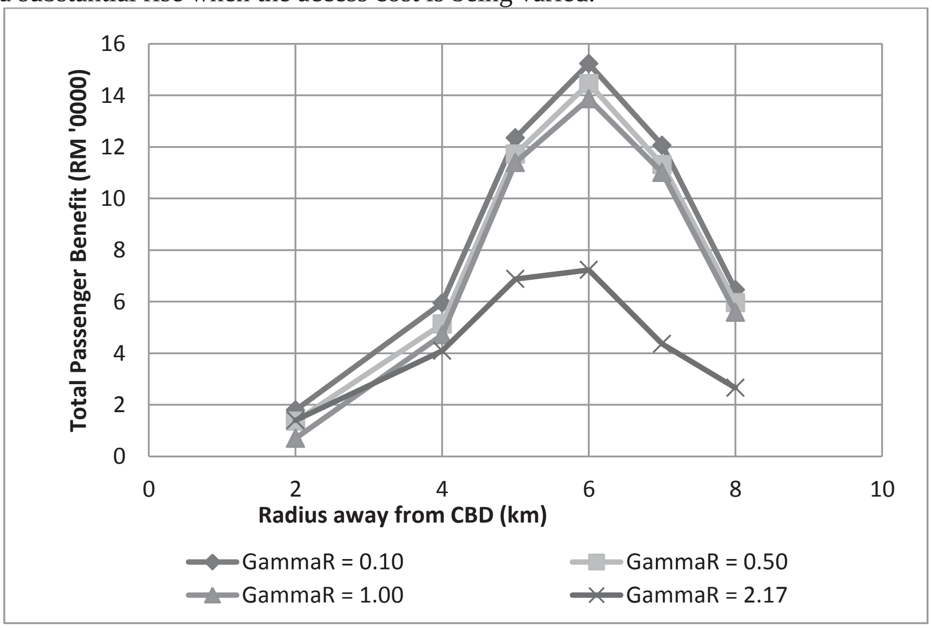

Figure 4. Total passenger benefit against radius away from CBD (ride cost factor)

3.4. Effect of Value of Time

Figure 5. presents the changes in total passenger benefit due to different value of time (VOT). It can be clearly seen that the higher the VOT, the more efficient the implementation of a circle line. Assuming all other variables to be fixed, the VOT will be proportional to the mean per capita income, and the higher mean per capita income implies a higher VOT. According to Department of Statistics Malaysia [13], mean monthly household income of KL has a compound annual growth rate of 10.7%, which means that the VOT in KL is predicted to be growing annually. This has again proven that building a circle line will bring more advantages in the long run. Although the change of VOT does not shift the optimum radius of circle line away from its original optimum radius, a decrease in VOT is evidently making the circle line undesirable and of no benefit to the passengers.

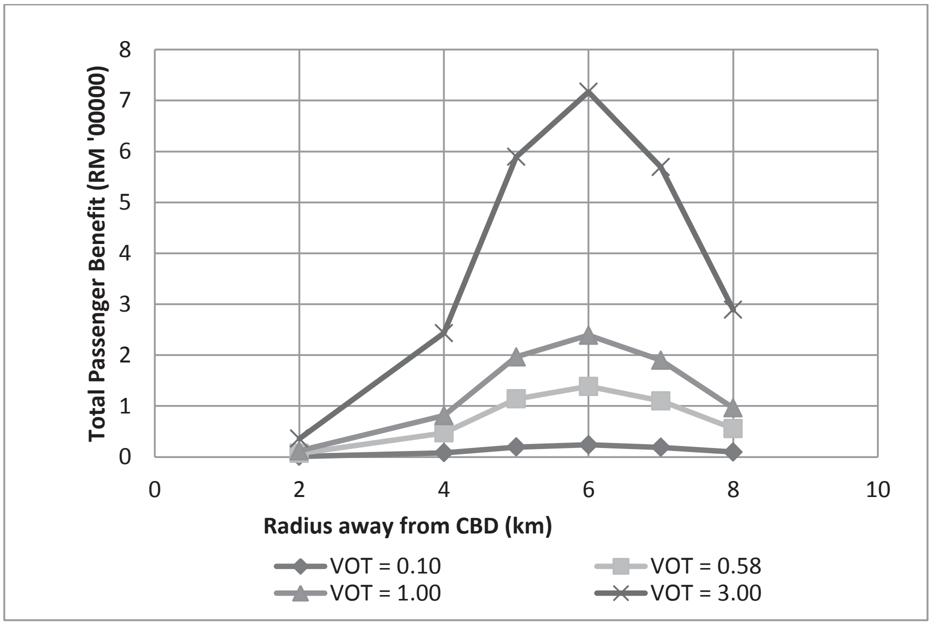

Figure 5. Total passenger benefit against radius away from CBD (value of time factor)

4. Conclusion

In this paper, an approximate mathematics analytical model for circle-radial rail network has been applied in finding the optimal alignment of circle line in Kuala Lumpur, Malaysia. This model is said to be comparable and easily applicable to any radial-circle rail network, especially in a monocentric city. In this study, only a single circle line, based on the passenger route choice that gives the lowest minimum passenger cost. Parameters in KL that affect the cost of a journey of a passenger for each OD pair, such as access cost and ride cost have been utilized to determine the optimum alignment of a circle line. Despite a uniform travel demand distribution is used in this study. Nonetheless, a prospective net benefit of a circle line has also been acquired by evaluating the projected reduction in total passenger cost. Thus, the passenger route choice plays an extremely important role in manipulating the outcome of the result. In the case where most passengers travel to CBD, the circle line is only acting as a feeder service to the nearby radial line rather than providing cross-suburban movements. Certainly, a decrement in the ride cost, plus the increase in the access cost and value of time will lead to a greater attractiveness of introducing a circle line.

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