

Integration of geospatial multi-mode transportation systems in Kuala Lumpur

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Abstract. Public transportation serves people with mobility and accessibility to workplaces, health facilities, community resources, and recreational areas across the country. Development in the application of Geographical Information Systems (GIS) to transportation problems represents one of the most important areas of GIS-technology today. To show the importance of GIS network analysis, this paper highlights the determination of the optimal path between two or more destinations based on multi-mode concepts. The abstract connector is introduced in this research as an approach to integrate urban public transportation in Kuala Lumpur, Malaysia including facilities such as Light Rapid Transit (LRT), Keretapi Tanah Melayu (KTM) Komuter, Express Rail Link (ERL), KL Monorail, road driving as well as pedestrian modes into a single intelligent data model. To assist such analysis, ArcGIS's Network Analyst functions are used whereby the final output includes the total distance, total travelled time, directional maps produced to find the quickest, shortest paths, and closest facilities based on either time or distance impedance for multi-mode route analysis.

1. Introduction

An efficient transportation network can stimulate economic transformation, physical development and improve mobility. Urban areas are populated by over half the world's population and are anticipated to witness most of the population growth in the next forty years [1]. With an increasing population, the demand for transportation will also increase [2]. In certain location such as urban areas, human mobility usually happens over a multi-mode transportation network. People tend to use more than one mode of transportation to arrive at a particular destination due to many reasons. Accordingly, when analyzing transportation systems people should not simply consider each mode of transport separately but should look at it as a multi-mode transportation systems with relationships and dynamics between components. Moreover, each mode of transport has its weaknesses and strengths and by using a combination of modes potentially can cancel their negatives out, offering an advanced platform for more flexible, efficient, sustainable and reliable transportation [3].

There are works done beyond the urban territories such as reported by Frederic S *et al.*, [4] who highlighted the development of databases regarding territories where multi-mode transport systems are being established, all around the world. These databases are not only to be used for integrated mobility information services, but also for new analysis to improve the global multi-mode transportation over a territory. In fact, transportation planners and decision-makers are increasingly considering multi-mode transportation strategies to support sustainable transportation associated with urban development [5]



[6]. This is of a particular importance when more people are getting mobile with the availability of new public transportation options that connects the routes.

In Malaysia, mainly in Kuala Lumpur, the network becomes more complex and complicated. Common transportation features that can be observed include multi-layer highways and major roads with many intersections. In fact, urban public transportation such as Light Rapid Transit (LRT), Kereta api Tanah Melayu (KTM) Komuter, Express Rail Link (ERL), and Monorail exist to boost economic development in Kuala Lumpur. Currently, public transportation that operates within Klang Valley area is managed by various separate companies. For instance, RapidKL operates on LRT which consist of two lines namely Kelana Jaya Line and Ampang Line. RapidKL is also in charge of the KL Monorail. Kereta api Tanah Melayu Berhad (KTMB) on the other hand operates on KTM Komuter, while Express Rail Link Sdn Bhd operates on ERL. However, none of these network lines lie on the same platform as each other, for example KL Monorail line is not connected physically with any other line.

Determination of an optimal path within a highly complex transportation network is not an easy task, especially for those who are unfamiliar with the local transportation system. Users might get confused when travelling from one place to another. Integration of multi-mode transportation systems would not only ease travellers' transfer from origin to destination, but also make their journey a more enjoyable [7] and less stressful experience. Complicated network of route systems requires critical analysis which can only be realized with the implementation of GIS to improve the movement of people. Moreover, they are not integrated, i.e. they exist as separated systems.

Even though some of well-known route planning systems (see Figure 1) are making efforts to integrate more transportation modes, it is unfortunately performed totally separated for each mode i.e. one mode at a time. In fact, several problems have been identified for route determination of Kuala Lumpur area using Google Maps such as lack of or missing pedestrian paths. The combination of modes is not logic, and the pinpoints of origin-destination are not snapped precisely. This can lead to misunderstanding of information generated and might get users into a troublesome situation.



Figure 1. Separation of modes in (a) Google Maps (b) Bing Maps (c) MapQuest.

To date, there is no such work which involves the modelling and integrating of urban public transportation in Kuala Lumpur. So, the main aim of this study is to develop an intelligent and integrated data model of route network systems within a GIS environment.

2. Modelling multi-mode transportation framework

The metropolitan city of Kuala Lumpur, Malaysia has been selected as the study area. This area contains most of the transit systems (LRT, Monorail, ERL, KTM Komuter) in Malaysia. This Federal Territory covers an area of 243 square kilometres [8]. Under the 1984 Kuala Lumpur Structure Plan, the city centre was designed as the principal core to provide specialized metropolitan services, national and international commercial and business activities, central government activities, and much more.

2.1. Designing abstract connector

One of the crucial parts in designing a geospatial multi-mode transportation network is the integration of available networks (road, rails, pedestrian) into a single layer. In this research, the abstract connector (see Figure 2) is adopted which acts as a 'bridge' to connect between different modes of transportation. It also reflects the transfer process within the movement of people. The solid lines as shown in Figure 2 represent physical networks while the dashed lines illustrate the abstract connector links. The physical network edges contain required attributes such as travelled time, speed limit, length, etc. The physical nodes (shown with green circles in Figure 2) represent locations associated with X, Y coordinates as required attributes.

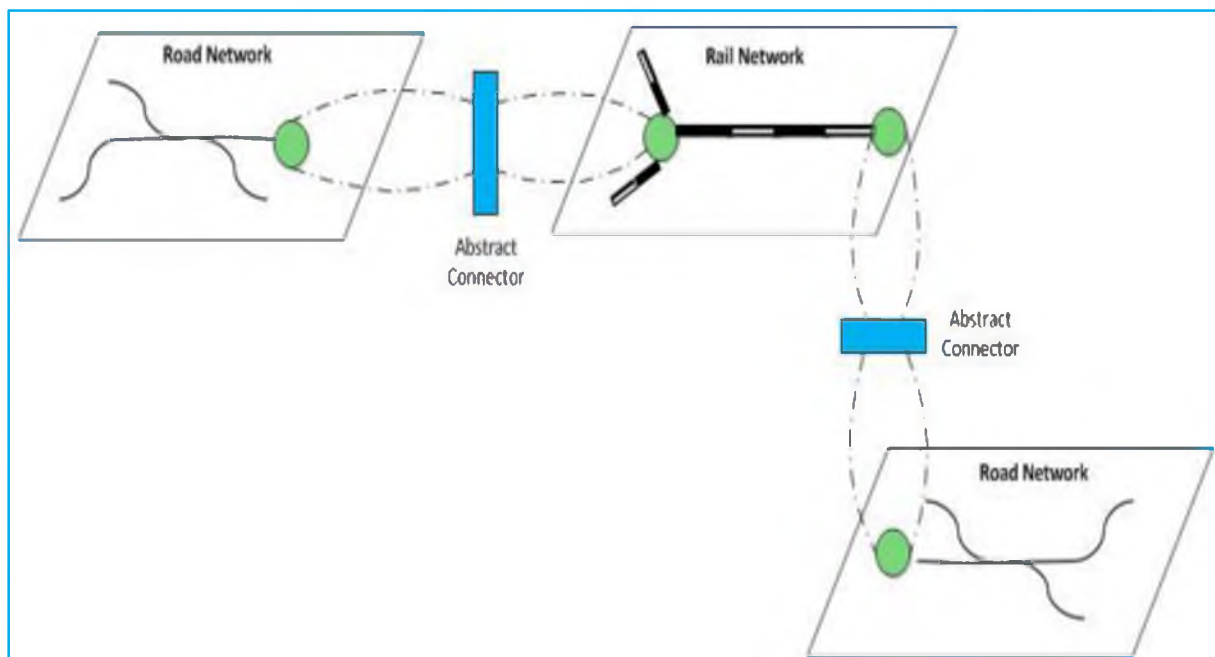


Figure 2. Adopting an abstract connector system in a multi-mode transport network.

In the Kuala Lumpur area, transit stations are accessible using the pedestrian network. The pedestrian network plays a key role in mode transfer. Thus, abstract connectors are properly situated at the intercept point between transfer link and the walkways that lead to the transit stations. It is to be noted that there are two types of transfer; one is transfer within the same mode (e.g. transfer from KTM Sentul Pelabuhan Klang Line to Seremban Rawang Line), the other is between different modes (e.g. transfer from KL Sentral's LRT to Tun Sambathan Monorail).

2.2 Building network dataset

Building network dataset is a compulsory procedure. It is to ensure the data is ready for network analysis to take place. There are 5 steps required in order to create a network dataset which are (i) naming the network dataset and choosing source feature classes (ii) assigning connectivity policy, connecting groups (iii) setting elevation policy (iv) specifying the attributes for the network dataset, and (v) configuring directions.

For the travel time calculation, the formula as shown in Equation 1 is used. It is very important to ensure the unit is correct and comply with the formula. The distance refers to the road length in m unit while the speed limit is converted from km/hr into m/minute.

$$\text{Travel_time (minutes)} = \text{Distance (m)} / (\text{Speed limit} \times (1000/60)) \quad (1)$$

A measure of the amount of resistance, or cost, required to traverse a path in a network is known as impedance. If the impedance is the distance (m), the optimal route is the shortest route. On the other hand, if the time (minutes) is chosen as impedance, the optimal route is the quickest route. Figure 3 shows how a user can define the suitable impedance for a journey.

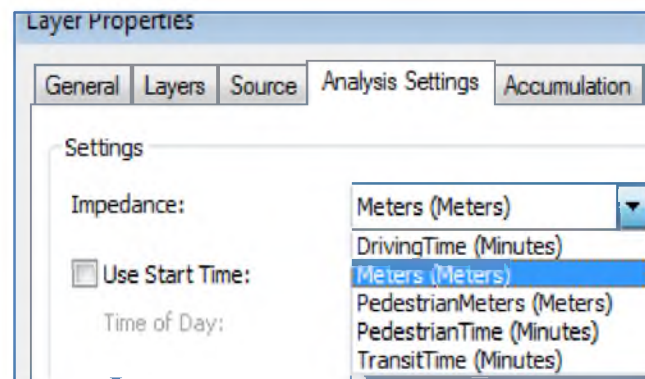


Figure 3. The choice of impedance.

2.3. Assumptions of the analysis

The analysis is based on two assumptions, i.e. (a) for the travel time, it is calculated in the condition that there is no traffic jam in the streets and (b) travel speed is considered as the maximum speed limit. The maximum speed limit is assigned based on the Malaysia's road class as presented in Table 1.

Table 1. Maximum speed limit based on the road classes.

Road Class	Speed (km/hr)
Highway	110
Federal	90
State	90

2.4 Geodatabase design and development

Geodatabase design is the process of producing a detailed data model of the database to meet end user requirements. The Entity Relationship Model (ERM) is most commonly used during conceptual design. The resulting Entity Relationship Diagrams (ERD) provides a data-centric and structural view of the database. A new option is to use a Unified Modelling Language (UML) which contains class diagrams that also incorporate structural views of the database. Figure 4 depicts the conceptual design adopted for the data model.

For this research, the major (required) feature classes (map layers) are road networks, and transit stations and lines (LRT, ERL, KTM Komuter, monorail) – with the correct network topology. Meanwhile, the supporting feature classes include Points of Interests (POIs), transfer points, connecting stations and interchange stations. As accuracy is not an issue for this research, the point and line data are extracted from Google Earth’s images, Google Maps, websites and Garmin BaseCamp 4.2.5 map data. Figure 5 shows the geodatabase model developed for this application based on MS1759. The personal geodatabase is divided into 3 main feature datasets such as the built environment, demarcation, and transportation. Therefore, it enables the geodatabase to more accurately model the network dataset relationships, and maintains data integrity, resulting to more reliable output.

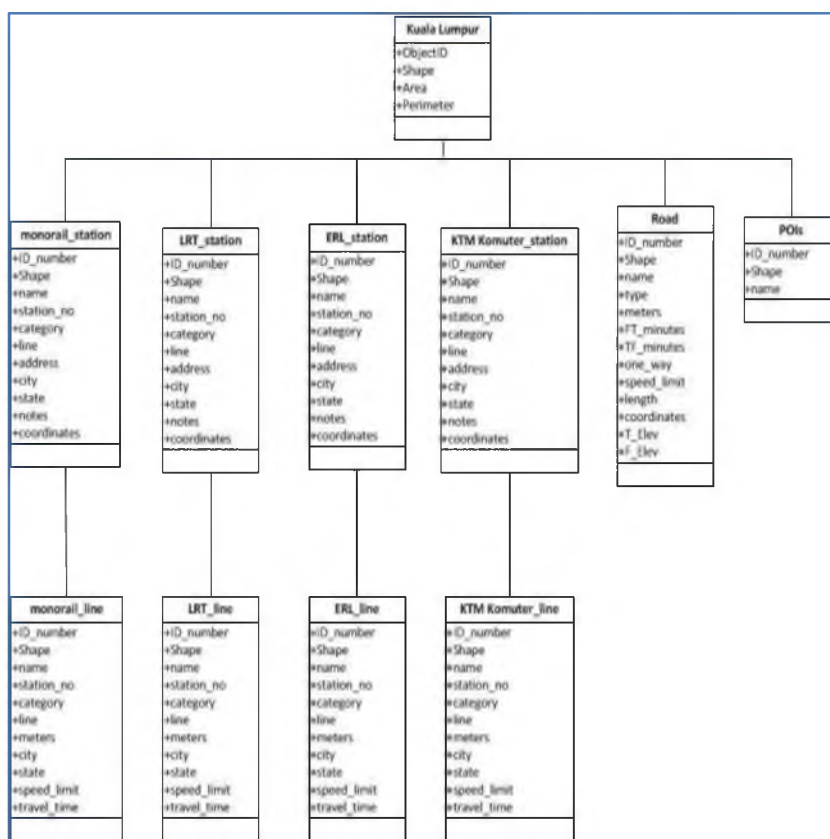


Figure 4. Database conceptual (UML) design.

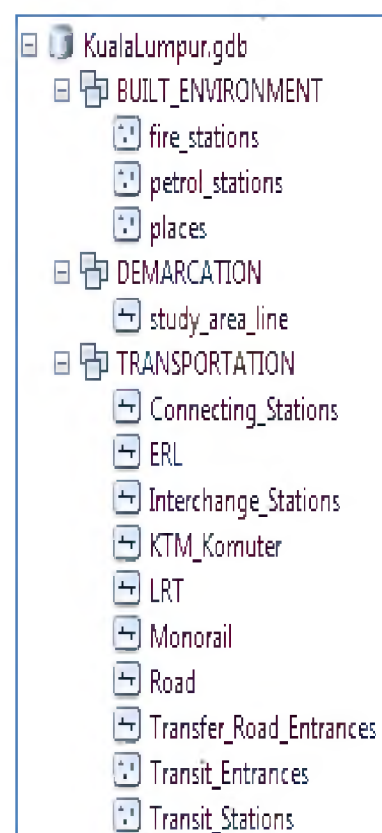


Figure 5. Geodatabase.

3. Application testing

The framework presented in the previous section is used to model and analyze the public transportation systems in Kuala Lumpur’s metropolitan area. The user can visually select the origin-destination without having to input manually information regarding the facilities on the networks. Moreover, with the database associated, it will assist users to have a better interpretation of the network characteristics and minimize the potential for errors generating in the network data files. The well-known Dijkstra’s algorithm embedded within Network Analyst extension makes it possible to perform analysis such as optimal path and closest-facility determination.

3.1. Route analysis in multi-mode transportation network

In the real world, commuters and travellers frequently use several modes of transportation such as walking, driving, and taking the trains. Figure 4 displays the transit systems available in Kuala Lumpur's city including the LRT, Monorail, KTM Komuter, ERL, roads (driving) and footpaths (walking). For LRT, it comprises of 3 lines, the Ampang Line, the Kelana Jaya Line and the Sri Petaling Line. Likewise, the KTM Komuter consists of 2 lines which are the Sentul-Pelabuhan Klang Line and the Seremban-Rawang Line.

To demonstrate a multi-model route analysis, the starting point or source is set to Chowkit Monorail Station and the destination is KL Sentral KLIA Transit ERL. The bold pink colour in Figure 6 highlights the best route to travel from the source to destination. Meanwhile, Figure 7 shows the direction, total time and total distance for multi-modal transportation. In this scenario, the individual travelling uses 5 modes of transportation, Monorail, LRT, KTM, walking and ERL.

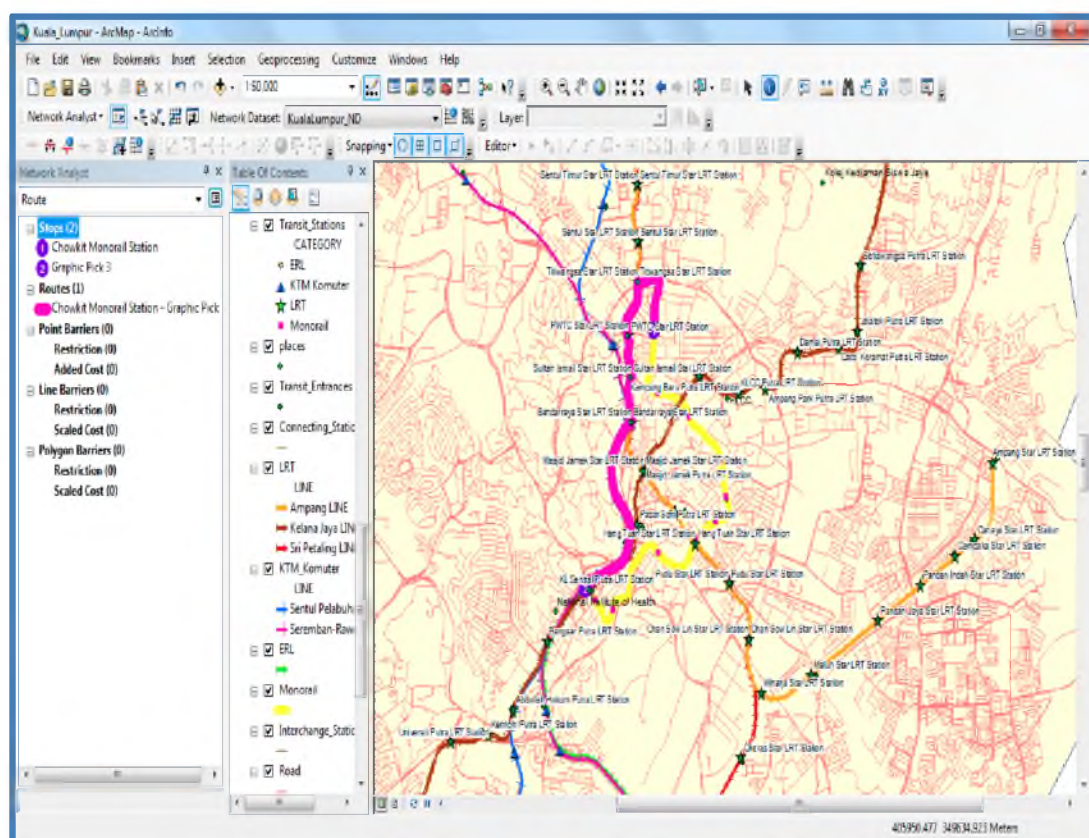


Figure 6. Map of multi-mode transportation analysis.

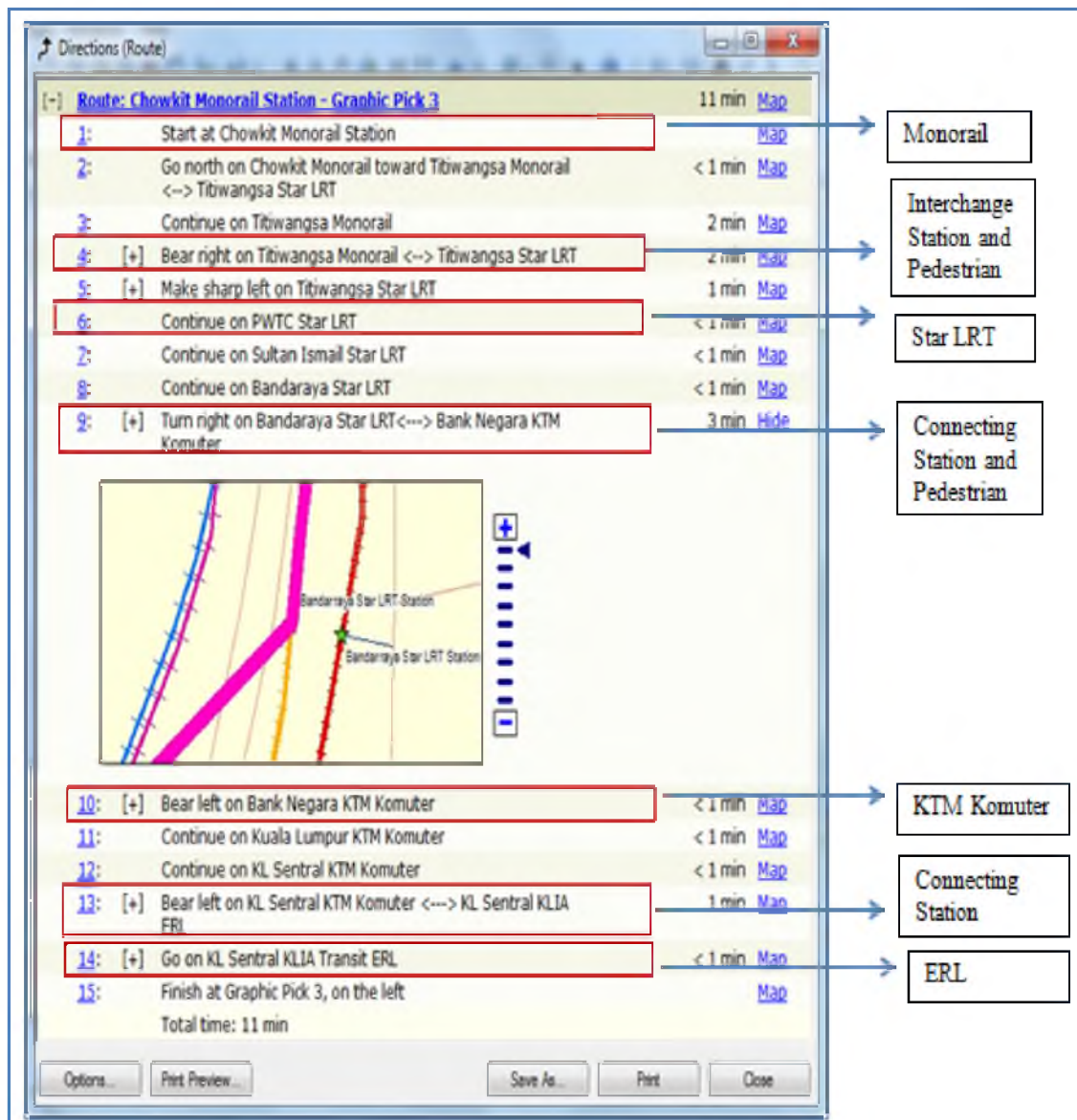


Figure 7. The directions, total time and total distance for multi-modal transportation.

It has to be noted that the definition of connecting stations and interchange stations adopted for this application is as follows:

- **Connecting station:** Is the station that connects two different train modes. For example, Putra Station connects PWTC Star LRT and KTM Komuter
- **Interchange station:** Interchanges between the stations requires an individual to exit the station and then proceed to cross a footbridge that crosses a major roadway. For example, Titiwangsa station is a rapid transit interchange station that allows for transfers between the Ampang Line rapid transit system (formerly known as Star, and the Ampang and Sri Petaling Lines) and the KL Monorail.

3.2. Closest facility analysis

Closest facility is a type of network analysis for finding the closest locations (facilities) from sites (incidents), based on the impedance chosen. For instance, finding transit stations near a current location. The users can specify a cutoff threshold beyond which the algorithm will not search for a facility. Figure 8 displays the results of finding the closest transit stations from a particular location (denoted as “A” in Figure 8) by using pedestrian mode. The green line is the monorail network whereas the blue and orange line represent the LRT network for the Sri Petaling Line and the Ampang Line respectively. As network analysis function is executed, the output shows there are 3 nearby transit stations; Titiwangsa Monorail Station, Titiwangsa Star LRT Station and Chowkit Monorail Station. The yellow line colour shows the direction to those stations. As depicted in Figure 9, the closest transit station is Chowkit Monorail Station which is about 8 minutes from the current position. The result does not only give information about total distance and total time, but also the direction and map to the location.

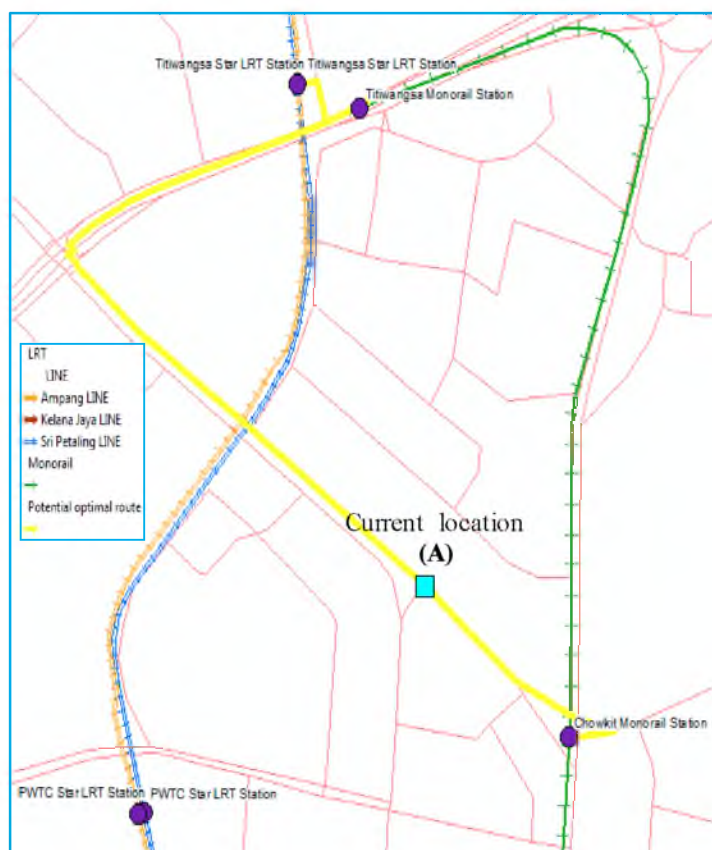


Figure 8. Closest facility analysis.

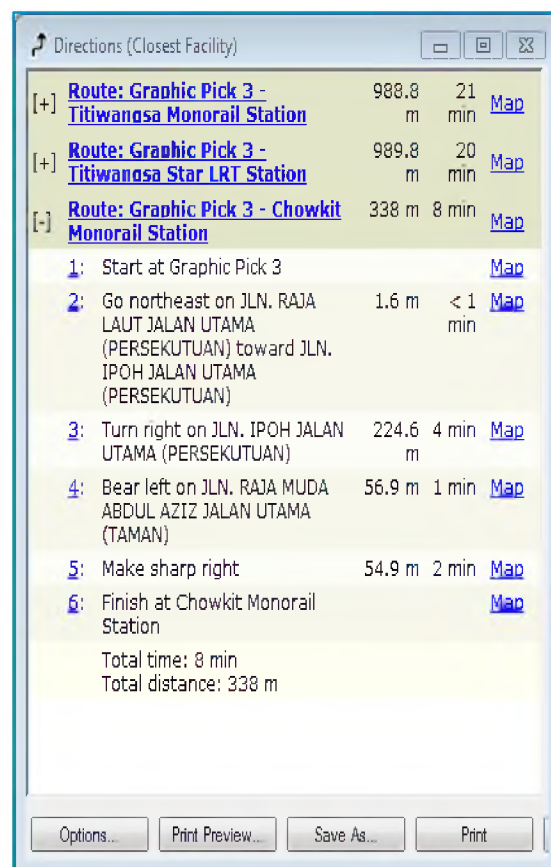


Figure 9. Least time, distance and direction of closest facilities.

4. Conclusion

Throughout this study, all of the urban transportation systems (LRT, Monorail, KTM Komuter, ERL, driving and walking) in the city of Kuala Lumpur are successfully integrated into a single database model by adopting an abstract connector approach. This is to support the real needs of people when moving from one place to another in a situation that has many modes of transport available. All of these facilities are modelled in such a way that they are interconnected and an individual can travel from the start point to the end point. With a proper design of the database, users can freely choose the mode of transportation by either selecting the single or multi-mode. This data model supports the display of the information regarding the total time, total distance, directions and a map to the selected destination. It is particularly useful to assist travellers planning their journey. This type of analysis can be used to find not only the shortest or quickest routes but also for other network applications such as modelling hydrologic flow, traffic flow, and service areas. Consequently, by using GIS, complicated network of routes can be visualized and worked out in a very precise manner.

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