Analysis of Accessibility in an Urban Mass Transit Node: A Case Study in a Bangkok Transit Station

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Received: 19 November 2018; Accepted: 13 December 2018; Published: 17 December 2018

Abstract: Urban mass transit is significant for the urbanization of cities, and the demand for public transit has increased rapidly in recent years. Bangkok, the capital of Thailand, is experiencing an imbalance between demand and supply. Bangkok is facing a transportation problem, particularly in terms of public transport. Accessibility is one of the issues that should be addressed as soon as possible, as it is one of the most important aspects of a transit station. However, there is little analysis of the accessibility of transit nodes. The aim of this paper was to analyze the characteristics of connectivity and accessibility of existing transit stations and station buildings based on the theory of space syntax. This paper selected three transit stations located in high-potential areas, which are the main hubs of public transit in each zone of Bangkok. The integration values of different stations were compared, and objective, quantitative, and graphical methods were used to evaluate the effectiveness of their internal series of spatial accessibility through spatial syntax-related professional software Depthmap, theoretical interpretation of the derived data and images, and exploration of their spatial structure layouts. Also, a spatial analysis of activities located along the connection routes was conducted using betweenness analysis in order to identify the interaction between activities and architecture space in the station building regarding transit connection behavior. The results will contribute to a better understanding of the accessibility of transit stations and the relationship between the architecture spaces and station facilities that affect accessibility for passengers.

Keywords: accessibility; transit station; mass transit node; space syntax; integration value; betweenness

1. Introduction

Accessibility refers to the ease of access to services, activities, and destinations, known as the “potential of opportunities” [1]. An accessible transportation system can be defined as one that enables individuals to reach their destinations. An accessibility-based analysis can lead to better solutions to transportation problems by providing benefits and congestion reduction in cost-effective ways [2]. Access to mass transit stations has become a major issue in many cities in recent years [3]. Accessibility concerns both non-disabled and disabled people, so all users benefit when the main routes through stations are made accessible. Access to stations includes issues relating to safety, especially for pedestrians, as well as the need to make access attractive to passengers [4].

The accessibility of a transit system or one of its stations includes the standard of the connections between different modes of transportation [5]. High-quality public transit nodes improve the transfer experience and attract more passengers [6]. In Bangkok’s mass transit system, there are many problems posed by inconvenient transit setups, ranging from the connection area and the environment around the transit nodes to safety, security, and accessibility.

In recent years, Thailand and especially Bangkok have experienced rapid economic development, which has led to Bangkok’s high-speed expansion. Today, Bangkok is facing problems based on this
rapid development. Traffic congestion is a major issue, particularly in the central business district (CBD) at peak times, affecting the majority of people who work in this area. One can spend hours in traffic jams, moving only a few kilometers. The other major effect that traffic jams have on the city arises from air pollution from vehicles. Both problems result from a lack of decent infrastructure planning and poor availability of public transportation. Thus, future infrastructure planning should endeavor to develop public mass transit that can solve these issues.

Bangkok’s transport problem is enormous, encompassing the unreliability of public transportation, bad management, congestion, and poor-quality walkways. According to the Office of Transport and Traffic Policy and Planning (OTP), the average speed during rush hour on Bangkok’s main road in 2014 was around 16.5 km/h [7]. Changes in transportation have not appropriately matched transport policy and urban planning, a failure that has been fatal because the urban structure and public transport were not compatible. The mass motorization of Bangkok started in the 1960s, when Bangkok had buses operating in mixed traffic and at high density levels [8]. Inadequate planning created highly visible negative impacts for the rapid increase of motorization including congestion, sprawling, and high pollution. Bangkok is in a highly volatile position, and immediate action is required, due to its status as a car city. Bangkok has long favored the car as its main mode of transportation, however, it should now be transitioning to a transit city. Bangkok appears to have an urban transit system in which urban and transport planning are not necessarily executed in the interest of the people. Bangkok suffers from many standalone projects across the city, which can cause troubles with urban design efficiency. Inconvenient access is an outstanding issue in Bangkok public transit.

To enhance station accessibility, the item inventories of Bangkok’s mass transit systems need to be considered. Access facilities to transit stations are unfriendly to all user groups, especially walking access facilities. Walking conditions have limitations not only in the walkways to access the station buildings but also for circulation in the stations and rush hour management. Most studies that have undertaken metro accessibility assessments have centered on spatial-based accessibility [9–11] or on economic value and location-based accessibility [12–14]. These were usually measured by the three indices of distance, time, and cost.

These endeavors have not specifically focused on transit station accessibility performance in the context of urban connectivity and the relationship between architectural spaces and accessibility. In addition, traditional approaches have failed to capture the relationship between accessible routes and the activity nodes at transit stations. Discussions about the opportunity to access transit stations can be judged in terms of urban connectivity, architectural space, and activity aspects [15].

This study aimed to evaluate and compare accessibility performance across transit stations in Bangkok’s mass transit nodes and to interpret transit mode connection behavior according to the road systems on an urban scale and the design space in the architectural aspect. The findings will contribute towards a better understanding of the accessibility of transit stations and their relationship with their surrounding environments, in order to improve the efficiency of transit station accessibility and decrease the traffic problem around transit stations. In terms of architectural spaces, the findings will make recommendations about the relationship between passengers’ accessibility, architectural spaces, and station facilities that could make the station more convenient to access. The results can also be useful for improving transit stations or ongoing transit projects and for similar transit systems in other cities.

2. Literature Review

2.1. Transit Accessibility

The concept of accessibility was introduced by Hansen in 1959, who defined it as the opportunity to interact between different nodes in a transportation network [1]. Researchers have different understandings of the idea of accessibility [16–18]. Most include both destinations and activities, as well as travel resistance. There are three common elements of accessibility: How easy it is to travel [19–22],
how much it costs to travel \[23\], and the intensity of space interactions \[24,25\]. The components of accessibility are categorized into four types by different definitions and practical measures: Land use, transportation, temporal, and individual \[26\]. Although an accessibility measure should consider all four of these components, in practice, most accessibility analyses only focus on one or two components of accessibility, depending on the purpose and perspective taken.

Researchers have employed various methods and criteria to evaluate the walking accessibility of transit stations. The walking environment at a station was analyzed by Park \[27\], who summarized the environmental factors that could affect walking accessibility. Schlossberg and Brown \[28\] studied walking accessibility within 0.25–0.5 miles of a transit station, taking street networks, intersections, and impedance intersections into consideration. Zhang et al. \[29\] discussed the walking accessibility of transit stations by taking into account walking comfort level, road network patterns, and street-crossing facilities. Most of the existing studies on accessibility show that walking can be the primary access mode, especially if the station is within 1 km of the departure point \[30\]. However, walking access could be inconvenient, unsafe, or unpleasant if there are circuitous routes, dark corridors, poor footpath conditions, heavy traffic, or physical or psychological barriers \[31\]. Another significant factor that assists users to access transit modes can be assessed by observing transit development in terms of architecture and built environmental design \[32,33\]. One significant issue involves the corridor spaces connecting public transit modes which create continuity of accessibility and encourage walkability and other characteristics of the space nearby. The functions of the transit corridor have a direct impact on passenger accessibility \[7,34\]. This is also supported by Hickman \[35\] who found the facilities of the transit station, such as shops, restaurants, other services, in addition to convenient access are important to consider for passengers.

2.2. Bangkok’s Mass Transit Systems

Bangkok appears to have an urban transit system in which urban and transport planning are not necessarily executed in the interest of the people. Bangkok suffers from many standalone projects across the city, which can cause troubles with urban design efficiency. Since 1999, the Bangkok Skytrain (BTS) has operated to serve people as a mass transit mode in the Bangkok metropolitan region (BMR), which comprises the Bangkok metropolitan area and five surrounding provinces (Samutprakan, Nontaburi, Nakhonpathom, Pathumtani, and Samutsakhon). Five years later, the mass rapid transit subway (MRT) began operating in 2004. Both systems were built in the central business district (CBD) of Bangkok, including the downtown areas of Sathorn, Silom, Siam, and Sukhumvit Road.

The BTS system consists of 35 stations along two lines: The Sukhumvit Line running northwards and eastwards, terminating at Mo Chit and Samrong, and the Silom Line, which serves Silom and Sathon Roads, the central business district of Bangkok, terminating at the National Stadium and Bang Wa. It serves more than 900,000 passengers each day. The lines interchange at Siam Station and have a combined route length of 38.7 km (24.02 km in the Sukhumvit Line and 16.67 km in the Silom Line) \[36\]. Subsequently, an additional 95.7 km of new lines have been secured: The Northern and Southern Green Line extensions (from Bearing to Samut Prakan and from Mo Chit to Khu Khot) in March 2017, as well as the Pink Line (from Khao Rai to Min Buri) and the Yellow Line (from LadPrao to Sam Rong) in June 2017. The network coverage will increase by approximately three times its current coverage (38.7 km) in the next three to four years when all these lines become operational \[37,38\].

The MRT system has 35 operational underground stations along 43 km with two lines. The system serves more than 410,000 passengers each day (Blue Line, 360,000, and Purple Line, 50,000). The Blue Line was the first of the two lines to operate from mid-2004, officially known as Chaloem Ratchamongkhon. It runs eastward from Tao Poon Station along Kamphaeng Phet, Phahon Yothin, and Lat Phrao Roads, then turns south following Ratchadaphisek Road, then west following Rama IV Road to Hua Lamphong station. The second line, MRT Purple Line, officially known as Chalong Rachadam, began operating in 2016, connecting Tao Poon with Nonthaburi Province in the northwest, and there is a planned 19.8 km southern extension from Tao Poon and Phra Pradaeng.
Passengers will be able to interchange from the MRT Purple Line to the Blue Line Extension at Tao Poon station [39]. Figure 1 shows the map of the mass transit systems in the Bangkok metropolitan region.

![Map of mass transit systems in Bangkok.](image)

Figure 1. Map of mass transit systems in Bangkok.

Access to Bangkok mass transit has become a critical issue in recent years, as the pedestrian network around transit stations is not suitable and is inconvenient along access routes [40]. There are many disjointed road networks around the transit stations that make pedestrian accessibility disconnected from one node to another node, also the physical suitability of sidewalk conditions is poor due to the limited conditions of the sidewalks in general, as well as a lack of pedestrian safety [41]. To enhance station accessibility, the item inventories of both transit systems need to be considered. Access facilities to transit stations are unfriendly to all user groups, especially walking access facilities. Walking conditions have limitations not only in the walkways to access the station buildings but also for circulation in the stations and rush hour management.

3. Research Methods

3.1. Research Purpose

This research is based on the theory of space syntax and betweenness, using the concept of integration value and Depthmap and Rhinoceros software to quantify the spatial structure of the transit stations. Firstly, the current situation of the urban mass transit node in Bangkok will be surveyed, and space syntax will be used to analyze its accessibility. Finally, the accessibility of Bangkok’s urban mass transit nodes will be compared in different aspects, and recommendations will be made on the accessibility of the transit nodes.
The aim of this research was to analyze whether there are differences between mass transit stations in different aspects in order to better understand the connectivity between different transit systems at the same transit node.

3.2. Space Syntax Method

Space syntax is an architectural theory proposed by Bill Hillier that studies the correlation between space and human societies using the space organization concept. Space syntax is also defined as a graph-based theory used to examine how the spatial layout of buildings and cities influences the social, economic, and environmental outcomes of human movements and social interactions [42]. Its techniques offer precise quantitative descriptions of the way in which the built spaces of a setting are organized [43].

Space syntax is related to three concepts: Convex space, axial line, and isovist field. Convex spaces include (a) spaces exhibiting non-linear behavior and (b) the buildings and common spaces among them, as well as the interior arrangement of houses. Axial line analysis is usually used in the analysis of structures in cities, villages, or neighborhood units [44]. A connection graph is defined depending on how each line connects to its surroundings.

This research chose the method of axial analysis to analyze the accessibility of the station buildings. In this method, according to spatial perception, a large-scale space is divided into a series of small-scale spaces. The relevant index of each axis represents the convenience of movement, transfer, forward, and other capabilities. All lines in a spatial layout are a certain distance from all other lines in the system, and travel along the axial direction is the most economical and convenient movement.

For analysis of station buildings, the space in the architectural sense is three-dimensional. It is assumed that the person is active on the floorplan, and the function of the building space is mostly related to the floorplan. Therefore, the space is assumed to be two-dimensional, summarized by its plan view and the calculated relationships between the spaces. Restoring the building’s floorplan to a connected convex space and enclosing the spaces in a closed curve are the functions of software simulation analysis.

Depthmap is an analysis software associated with two strands of thought: Isovist analysis and space syntax. In the software, visibility is used as an independent variable derived from the connectivity graph. Connectivity ($C_i$), as defined by Jiang et al. [45], is the first variable as a direct connection of nodes (k) to each individual node in the connectivity graph, as shown in Equation (1):

$$C_i = k$$

The second dependent variable is step depth, defined as the number of steps from one node to the other nodes. It is measured by averaging the transfer times required from a given node to all other nodes. Then, if $i$ to $j$ is the shortest distance ($d_{ij}$) in a connectivity graph, total depth is the sum of steps from $i$ to $j$, and $n$ is the number of the nodes in the topology graph as in Equation (2):

$$\sum_{j=1}^{n} d_{ij}$$

The third variable (Equation (3)) is an integration, and the focus is HH-integration, that is, the integration developed by Hillier and Hanson [42]. Integration defines the degree to which a node is integrated in or segregated from a system as a whole (global) or partially (local). The values from integration represent how easily a space can be reached from the street. The summary of variables measured in Depthmap software are shown in Table 1.

$$MD_i = \frac{\sum_{j=1}^{n} d_{ij}}{n - 1}$$
Integration value (Int. V) was used for analysis, which also includes the global integration value (Global Int. V) and local integration value (Local Int. V) for the analysis of accessibility around the station. QGIS software was used to import the vector data to analyze the accessibility of route systems around the transit stations.

3.3. Betweenness Method

To measure the connectivity space performance in transit stations, the study found common paths by using the betweenness index in the urban network analysis (UNA) toolbox that runs in Rhinoceros software [46]. The betweenness index ([i]r) in particular was used to simulate the spatial relationship between the street network (i) and the surrounding architectures, which represents the trajectory on which trips might occur according to the subjected network. By calculating the shortest path between origins and destinations (njk) within the assigned network (i), the normalization of the betweenness index is defined as Equation (4).

\[
\text{Betweenness } [i]_r = \sum_{j,k \in G} d[j,k] \leq r \frac{n_{jk}(i)}{n_{jk}} \cdot W_{[j]}
\]

where:
- \( i \) = network
- \( j \) = origin location
- \( k \) = destination location
- \( r \) = search radius
- \( n_{jk} \) = the number of shortest paths between origin \( (j) \)
- and destination \( (k) \)
- \( W_{[j]} \) = the weight of origin \( j \)

The study counted the number of activities located around the nearest connection route between the entrance/exit gates and the staircases connected to the platform on the upper floor by representing them as an observer point function in the UNA tool. The observer points were counted as the number of trips that passed by each observer point. Then, the study used observer points to represent the location of each activity in the station area, which is illustrated in Figures 2–4, in order to interpret how activities along the corridor area impact the potential connection routes. The network lines show the connection between the origin nodes (station entrance/excite) to the destination nodes (staircase to platform) through the facilities node in the station building.

Moreover, the detour ratio variable was analyzed in this study through the interpretation of alternative route analysis on pedestrian accessibility. The study area that was investigated covered 30% of the detour ratio from the shortest paths of transit modes’ connection paths, according to pedestrian behavior, which usually deviated around 10–20% above the shortest route [47]. The investigation did not limit the search radius to rule out the additional time spent on access that might occur due to other factors and to concentrate on the distance factor via the nearest route, and the detour ratio already included the limitation of time of accessibility.
which is fed by several transit modes on Phahon Yothin Road. The station is an important interchange station in central Bangkok, with a major Bangkok Mass Transit Authority (BMTA) bus stop as well as van terminals connecting to suburbs and provinces around the capital.

Sustainability

Figure 2. Location of facility nodes interpreted as observer points of Mo Chit Station.

Figure 3. Location of facility nodes interpreted as observer points of Victory Monument Station.

Figure 4. Location of facility nodes interpreted as observer points of Saphan Taksin Stations.

3.4. Selection of Site Stations

The key criterion used for site selection was each station’s ability to give a variety of connectivity, in particular different transportation modes. In addition, site selections must be located in the transit node of each Bangkok zone, such as the big transportation node in northern Bangkok. After pre-survey, three BTS Skytrain stations (Mo Chit, Saphan Taksin, and Victory Monument) were selected to assess transit accessibility performance in Bangkok, Thailand. All the stations were located in business or commercial areas. The stations presented different characteristics regarding their functions, including station building, interchange area, and transit systems.

3.5. Overview of Selected Stations

Mo Chit Station is a Skytrain station on the Sukhumvit Line located in Mo Chit transit node, which is fed by several transit modes on Phahon Yothin Road. The station is an important interchange station in northern Bangkok where passengers can directly connect to Chatuchak Park subway station (MRT Blue Line) and inter-city buses at Mo Chit Bus Terminal, the biggest bus station in Bangkok, which connects the north, central, eastern, and northeastern provinces to the city. The station is also located near Bang Sue Railway Station, also known as Bang Sue Junction, where the train is bound for northern and northeastern Thailand. Moreover, Bang Sue Station will be Thailand’s new railway hub, replacing the current Bangkok railway station at Hua Lamphong as the terminus for all long-distance rail services from Bangkok. It will increase the number of passengers at Mo Chit Station when the new Bang Sue railway is operational.

Victory Monument Station is a Skytrain station on the Sukhumvit Line located on Phaya Thai Road to the south of the Victory Monument, one of Bangkok’s landmarks. It is near the major traffic circle at the intersection of Phahonyothin Road, Phaya Thai Road, and Ratchawithi Road, which has long served as one of the busiest transportation nodes in Bangkok. The station is linked to all four exits of the traffic circle by the skywalk and almost stretches around the monument. The station is
an important interchange station in central Bangkok, with a major Bangkok Mass Transit Authority (BMTA) bus stop as well as van terminals connecting to suburbs and provinces around the capital.

Saphan Taksin Station is a station on the BTS Silom line in Sathon District. It is located at the entry ramp to Taksin Bridge below Sathon Road and east of the Chao Phraya River. The station was established in a highly developed area with business and commercial uses. The diversity of uses near a station is a major driver of intense activity centers that can enhance accessibility. The population, housing, and physical surrounding density at the stations are very high. Saphan Taksin Station is the only rapid transit station in Bangkok whose passengers can transfer to a river pier for the ferry to Thonburi and the Chao Phraya Express Boat service. That makes the station popular for both daily passengers and tourists sightseeing on river boats in the historical area around the Chao Phraya River, as shown in Figure 5.

Based on site surveys, the selected stations presented a variety of feeder modes, including Skytrain, subway, local train, bus, passenger van, taxi, hired motorcycle, boat, and other para-transit modes. Some stations had good-quality access facilities and available elevators, staircases, and escalators. However, not all stations presented good-availability and -quality facilities. This situation makes access difficult to disadvantaged groups such as the elderly, pregnant women, and disabled people, as shown in Table 2.

Table 2. The available facility at Bangkok mass transit node.

<table>
<thead>
<tr>
<th>Available Facility</th>
<th>Saphan Taksin</th>
<th>Mo Chit</th>
<th>Victory Monument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle parking</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Parking area</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Stair</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Elevators</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Escalator</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Skywalk</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Time table</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Priority way for disabled users</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Information for disabled and elderly users</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Adequate signage for blind</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
For pedestrian access, all selected stations were found to have sidewalks between 1 and 3 m wide (Table 3). Parking was offered at Mo Chit Station only. Except for Saphan Taksin Station, all stations provided an elevator to access the station building but did not provide priority for disabled users or adequate signage for the blind. Victory Monument Station provided a skywalk to access the station, and it was the main way passengers accessed the station building. The feeder connectivity was found to be different at the different stations. Saphan Taksin station was the only station with feeder by river transport, as shown in Table 3.

Table 3. The connectivity at Bangkok mass transit node.

<table>
<thead>
<tr>
<th>Size of Pedestrian</th>
<th>Saphan Taksin</th>
<th>Mo Chit</th>
<th>Victory Monument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sidewalk (width)</td>
<td>Between 1 and 3 m.</td>
<td>Between 1 and 3 m.</td>
<td>Between 1 and 3 m.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Connectivity at Transit station</th>
<th>Saphan Taksin</th>
<th>Mo Chit</th>
<th>Victory Monument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus lines</td>
<td>11 lines</td>
<td>40 lines</td>
<td>77 lines</td>
</tr>
<tr>
<td>Boat</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Train</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>BRT (Bus rapid transit)</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>MRT Subway</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>BTS Skytrain</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SRT (Suvarnabhumi Airport Rail Link)</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Para-transit</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

4. Results of Accessibility Analysis

4.1. Analysis of Accessibility around the Stations

The specificity data of the connectivity transfer and the road space into axial lines were used to calculate the integration value. The results analysis uses integration value (Int.V) and global integration value (Global Int.V) to represent the tightness of the contact between one node and all the nodes throughout the system, and the partial integration value (which usually takes the activity goal center and has three topology steps) as the tightness between one node and its surrounding nodes in the system [45]. It disperses the degree to which one unit space connects with all other parts in the same system. A high integration value means a more convenient space.

Minimum Global Int.V is the minimum integration value of accessibility. A place with the minimum Global Int.V is remote and hard to get to. Maximum Global Int.V is the maximum integration value of accessibility. A place with the maximum Global Int.V is very convenient to get to and has a high degree of utilization. Mean Global Int.V is the mean integration value of accessibility, it describes an average degree of accessibility. The last value, local integration value (Local Int.V), is the partial integration value of accessibility. It describes the relationship between one space and its surroundings. Table 4 shows the integration values of accessibility around the three selected stations which calculated the range of accessibility value from 0 to 1.

Table 4. The Integration values of accessibility around the stations.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Global Int.V</th>
<th>Local Int.V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Mean</td>
</tr>
<tr>
<td>Mo Chit</td>
<td>0.128</td>
<td>0.286</td>
</tr>
<tr>
<td>Victory Monument</td>
<td>0.142</td>
<td>0.304</td>
</tr>
<tr>
<td>Saphan Taksin</td>
<td>0.133</td>
<td>0.289</td>
</tr>
</tbody>
</table>

Color graphics are often used to distinguish the relevant variable values. Figures 7, 9, and 11 use a series of color gradation, which changes from warmer to cooler colors, such as red, yellow, green,
and blue. It is generally used to express the distribution of the variable values from high to low. Here, the differently colored lines represent the integration value.

4.1.1. Mo Chit Station

The connectivity around the stations includes the bus stops that service the buses in the capital area and van taxis. Motorcycle taxi is also a popular mode of transit at Mo Chit Station for passengers who have destinations within 5 km of the station. The connectivity of transportation nodes at Mo Chit Station are shown in Figure 6.

![Figure 6. The connectivity at Mo Chit Station with the different transit modes.](image)

The minimum Global Int.V at Mo Chit Station is 0.128, its mean Global Int.V is 0.286, and its maximum Global Int.V is 0.422. Its minimum Local Int.V is 0.105, its mean is 0.311, and its maximum is 0.670, as shown in Figure 7. The main road that directly connects to the station has a Global Int.V of 0.277, which is a normal accessibility but is lower than the mean Global Int.V. The space surrounded by this road is not particularly convenient to reach, including the station building. Access to the station is inconvenient for passengers, especially during rush hour. Considering that the roads around the station that are connected to the main road also have low Global Int.V, their positions are relatively remote and lack activity.

4.1.2. Victory Monument Station

Connectivity around the station includes motorcycle taxis located near the bus stops. The passengers can connect to all bus stops via a skywalk that is linked to all four exits of the traffic circle. The skywalk from the station is also connected to shopping malls around the Victory Monument, so passengers can access the station building directly from the shopping malls. Figure 8 shows the connectivity nodes at Victory Monument Station.
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Figure 8. The connectivity at Victory Monument Station with the different transit modes.

As Figure 9 shows, the minimum Global Int.V is 0.142, the mean Global Int.V is 0.304, and the maximum Global Int.V is 0.442. Its minimum Local Int.V is 0.129, its mean is 0.530, and its maximum is 0.715. In the center of the Victory Monument, there is one road that has the highest value and four roads that have high values, which make for high accessibility and the most dynamic places.

Figure 7. The integration value analysis of Mo Chit Station.

Figure 8. The connectivity at Victory Monument Station with the different transit modes.

As Figure 9 shows, the minimum Global Int.V is 0.142, the mean Global Int.V is 0.304, and the maximum Global Int.V is 0.442. Its minimum Local Int.V is 0.129, its mean is 0.530, and its maximum is 0.715. In the center of the Victory Monument, there is one road that has the highest value and four roads that have high values, which make for high accessibility and the most dynamic places.
The space surrounded by these roads of high integration value is more convenient to reach. Meanwhile, the main road that directly accesses the station has a Global Int.V of 0.30, which is close to the mean Global Int.V, indicating average accessibility. However, the ring road around the center of the Victory Monument can support the main road to access the station.

**Figure 9.** The integration value analysis of Victory Monument Station.

4.1.3. Saphan Taksin Station

Saphan Taksin Station is a station on the BTS Silom line in Sathon District. It is located at the entry ramp of Taksin Bridge, below Sathon Road and east of the Chao Phraya River. Saphan Taksin Station is the only rapid transit station in Bangkok whose passengers can transfer to a river pier for the ferry to Thonburi and the Chao Phraya Express Boat service. That makes the station popular for both daily passengers and tourists sightseeing on river boats in the historical area around the Chao Phraya River.

The connectivity around the station also includes bus stops, motorcycle taxis, and Songtaew (minibuses) that serve Sathon District. The connectivity nodes at Saphan Taksin Station are shown in Figure 10.

The minimum Global Int.V at Saphan Taksin Station is 0.133, the mean Global Int.V is 0.289, and the maximum Global Int.V is 0.426. Its minimum Local Int.V is 0.117, its mean is 0.598, and its maximum is 0.726, as shown in Figure 11. The main road that directly connects to the station has a high value of 0.303, which makes for high accessibility and the most dynamic places. Access to the station is therefore more convenient. Moreover, the two routes of river transport that access the station have the highest value, which means that Saphan Taksin Station also has high accessibility via river transport. The three roads that connect to the main road also have a Global Int.V greater than 0.32, which means that these roads also have high accessibility. These support the accessibility at the main road and improve the accessibility around the station.
Figure 10. The connectivity at Saphan Taksin Station with the different transit modes.

Figure 11. The integration value analysis of Saphan Taksin Station.
4.2. Accessibility Analysis Inside the Station Building

In the analysis results, color graphics are used to describe the variable values. The red in the analysis results illustrates that a space has the highest integration value, indicating that it has the most potential destinations, shallowest spatial depth, and highest accessibility. The cooler colors indicate that a space has a lower degree of integration, and the deeper the spatial depth, the less accessibility it has.

A station building with the minimum Int.V is remote and hard to get into, while one with the maximum Int.V is very convenient to access and has high utilization, and one with the mean Int.V has an average degree of convenience. Table 5 shows the integration values of accessibility in the stations.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Minimum</th>
<th>Mean</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mo Chit</td>
<td>0.591</td>
<td>1.104</td>
<td>2.318</td>
</tr>
<tr>
<td>Victory Monument</td>
<td>0.722</td>
<td>1.212</td>
<td>2.413</td>
</tr>
<tr>
<td>Saphan Taksin</td>
<td>0.480</td>
<td>1.347</td>
<td>2.901</td>
</tr>
</tbody>
</table>

4.2.1. Mo Chit Station

As shown in Table 5, the maximum Int.V is 2.318, which belongs to a corridor space at the center of the station, near the stairs that access the platform. The minimum Int.V is 0.591, belonging to the circulation space that connects the station building and surrounding area. The mean Int.V is 1.104. The integration values of the station’s two entrances are quite similar, and both have high accessibility. Except for the corridor that connects inside and outside the station, the corridor and circulation spaces of Mo Chit Station have good accessibility and high dynamicity.

Figure 12 illustrates Mo Chit Station’s floorplan. The station building can be accessed via four entrances. Entrances/exits one and three are located at the west of the station—entrance/exit one is connected to Chatuchak Market, while entrance/exit three is connected to Queen Sirikit Park. Entrances/exits two and four are located at the east of the station and connect to a van taxi terminal and a parking area. The station provides staircases and escalators to access the station building as well as an elevator for disabled users. The ticketing machines are located at the north and south of the station, near the station’s entrance gate. In the station area, staircases and escalators are also provided for access to the platform on the upper floor.
Figure 13 shows the accessibility values at Mo Chit Station. The spaces inside the entrance gates have high accessibility along two lines in the corridor space, especially the spaces in front of the staircases that connect to the platform on the upper floor. These spaces have high values of accessibility, so they are very convenient to access and have high utilization. Meanwhile, the accessibility at the entrance/exit areas is of low value, so it is difficult to access these areas.

4.2.2. Victory Monument Station

The minimum Int.V is 0.722, which belongs to the stairs and escalators that connect the station building and the surrounding area. The mean Int.V is 1.212. As Figure 15 shows, the maximum Int.V of Victory Monument Station of 2.413 belongs to the spaces on both sides of the station near the entrances. This means that these spaces have the highest accessibility, are the most dynamic spaces, and are the most convenient to reach. The integration values of most of the station spaces are close to the mean Int.V, which means most of the spaces in this station have good accessibility and are convenient to access.

Victory Monument Station can be accessed through five entrances. Entrances/exits one and three are located at the west of the station—entrance/exit one is connected to Boromarajonani College of Nursing, while entrance/exit three is connected to Rajavithi Hospital. Entrances/exits two and four are located at the east of the station—entrance/exit two is directly connected to the Century Movie Plaza via the skywalk, and entrance/exit four is connected to the Siam International building. Entrance/exit five is directly connected by the skywalk to other buildings other transit modes around the Victory Monument. The entrance gates are located at the north and south of the station building next to the ticket machines as shown in Figure 14.

Figure 15 illustrates the quality of accessibility at Victory Monument Station. The highest accessibility belongs to the ticketing machine areas at the north and south of the station building (red zones), these spaces are convenient to access and have good connectivity with other spaces. The space in the station building between the two entrance gates also has good accessibility to the passengers inside the station areas, whereas the entrance/exit areas have the lowest accessibility.
4.2.3. Saphan Taksin Station

As Figure 17 shows, the minimum Int.V of Saphan Taksin Station is 0.480, which means the space is remote and hard to get into. The long corridor and the circulation space in the station building have the highest accessibility and are the most dynamic, with a maximum Int.V of 2.901. However, the spaces near the stairs connected to the platform have an Int.V that is close to the minimum, meaning that these spaces have low accessibility and are inconvenient to access.

This station building is located at the entry ramp of Taksin Bridge. Entrances/exits one and two are located at the west of the station and connect to the Sathorn Pier, while entrances/exits three and four are connected to Charoen Krung road at the east of the station. The ticketing machines and
entrance gates are in the east wing and the west wing of the station building. To access the platform on the upper floor, passengers must use the staircases at the south side of the station as shown in Figure 16.

Figure 16. Saphan Taksin Station’s floorplan.

Figure 17 shows that the linear corridor has the highest accessibility from entrances/exits one and three. This space is capable of channeling passengers with its convenience and highly dynamic activity. However, entrance/exit two has very poor accessibility, and entrance/exit four has poor accessibility, making it inconvenient for passengers who access the station from both of these entrances.

Figure 17. Accessibility analysis in Saphan Taksin Station’s building.

4.2.4. Analysis of the Nearest Connection Route in the Station Buildings

Considering the relationship between facility nodes in the corridor space and the connection route in the station, corridor spaces were investigated to identify the relationship between activity arrangements and effective transit station connecting routes in transit station buildings. The circulation of connection routes was surrounded by facility nodes. The spatial circulations were interpreted by analyzing the most common connection routes between station entrances/exits and platforms by the betweenness index value, which shows the number of trips that occur with the shortest distance among nodes. This study assigned a detour ratio of up to 30% from the shortest route, whereby the station entrances/exits could access the staircase to the platform.

As a result, the facility nodes were connected with transit connection paths differently based on the priority of space and activity arrangement in the Mo Chit Station area. Figure 18 illustrates the facility nodes’ involvement in major connection routes, which follows the percentage of detour ratios that were assigned in the simulation process. The nearest routes occasionally passed the facility nodes, which means that the main accessibility route could not be easily reached by the passengers via the main facilities such as ticketing machines. However, if these connection routes were followed by passengers during rush hour, access to the platform and station area would not be obstructed by other activity, which could improve the efficiency of transit accessibility.
which connects the west and east wings of the station via a long linear corridor. Figure 20 shows the
within a 30% detour between every station entrance/exit and the platform through the value of the
trajectory paths passed by the facility nodes in Victory Monument Station. The nearest routes in this
station also occasionally led the passengers past the facility nodes. However, most of the connection
routes led passengers through the ticketing facility, giving passengers easy access to the main facility
of the station. Conversely, with the large number of passengers, the activity at the facility nodes could
obstruct accessibility, especially during rush hour.

Figure 18. The nearest connection routes between every station entrance/exit and the staircases that
connect to the platform on the upper floor of Mo Chit Station.

Figure 19. The nearest connection routes between every station entrance/exit and the staircases that
connect to the platform on the upper floor of Victory Monument Station.

Saphan Taksin Station has a different design compared to other stations due to its location at the
entry ramp of Taksin Bridge, which limited its construction. The station building has only one platform,
which connects the west and east wings of the station via a long linear corridor. Figure 20 shows the
nearest connection route between station entrances/exits and the platform; the nearest connection
routes have the shortest distance compared with the other stations. However, the circulation that
connects the west and east wings of the station has a long distance and lacks a facility node, so this
corridor lacks activity and is inaccessible to passengers.

Figure 20. The nearest connection routes between every station entrance/exit and the staircases that
connect to the platform on the upper floor of Saphan Taksin Station.
5. Discussion

5.1. Comparative Analysis of Connectivity around the Stations

Figure 21 shows the results of the integration value analysis of each station. The blue lines are the Global Int.V of all the stations, and the orange lines are the Local Int.V of all the stations. Among the three transit stations, both the lowest minimum and maximum Global Int.V was at Mo Chit Station, at 0.128 and 0.422, respectively. The connectivity lines in this station must have some spaces with the lowest accessibility, and it may be hard to transfer from this part to anywhere else around the station. On the other hand, the highest maximum Int.V of 0.442 was at Victory Monument. This must be due to its location on a road that has the best accessibility and its connection to several other high-accessibility roads. Passengers can thus transfer conveniently. Mo Chit Station also had the lowest minimum Local Int.V, 0.105, and the lowest Local Int.V, 0.670. The highest maximum Local Int.V 0.726 was at Saphan Taksin Station, where it is convenient to transfer to the surrounding area.

The Integration value of accessibility around the stations

![Integration value graph](image)

Figure 21. The comparative analysis of connectivity around the stations.

There are several types of connectivity within different road systems. As shown in Figure 22, the ring road system and the tandem road system are the two most common ways to organize a road network [42]. Both of these road systems are used for station accessibility; in this study, the main roads through the stations are ring roads, which combine with branch roads to form a road network system. Based on the analysis results, the ring road system has a high accessibility value at all stations. Considering the roads within a radius of 500 m of the station (Figure 23), Victory Monument Station is more efficient to reach than the other stations, especially via the ring road around the monument, which means that passengers can conveniently transfer between different transit modes around the monument and the station. At Saphan Taksin Station, the road network within a radius of 500 m has moderate efficiency. However, access to the station areas by river transport has the highest accessibility value. In fact, access to Saphan Taksin Station by river transport is more convenient and effective.
due to there being no traffic conditions such as traffic jams, especially during rush hour. At Mo Chit Station, the road networks around the station have a fair accessibility value. Within a radius of 500 m, access to the station from the west, especially from the northwest, is inconvenient because the route that connects to the station is a large ring road with a big market and park; therefore, accessibility from these areas is limited.

![Diagram of ring road and tandem road networks](image)

**Figure 22.** (a) The connectivity ring road systems; (b) The connectivity tandem road systems.

![Image of station accessibility](image)

**Figure 23.** The road systems connected to the stations within a radius of 500 m. (a) Mo Chit Station; (b) Victory Monument Station; (c) Saphan Taksin Station.

According to the analysis results, a ring road network has more efficient accessibility than a tandem road network. Geoff (2017) discussed that most street networks should have connectivity, however tandem road networks have a high percentage of single dead-end routes that mean the removal of just one node can disconnect the network [48,49]. To improve the efficiency of accessibility,
planners should design the road network with ring roads, especially small ring roads that could spread out passengers’ access to the station building from different directions. This could give passengers convenient access to the station building and station area.

5.2. Comparative Analysis of Accessibility at the Station Buildings and Activities Involvement along Station Building Connection Routes

As shown in Figure 24, the integration value analysis of the stations’ accessibility is shown in Figure 17. The blue line is the integration value of Mo Chit Station, the orange line is the integration value of Victory Monument Station, and the gray line is the integration value of Saphan Taksin Station. Among the three transit stations, the lowest minimum Int.V is 0.480, at Saphan Taksin Station. This means that some spaces in this station have low accessibility, making it inconvenient to transfer from that space to other spaces. Meanwhile, the highest maximum Int.V, 2.901, is also at Saphan Taksin Station. This means that there is a space in Saphan Taksin Station that has the best accessibility, from which it is very convenient to reach other spaces.

The corridors interacted with the stations’ major connection paths strongly, as illustrated by the betweenness index values of the facility nodes. This indicates that the major connection routes are within a 30% detour between every station entrance/exit and the staircase connecting to the platform on the upper floor through the value of trajectory paths that passed by the station facilities in transit station buildings. Figure 25 interprets the percentage of facility nodes that were involved along the main connecting route. Facility activities involved at Mo Chit Station were at 3.60% along the nearest connecting route, which expanded to 7.56%, 10.35%, and 12.85% when assigned detour ratios of 10%, 20%, and 30%, respectively. Meanwhile, Victory Monument Station had a higher level of 4.73% of such facilities located along the nearest route between entrances/exits and platform, which rose to 8.21%, 10.35%, and 12.85% when assigned detour ratio was 10%, 20%, and 30% respectively.

Although Saphan Taksin Station also expanded when assigned a higher detour ratio, the activities involved along the main connection route were on the lower level at 0.24%, which increased to 0.77%, 1.03%, and 1.24% when the assigned detour ratio was 10%, 20%, and 30% respectively.
Figure 25. Activities involvement within a 30% detour of the nearest connection route from every station entrance/exit to the platforms of Bangkok transit station buildings.

According to the analysis results, Saphan Taksin station has more efficient accessibility than the others, due to the long corridor that connects between the east gate and the west gate. Saphan Taksin station has a different floor plan compared to other stations, and it has only one platform while the other stations have two platforms as shown in Figure 26. This means Saphan Taksin station has different spaces and circulations inside the station building. However, the long corridor has no function and activity because all the station facilities are located only in east gate and south gate areas. The circulations and activities in this station do not reach passengers through this corridor. It makes the spaces around the facility nodes crowded with a large number of passengers during rush hour that obstruct accessibility inside the station area. Whereas, the facility nodes at Mo Chit station and Victory Monument station are spread about the station to spread out passengers’ access to the station facilities and improve the flow for a large number of passengers.

Figure 26. The accessibility values of space in the station building and accessibility values of the shortest routes between the station entrance and the staircases that connect to the platform at (a) Mo Chit Station; (b) Victory Monument Station; and (c) Saphan Taksin Station.
To improve the efficiency of accessibility and manage the passenger flow, the designer should spread the station facilities to reach the passenger through different circulations that could decrease the concentration of passengers. This could give the passenger convenient access to the station facilities and services in the station area.

5.3. Limitations

The assessment framework and design method proposed by this study drove novel viewpoints of accessibility contributions and of the urban and architectural scale of the transit station. This research investigated the current situation of the stations and the station buildings in Bangkok transit nodes and made a quantitative analysis of their accessibility through space syntax and the betweenness method. Nevertheless, there are still some limitations in this research. First, the cases only included transit stations in the big nodes of Bangkok’s transportation and thus cannot represent the characteristics of all mass transit stations in Bangkok. The second limitation is that, because of the theory of space syntax’s limitation and idealization, a lot of elements were not included. Indeed, accessibility is influenced by many practical factors, such as the width of roads and the road conditions. The result needs to be verified by field research. Also, the passengers’ psychosocial behavior should be investigated by further research. Duangporn and Vilas [16] discussed that the accessibility assessment needs to simultaneously consider various aspects of accessibility. Such an endeavor may need to modify the techniques or measures when considering passenger behavior.

6. Conclusions

Based on the above analysis of Bangkok transit stations by integration degree, depth value calculation, and analysis of the surrounding areas and building spaces of the transit stations, the accessibility of Bangkok transit stations was analyzed and compared based on the theory of space syntax and Depthmap software. Some basic information, including the available facilities and connectivity modes was collected for comparative analysis. It was found that facilities and feeder modes may support accessibility. For example, Victory Monument provides more facilities and transfer modes, which improves the convenience of accessibility.

However, the accessibility inside the station buildings, especially the corridor spaces that connect the station buildings and surrounding areas, had low integration values. Therefore, the total depth of the location space plans needed to be low, so they could be quickly reached and evacuated. In the layout, corridors and circulation spaces were located in the core area of integration. The entrance gates were crucial to the accessibility of each space, but the connections with the horizontal corridors that connect to the platform should be increased to make it easier to reach. Thereby, the spatial depth of the free space can be reduced to use higher-intensity areas to improve the convenience of accessibility.

The performance of corridor spaces in transit station buildings identified the connection characteristics among spaces in transit stations through activities along the corridors. Siewwuttanagul et al. [15] discussed how corridor space characteristics are investigated for identifying the relationship between activity arrangements and effective transit mode connection routes in transit stations. Involvement of corridor spaces can integrate transit mode accessibility development solutions toward better connectivity of space usage in station areas to assist passengers during their trips. Conforming to the spatial planning of transport facilities will encourage potential transit mode connections with high-level accessibility integration. The arrangement of activities in corridor spaces was significantly related to the priority of uninterrupted circulation. Major route connections were considered as high circulation areas for accessing particular modes of transport.

7. Recommendations

Analysis of transit station’s accessibility with the road networks and design space in transit stations was conducted to provide comprehensive data, from which it is possible to make recommendations for future improvements to mass transit station accessibility. The main recommendations are:
1. Improvement of connectivity around the station For connectivity around the station, the ring road system has higher efficiency accessibility than the tandem road system which could allow passengers to access the station from a different direction. Planners and designers should design the road system around the station as a ring road system. Regarding three stations in this study, there are many tandem roads around Mo Chit station that make unconnected access from one node to another node. The planner should design the connection of the single dead-end route and change it to be the ring road. It could give more convenient access to the station. For Saphan Taksin station and Victory station, some routes that connect to the stations are also single dead-end routes, Bangkok Metropolitan administration should consider this to reduce the traffic problem, especially traffic jams during rush hour around these three stations.

2. Improvement of accessibility in the station The results revealed that Saphan Taksin station has the highest accessibility at the long corridor, but in reality, this corridor lacks a facility and is inaccessible to passengers. The design of this station could not reach passengers through this corridor. The station is usually unmanageable for a large number of passengers in the areas around both the station entrances during peak hour, because the activity at the facility nodes are obstructed passengers’ accessibility. Compared with Mo Chit station and Victory Monument station, both stations have fair accessibility, however, the station’s circulation of both stations could spread passengers’ access through the facilities along the corridor. Improvement programs of company agencies should consider the location of the station’s facilities that could spread the passengers’ access to the station by a different direction. For example, the ticketing machines in and out of the station gate should provide at different node (i.e., move the ticketing machines which are located inside the station gate to the long corridor area).

To conclude, the results of this research into the transit station’s accessibility for three transfer stations may assist company agencies and relevant public transit stakeholders to improve the convenience of station accessibility. It should aim to improve the accessibility quality and could solve traffic problems around the transit station not only for transit stations in Bangkok but also other transit stations that have the same station characteristics.

Author Contributions: Methodology, R.N.; Software, R.N.; Formal Analysis, R.N.; Investigation, R.N.; Writing-Original Draft Preparation, R.N.; Writing-Review & Editing, B.D; Supervision, B.D.

Conflicts of Interest: The authors declare no conflict of interest.

References


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