Resilience in Urban Transport Towards Hybrid Canal-Rail Connectivity Linking Bangkok's Canal Networks to Mass Rapid Transit Lines

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Abstract

The influence of rapid development has been more focused on the growth of built up area rather than proceed through its unique characters of urban morphology, especially the megacity of developing world. A huge network of waterways in Bangkok has been overlooked on its utilizations which has been the major evidence of unprepared urban mobility to cope with a changing climate along with tackling on affordability of urban poor for their daily transportation. Thus, the study on hybrid canal-rail system improvement in Bangkok will be a good example of rethinking about transportation development under the consideration of urban context to be consistent with land use factors affecting the current mobility development. The deliberations of spatial management become crucial and being used as a tool for revitalizing urban area in particular of the Water Transit-Oriented Development (WTOD) which becomes the key measure for improving the existing physical condition of area nearby the station to increase ridership as to input to the transportation system. These findings can help city planners and decision-makers to understand WTOD formation as well as in planning and decision-making processes towards an enhancing the level of connectivity in an urban area.

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1. Introduction

Bangkok as a canal city has evolved through series of transformation since its founding in 1782. Subsequently, with its 1,682 canals and waterways stretching 2,600 km, Bangkok possesses a rather unique and extensive canal system which led to it being called "Venice of the East" in the past. Eventually, the canal-based structure of Bangkok in early Rattanakosin era has been under transition to be a road-based city since the modernization of the kingdom under the political pressure of colonialism. The transformation into a car-dependent city since the postcolonial era has critically reshaped the urban form and landscape of Bangkok. Over time, the urban morphology based on canals and river of early Bangkok has been transformed into one based on road system and expressways, which become infrastructure corridors accompanied by multistory and high rise structures.

Finally, new layers of mass transit systems, both elevated and underground trains, were subsequently added to the urban mesh of complexity. The paradigm shift in urban morphology, from canal-based development to land-based development structured could be obviously seen around the road-based vehicular network as proliferated in the past decades which has actually created negative impacts to the legacy of canal-oriented development. The early systems of transportation and settlement have been dominated by, and poorly connected to, the modern road and later mass transit systems. As a result, Bangkok's canal network has been neglected as transit routes and the deteriorated canal-side communities together with the squatter settlements which have changed traditional community life and the urban landscape. The urban fabric reveals contrasting developments immediately adjacent to one another.

Bangkok's urban growth and the proliferating urban sprawl are inextricably tied to transit congestion and environmental problems. In following the footsteps of western cities' automobile-based development, Bangkok neglected the city-wide resources of canal transit network over the years and has become a road-based city. Bangkok now faces challenges for critical reform towards a sustainable future. To guide the development of canal-rail transfer stations and nearby communities, relevant urban design guidelines should be applied to enhance the canal-rail connectivity. In this context, the "Transit-Oriented Development" (TOD) concept could be the leading development approach in revitalizing and restructuring urban communities in responding to hybrid canal-rail connectivity (Freedman, 2012, p. 52). The underlying concept and elements of TOD should become determining factors of community development in the vicinity of canal-rail transfer stations as well as along the transit routes.

1.1 The Existing Canal and Rail Networks

The Chao Phraya River is well-known for its role as the initial point of development of Bangkok's urban morphology. The excavation of moats mirroring the curve of Chao Phraya River formed Rattanakosin Island, the present metropolis' royal core. As Thailand's main center shaped by canal-based settlements, most of the commoners lived on floating houses along the river or around its tributary canals. The presence of the river and canal system is a significant physical feature within historic Bangkok. Thus, socio-economic and cultural aspects of the people are linked with rivers and streams (Askew, 1996, pp. 183-210; Mateo-Babiano, 2012, pp. 452-461). Conversely, since the 20th century, the role of water transportation has diminished due to the widespread development of inland transport network (Iamtrakul, Thongplu & Kritayanukul, 2013, pp. 34-45). The replacement of water transport has been filled with road based system. However, during the past decade, traffic conditions in Bangkok have worsened significantly due to the rapid increase in private vehicles. Not surprisingly, Bangkokians spend an average of two hours commuting from home to work and back (NSO, 2004). As a result of severe traffic congestion, commuters are inevitably exposed to high levels of vehicle-related air pollutants. Thus, a complete network of mass transit systems along with promoting the use of public water transportation is necessary to alleviate traffic congestion towards the more sustainable well-being of society in Bangkok. Regarding water transportation, the geographical locations of the waterway networks provide possible accessibility through their tributaries as depiected in Figure 1. Three different types of boat operations provide services which include express boat, ferry boat and long-tailed boat. These boats are different in sizes and purposes. Express boats cater to the needs of those who commute along the Chao Phraya River. Ferry boats serve passengers who wish to cross the river. The long-tailed boats offer their services to passengers who commute into the canals, locally known as "khlongs" (Tanaboriboon, 1995).

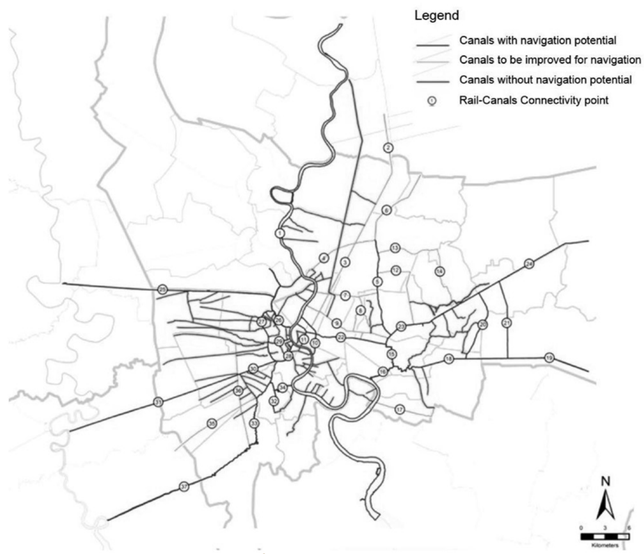


Figure 1. Waterway network of Bangkok

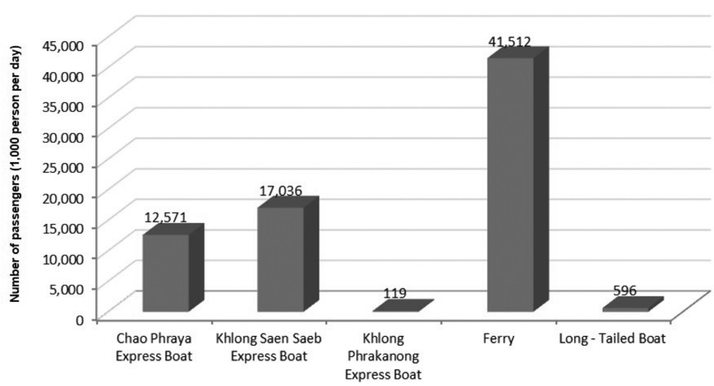


Figure 2. Boat commuters in year 2014. (Source: Marine Department (2014) (Data until 4 June 2014))

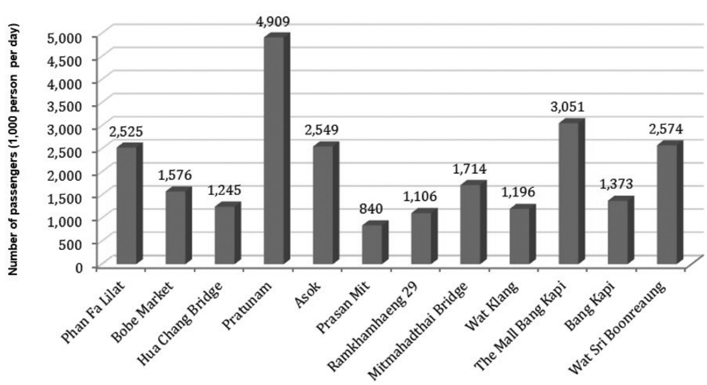


Figure 3. Boat commuters at Khlong Saen Saeb Piers in year 2014 (Source: Marine Department (2014) (Data until 4 June 2014))

1.2 Travel statistics of boat commuters

According to the boat commuter statistics collected by the Marine Department (MD) under the Ministry of Transportation, the number of boat commuters had decreased from 82 million persons in year 2011 to 76 million persons in year 2012. Currently, the numbers of passengers step down to 71 million persons in 2014. In addition, in regards to the frequency of use, boat commuters used ferry boats most, followed by Khlong Saen Saeb boat service, and finally by Khlong Phrakanong boat as depicted in Figure 2.

There are four routes considered as canal network in Bangkok Metropolitan Area. They are (1) Khlong Saen Saeb; (2) Khlong Phrakanong; (3) Khlong Ban Pa; and (4) Khlong Phasi Charoen.

• *Khlong Saen Saeb (Phan Fah Li Lat to Sri Boonreaung temple)*: Khlong Saen Saeb boat service has operated since 1990 by a private company. The travel time from the first stop (Phan Fah Li Lat Bridge) to final stop (Sri Boonreaung temple) is approximately one hour. The approximate distance from first stop to final stop is 18 kilometers in length. Each boat is able to accommodate 80 passengers per boat, and the frequency of services is every 5 – 15 minutes (from origin to destination) (Figure 3).

• *Khlong Phrakanong (Phrakanong – Iam Sombat Market)*: Khlong Phrakanong boat service is operated by a private company. The travel time from the first stop (Phrakanong) to final stop (Iam Sombat Market) is approximately 45 minutes. The approximate distance from first stop to final stop is 9 kilometers in length. Each boat is able to accommodate 30 passengers per boat, and the frequency of services is every 30 – 60 minutes. This service is operated by long-tailed boats. This route has connections to BTS station (On Nut Station and Phra Kanong Station) which is located nearby Phrakanong pier; however, presently, its popularity has been diminished due to the replacement with road-based transport (Figure 4).

The Office of Transport and Traffic Policy and Planning (OTP) had forecasted the numbers of commuters who commute by water transportation in the canal system in Bangkok Metropolitan Area, and expected that the number of commuters will increase from 298,000 trips/day in year 2011 to 487,000 trips/day in year 2032. In fact, according to data about the amount of commuters who used these two routes of canal network (Saen Saeb canal and Phrakanong canal), it was clearly seen that the number of commuters is still lower than forecasting (Figure 5).

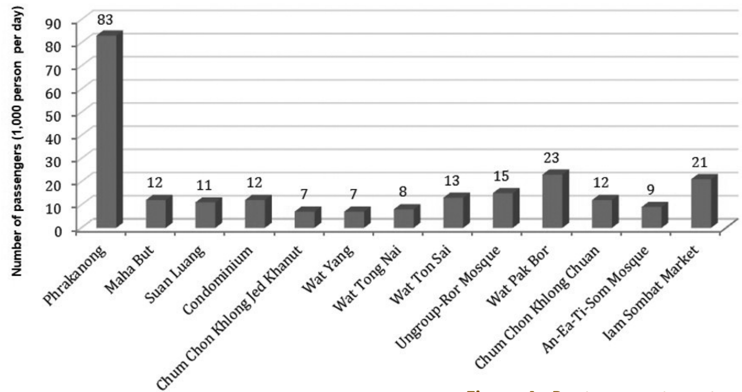


Figure 4. Boat commuters at Khlong Phrakanong Piers in year 2014(Source: Marine Department (2014) (Data until 4 June 2014))

1.3 Mass rapid transit in Bangkok

There are currently three main system of mass rapid transit in Bangkok which comprises of (Figure 6):

• *Bangkok transit system (BTS):* The Bangkok Transit System Corporation (BTSC) metro rail "skytrain" system began official operations in December 1999 but was initiated in 1994. BTSC has operated under a subsidiary of Tanayong PCL real estate. The system is estimated to cost $1.7 billion in the initial phase, including pre-operating expenses and finance charges during the construction period (BTS, 2015). It comprises of a 23.5 km. electrified train system with 23 elevated stations. The BTS operates two intersecting routes aligned north-south and east-west which are elevated over two of the most highly congested roadway corridors in the city, Silom and Sukhumvit Roads (BTS, 2015). In order to alleviate Bangkok's massive traffic problems, additional extension routes have been planned and now under construction (IBP, 2013).

• *Metropolitan rapid transit (MRT)*: MRT ystem is operated by Bangkok Metro Public Company Limited (BMCL). First planning in the mid 1970's, it is the first underground metro system to provide train service over a route of approximately 20 kilometers (UITP, 2014). Negotiation for the project was launched in 1990, but the project was delayed due to the financial constraints. Finally, the whole project was completed in 2003 with the estimated ridership of 404,880 passengers per day (BTS, 2015).

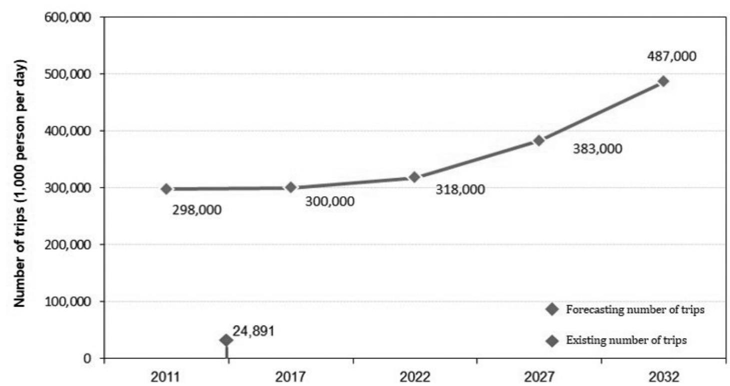


Figure 5. The boat transportation trend in BMR. (Source: Office of Transport and Traffic Policy and Planning (OTP), 2012)

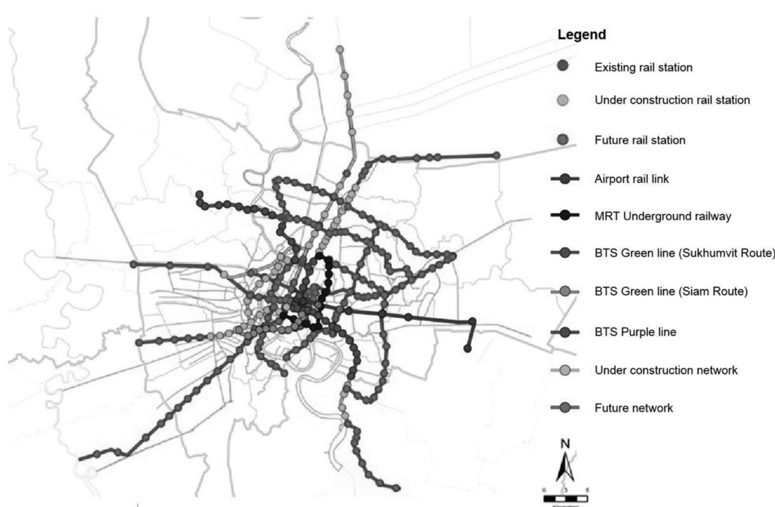


Figure 6. Map of rail transit network in Bangkok

The current system operates with 18 stations and a maximum of 19 trains that run with 5 minutes of headway during peak hours and 10 minutes for regular service.

• *Airport rail link (ARL)*: The Airport Rail Link is an express and commuter rail which provides a service from Suvarnabhumi Airport, via Makkasan, to Phaya Thai station in central Bangkok. Most of the line is on a viaduct over the main eastern railway. This system is owned by the State Railway of Thailand (SRT) and operated by SRT subsidiary SRT Electrified Train (SRTET). The Airport Rail Link opened for service since August 23, 2010 with the total length of service of about 28.6 km. Service consists of two express services (a 15-minute non-stop service between the Makkasan city air terminal and the airport, and 18-minute non-stop service between Phaya Thai and the airport) and the City Line with eight stations (SRT, 2015).

2. Water-based Transit-Oriented Development (WTOD)

Water based Transit-oriented development (WTOD) is similar form of urban development centered on the provision of access to high-quality public transportation and dense, walkable neighborhoods with focusing on the interconnecting between water-based transportation and other modes. WTOD is typically defined similar to the current idea of TOD as to support more compact development within easy walking or biking distance of a transit station, typically a half mile (CTOD, 2010).

2.1 Concept of Transit-oriented development

This proximity to transit would allow people to make daily commutes by using transit, walking and biking, rather than driving. The high density neighborhoods should support a mix of uses and activities including mixed-income housing, work places, child care, stores, and restaurants, etc. With the advantage of this type of development, people are able to reduce their travel expenditure. In particular, car usage and possibly even car ownership could be reduced as well (CTOD, 2010). TOD promotes the possibility that people with a wide range of incomes will be able to live and work in places with interconnected transportation networks that offer a variety transportation options. To bring about significant changes in behavior, however, people need alternative modes of transport that are convenient, punctual, seamlessly connected, and safe. Development should cluster around transit facilities and create a network of places and nodes at a community scale or even regional scale (CTOD, 2010). TOD can help mitigate various important challenges that currently face cities today by reduce congestion and increase mobility options, increase livability, increase economic activity, improve environmental quality and health, maximize efficiency of transportation and real estate investments, generate sustainable transit ridership and fare box revenues, and support diverse neighborhoods.

2.2 Linking Concept of Transit-oriented development for Urban Sustainability

The concept of Transit-Oriented Development (TOD) mentioned in topic 2.1 is to clarify the overall definition and the core of TOD. This is the process of linking development with transit routes and defined as a paradigm for creating attractive and sustainable communities, or compact neighborhoods (Bernick & Cervero, 1996). It aims to reduce the problems of travel, especially traffic congestion, fuel consumption, and wasting money and time on travel. The success of TOD will be enhanced through significant changes in traveling behavior. The highly interconnected transit networks that are convenient, timely, seamlessly connected, and safe can motivate passengers to choose a better mode of transport. Moreover, the development of land surrounding transit stations can reduce the need to travel through mixed-use development, high-density living and a close proximity to frequent passenger transport. Therefore, alternative solutions have been proposed by planners, which focus on reducing the demand for travel rather than spending enormous amounts of money on upgrading infrastructure to meet this ever-increasing demand (Hamton, 2010).

In regional scale (Steiner, Butler, & American Planning Association, 2007), TODs is a mechanism to encourage 'Compact City' that leads to urban sustainability. The compact city means a relatively high-density, mixed-use city, and an intensified city based on an efficient public transport system and dimensions that encourage walking and cycling (Burton, 2000, p. 1970). Compact city policies have often been designed primarily to reduce the use of private mobiles. These aspects of the compact city are related to changing land-use pattern around transit stations according to TOD concept. With higher density, the characteristics of TOD will help to reduce auto-dependency, making efficient use of sites, supporting pedestrian-friendly, and creating lively environment. Moreover, density allows sufficient customers within walking or bicycling distance of the transit stop. To take advantage of transit proximity and planning, design elements encourage walkability and create pedestrian-friendly that connect to surrounding communities. It will also help to ensure benefit in term of creating the sense of incentives in economic because of job-producing commercial development.

However, the implementation of design and development for urban sustainability that is mentioned above depends on the context and possibility in each country. In the case of Thailand, the proposal of higher densities and mixed-use development is related to land use regulation in the regional level. Meanwhile, the concept of active streets relates to micro scale that could be designed by planners with community participation. Therefore, the success of TOD requires significant planning, effective public/private partnerships, establishment of effective community participation, and design guidelines. Thus, prior to WTOD implementation, the suitable allocation of interconnecting point among multi-modes must be determined. This research focuses on the selecting the appropriate hybrid canal-rail connectivity location in order to demonstrate the typology of station in Bangkok and allow for recommendation of suitable develop patterns in the specified location.

3. Steps towards Developing a City-Wide Hybrid Canal-Rail Network

In order to guarantee the success of TOD, this research investigates the potential for connecting water-based and rail-based transportation within the Bangkok Metropolitan Region (BMR). This is due to the potential of the location of the interconnecting point play a vital role as an initial step prior to serve commuters with convenient, comfortable and safe transportation environment.
In conducting the research, the five-step conceptual framework and procedures, along with the methodologies are presented in Figure 7, containing 12 steps throughout the research process. This study was conducted and aimed primarily to identify potential connecting water-based and rail-based transportation for appropriate recommendation for future TOD. In this step, the geospatial analysis was adopted to obtain filter areas by integration of Geographic Information System (GIS) and spatial multivariate analysis (Malczewski, 1999). There are 37 potential canal routes and 135 potential rail stations, which was selected in the initial round of selecting preferred hybrid transit areas. The analysis began with investigating networks of canals and rails.

Step-1: The geospatial data of canal and rail networks were investigated for extracting determinants (Figure 8 and Figure 9). This study incorporated four major criteria which are constructed with the application of 11 sub-criteria for obtaining determinants can be explained as follows:

(1) Location of public transport stations (location of rail stations, location of piers, location of airports, and location of public transport hubs).

(2) Routes of public and private transport (railed routes, waterways, arterial roads, secondary roads)

(3) The operation of the rail system in terms of existing, under construction, and future phrase.

(4) Density information of buildings along canals: All determinants will then be ranked by experts

Step-2: Ranking method allows ranking factors concerned about significance levels given by experts that affect site selection. Thus, the success of this method depends on the experience and accuracy of experts, and the criteria used for rating significance level. For the ranking method, there are three formats in giving scores which are Rank Sum, Rank Reciprocal, and Rank Exponent. This is the most straightforward method for making decisions because it only needs to come up with a straight rank and weights in all three formats which will be derived by the analyst. Generally, the normalized values from Rank Exponent are the values used for analysis and comparison (Roszkowska, 2013, pp. 14-33).

After obtaining results of ranked significant factors of rail and water transportation in different scales, these two results were performed by the map overlay and analysis for showing the piers with potential to be connected to rail lines.

Step-3: Because there are a number of piers with connecting potential, cluster analysis was employed in classifying canal networks into clusters which each has its own characteristic.

Step-4: The book named ''New Decade for Water Transportation in Bangkok'' published by Traffic and Transport Department of BMA (2013) had identified additional canals with potential networks for development.

Step-5: A total number of canals were grouped by three criteria as follows: canals with navigation potential, canals to be improved for navigation, and canals without navigation potential. This is conducted on the capability of navigation in current network.

Step-6: It ended up with considering only the former two for further steps. Apart from canals, varying conditions of rail stations and networks were explored.

Step-7: This was followed by indicating area of 500 meters around BTS, MRT, and ARL stations. This distance is claimed to be a suitable distance for accessing the station by walking.

Step-8: Finally, the existing station, under construction stations and networks were selected because they are assumed to have potentials for hybrid canal-rail development.

Step-9: A meso-scale method is used to select the 44 stations having canal lines within its 500 meter radius (walkable distances) through overlaying maps of rail and waterway networks with potential.

Step-10: In order to precisely select representative sites, factor analysis was employed for picking up physical factors that highly affect the possibility and development of the research.

Step-11: It was analyzed through 4 main aspects as follows:

(1) Information regarding FAR, OSR, and BCR.

(2) Information regarding building usage such as building use, amount of buildings, building height, and areas.

(3) Information regarding circulation of areas within a radius of 500 meters from rail station.

(4) Information regarding distance from canal to rail station.

The 52 factors of physical appearances reflecting from the area within 500 meters around rail stations were grouped into new groups of 12 factors. Finally, these stations are classified into groups through 12 factors as the "Hybrid Canal-Rail Connectivity Index'' for considering the degree to which a particular project is intrinsically oriented toward transit ridership based on factor analysis.

Step-12: This process employed cluster analysis, which evaluates each connecting area and then groups areas that share the same characteristics. As for evaluation, total score given to all stations came from multiplying normalized value from 12 factors with weight of each factor. This is followed by ranking the significance from the highest to lowest significance. Rail stations were classified into different clusters through the filtering of twelve factors and the list of selected stations represents the consecutive highest potential to be connecting areas from canal to rail of each cluster.

4. Hybrid Canal-Rail Network and Stations

In order to explore possibilities for linking Bangkok's canal network to mass rapid transit lines in Bangkok Metropolitan Region (BMR), the site selection process is essential for identifying the appropriate study areas with development potentials. However, it inevitably concerns the existing canal and rail networks regarding the development of future hybrid canal-rail network. The existing canal and rail networks were analyzed in order to find the fundamental potential of canal-rail connectivity.

4.1 The Existing Canal and Rail Networks

This process started with the analysis of existing networks. Data of canal and rail networks of mass transit line were investigated for extracting determinants before ranking these determinants, with concern for significance levels given by experts which affect site selection (Roszkowska, 2013, pp. 14-33). In order to obtain the weights of different criteria for input into spatial analysis, this research employed three different techniques to determine different potential score which are Rank sum, Rank reciprocal and Rank exponent. Besides the analysis with ranking method, an evaluation by experts was employed to ensure the significance levels through SUM, or called total given score, of each station.

According to criteria of rail-based transport (Table 1), it is found that distance from rail stations to piers is highly weighted for 0.260 while the lowest weight was given at 0.003 for the distance from rail stations to SRT stations. Comparing between criteria for waterways (Table 2), the distance from canal to rail stations shows the highest significance at 0.239 while distance from canals to airports has the lowest significance at 0.002. After obtaining results of ranked significant factors of rail and water transportation in different scales, these two results were performed by the map overlay and analysis as depicted in Figure 10. The prevalence of 642 canal networks showed the potential to be connected to rail lines. The combination of multivariate statistical techniques with a geostatistical approach such as Cluster Analysis (CA), was employed to reduce the amount of canal networks into 7 clusters which each has its own characteristic. This analysis technique is to evaluate the potential of each connecting area between canal and mass transit network and then groups areas that is allow to share the same characteristics. As a result, the 5th cluster showed the 97 canals with highest potential for development as illustrated in Table 3. Additionally, there are 11 canals that showed potential for development which was derived from the book named "New Decade of Bangkok's Canals: A Handbook of Water Transit for Modern Bangkok'' (Office of Traffic and Transport [BMA] 2013; General of Traffic and Transport Department of BMA, 2013) To sum up, canals with the potential for development then increased from 97 canals to 108 canals (Figure 10).

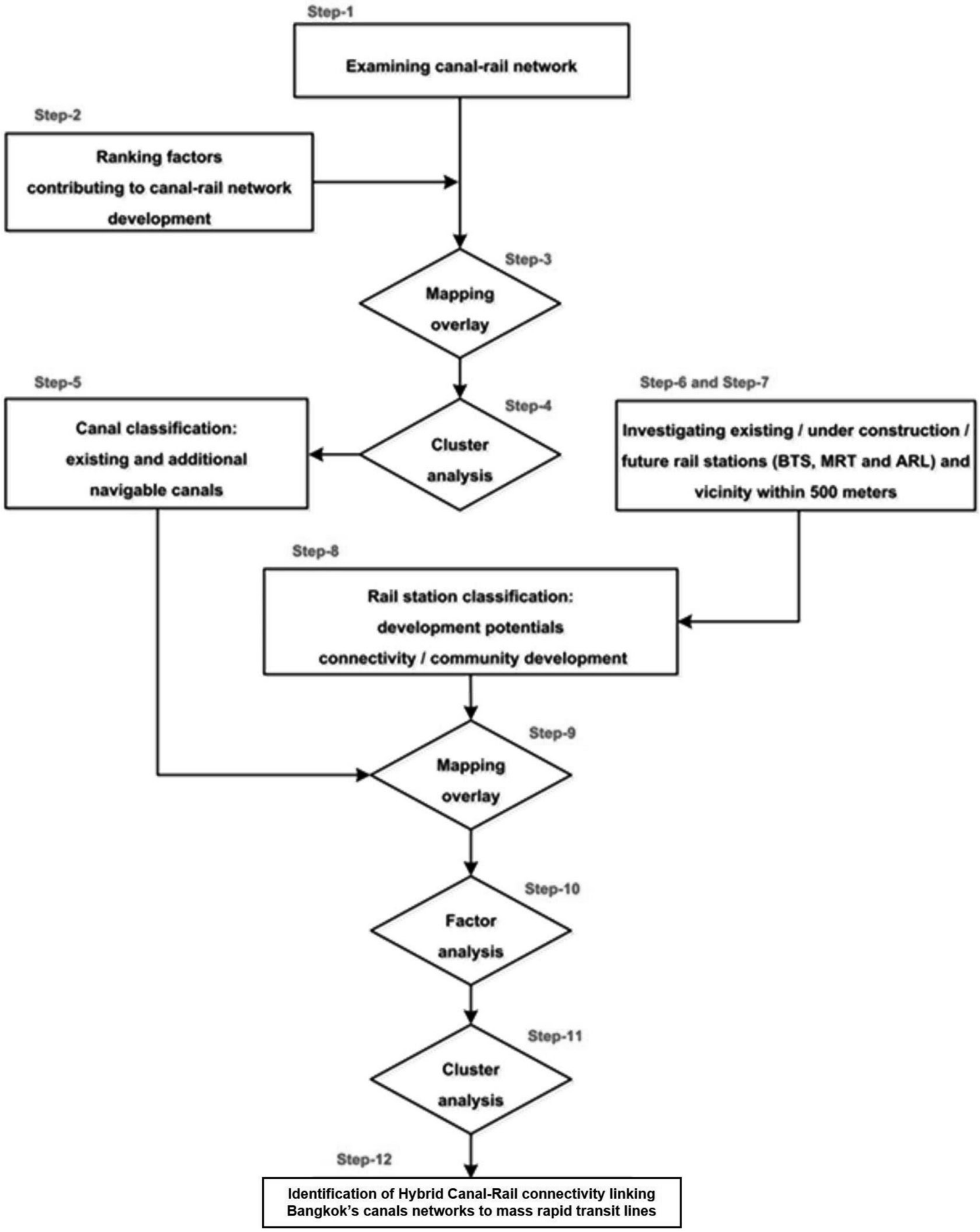


Figure 7. Method of analysis

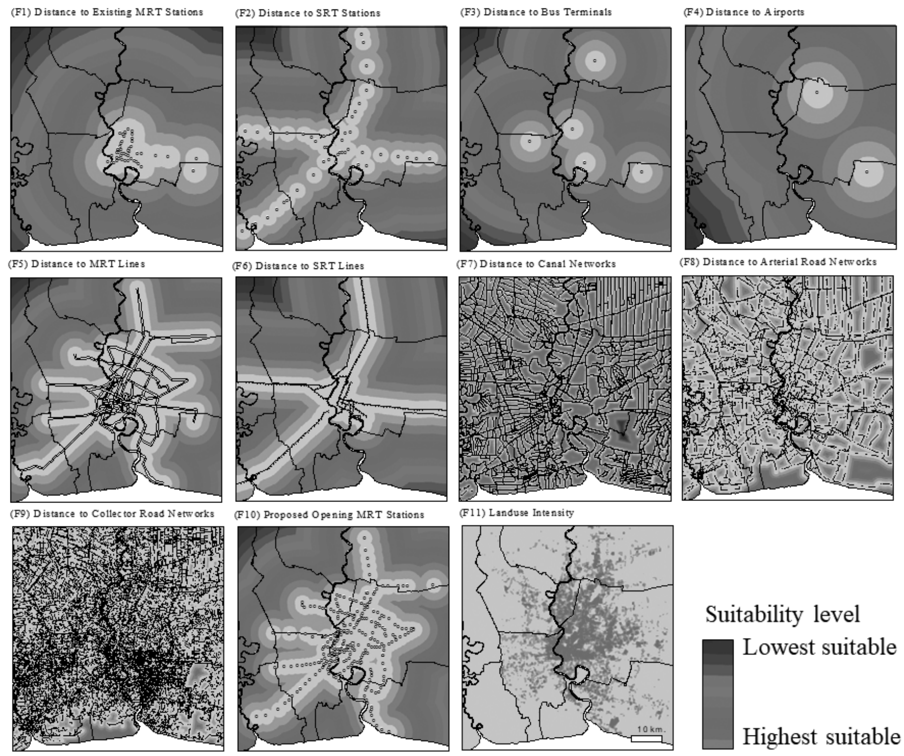


Figure 8. Geospatial factors contribute to the suitability of water transportation

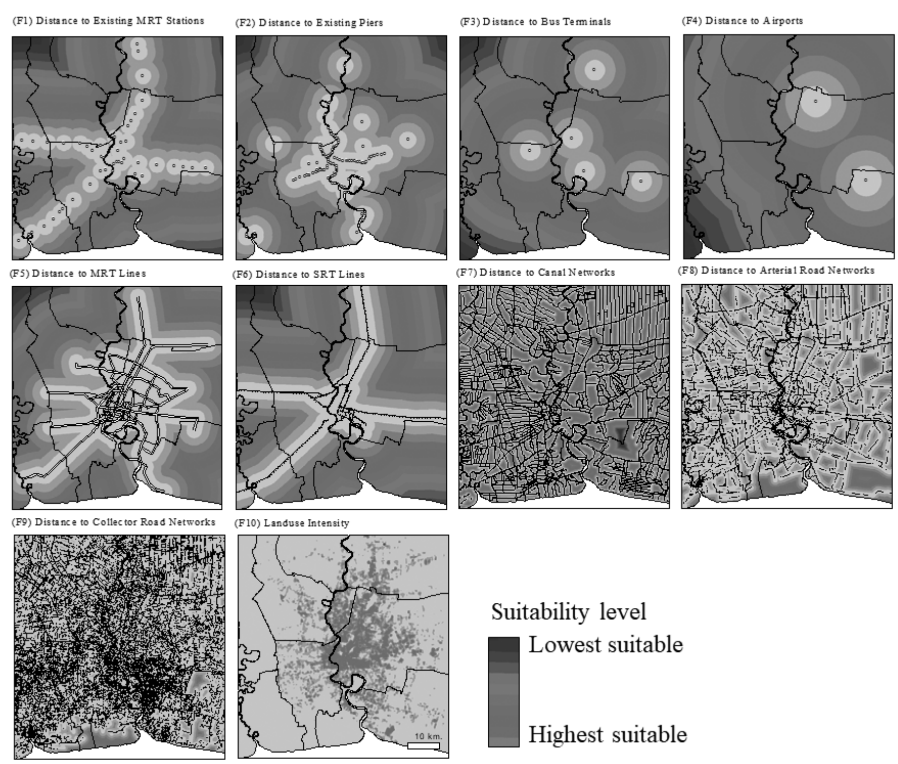


Figure 9. Geospatial factors contribute to the suitability of rail transportation

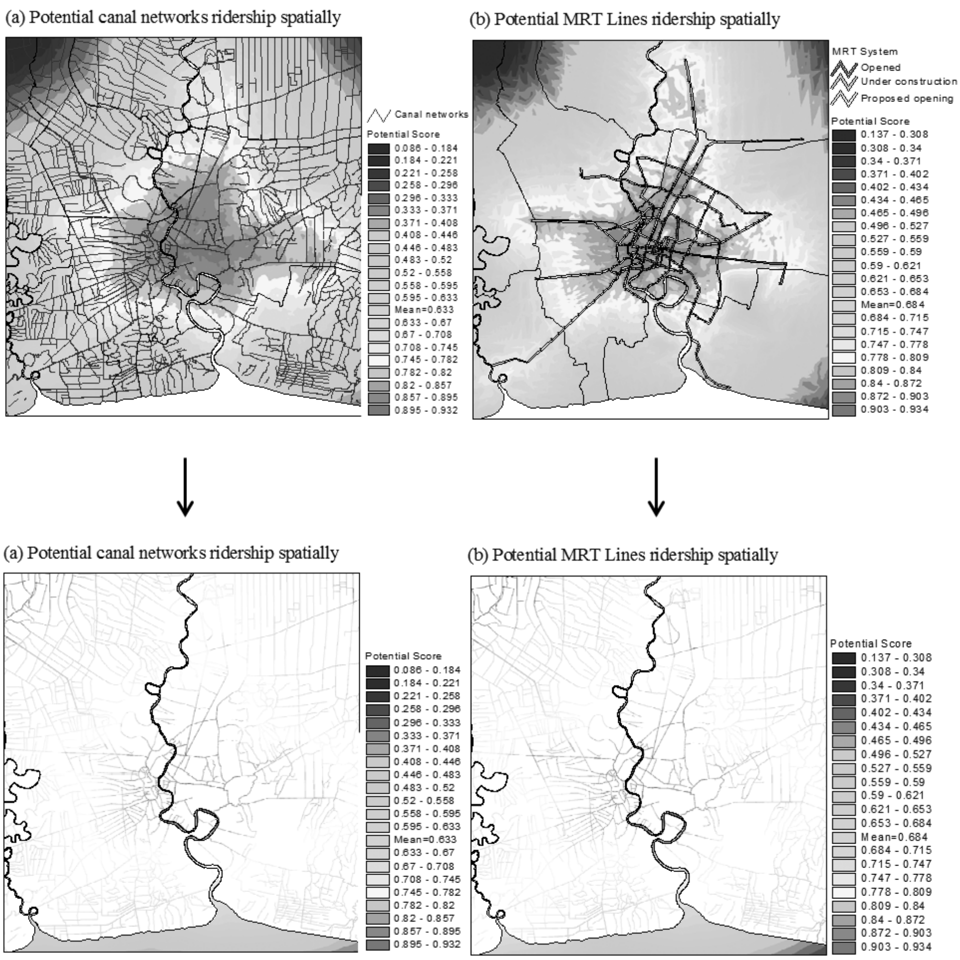


Figure 10. Overlay mapping made from factors from water transportation and from rail transportation

Table 1. Results of ranked significant factors of rail transport

Criterion	Straight rank	Rank Sum		Rank Reciprocal		Rank Exponent	
		Weight $(n-r_j+1)$	Normalized	Weight $(1/r_j)$	Normalized	Weight $(n-r_j+1)^p$ P=2	Normalized
(F1) Distance to SRT stations	2	9	0.164	0.500	0.171	81	0.210
(F 2) Distance to existing piers	1	10	0.182	1.000	0.341	100	0.260
(F 3) Distance to bus terminals	4	7	0.127	0.250	0.085	49	0.127
(F4) Distance to airports	9	2	0.036	0.111	0.038	4	0.010
(F5) Distance to existing and proposed Electric train lines	6	5	0.091	0.167	0.057	25	0.065
(F6) Distance to SRT lines	10	1	0.018	0.100	0.034	1	0.003
(F7) Distance to canal networks	3	8	0.145	0.333	0.114	64	0.166
(F8) Distance to arterial road networks	7	4	0.073	0.143	0.049	16	0.042
(F9) Distance to collector road networks	8	3	0.055	0.125	0.043	9	0.023
(F10) Land-use intensity	5	6	0.109	0.200	0.068	36	0.094
Total		55	1.000	2.929	1.000	385	1.000

The 108 canal routes could be grouped by three criteria: canals with navigation potential, canals to be improved for navigation, and canals without navigation potential. Based on the analysis result of Table 3, in order to select stations with connecting potential, the area within a radius of 500 m. from station, which is claimed to be a suitable distance for accessing to station by walking according to TOD theory, was identified through GIS. Finally, the study ended up with considering 37 canal lines demonstrating navigation potential and improvement potential in further steps (Figure 11). Finally, the 135 rail stations, which are the sum of existing and under construction stations, showed the potential for Canal-Rail Hybrid development (Figure 12).

4.2 A New City-Wide Hybrid Canal-Rail Network

The potential transit connections should link between Bangkok's canals network and mass rapid transit lines. In this section, it focuses on the result of study from step 9 to step 11. It is aimed to identify the representatives for a new city-wide hybrid canal-rail network. Both maps of the canals and rails networks with potential were overlayed in order to select the 44 rail stations that are suitable for linking canal network to Mass Rapid Transit Lines. However, the study still needs to identify a number of stations with highest potential. Factor analysis was applied to pick up physical factors that highly affect the possibility of future development of the project. As a result, 52 factors of physical appearances reflecting from the area within 500 meters around rail stations were grouped into new condensed 12 factors (Table 4).

Table 2. Results of ranked significant factors of water transport

Criterion	Straight rank	Rank Sum		Rank Reciprocal		Rank Exponent	
		Weight $(n-r_j+1)$	Normalized	Weight $(1/r_j)$	Normalized	Weight $(n-r_j+1)^p$ P=2	Normalized
(F1) Distance to existing Electric train stations	1	11	0.167	1.000	0.331	121	0.239
(F2) Distance to SRT stations	3	9	0.136	0.333	0.110	81	0.160
(F3) Distance to bus terminals	4	8	0.121	0.250	0.083	64	0.126
(F4) Distance to airports	11	1	0.015	0.091	0.030	1	0.002
(F5) Distance to existing and proposed Electric train lines	7	5	0.076	0.143	0.047	25	0.049
(F6) Distance to SRT lines	10	2	0.030	0.100	0.033	4	0.008
(F7) Distance to canal networks	2	10	0.152	0.500	0.166	100	0.198
(F8) Distance to arterial road networks	6	6	0.091	0.167	0.055	36	0.071
(F9) Distance to collector road networks	8	4	0.061	0.125	0.041	16	0.032
(F10) Distance to proposed opening Electric train stations	9	3	0.045	0.111	0.037	9	0.018
(F11) Land-use intensity	5	7	0.106	0.200	0.066	49	0.097
Total		66	1.000	3.020	1.000	506	1.000

Table 3. Classified clusters of canal having the highest and lowest potential for development

Result of Analysis	Cluster						
	1	2	3	4	5	6	7
Potential Rail Ridership Spatially	.0895	.7115	.6089	.2934	.9205	.4798	.8072
Potential Canal Ridership Spatially	.0803	.6679	.5694	.2864	.9144	.4676	.7866
	Lowest potential				Highest potential		

Figure 11. Clusters of canal having different potentials

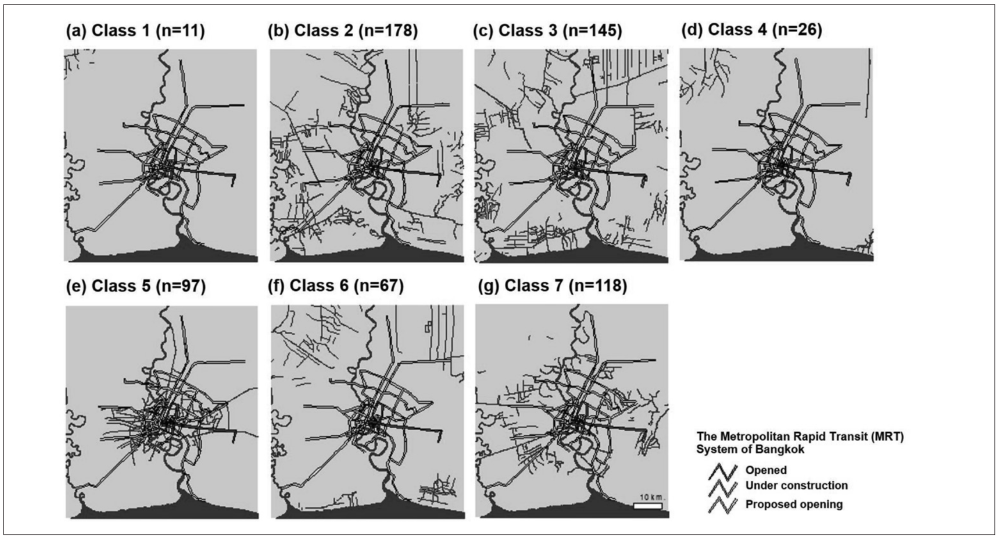
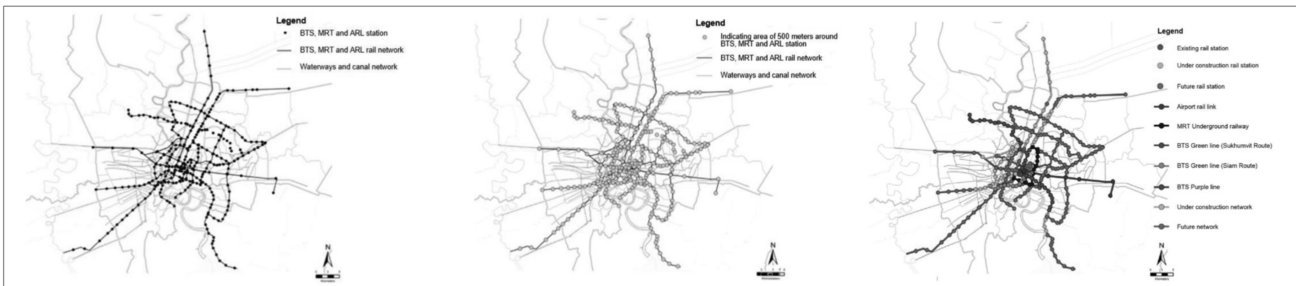


Figure 12. The 135 Hybrid Canal-Rail stations



a. Location of Rail network, stations and canal networks

b. Indicating areas of 500 meters around rail stations

c. Varying conditions of rail stations and networks.

Table 4. Twelve factors demonstrating grouped urban structure components

New Factor	Weighted value (W_{Fac})	No. of factor	Urban Structure Components
Factor 1	0.1475	10	Floor Area Ratio (FAR), Open Space Ratio (OSR), Average of buildings density, Number of residential, Building coverage of residential, Floor area of residential, Number of mixed use, Building coverage of mixed use, Floor area of mixed use, Average floor of religious institution
Factor 2	0.1329	6	Number of commercial, Number of religious institution, Number of conservation building, Building coverage of conservation, Floor area of conservation building, Average floor of conservation building
Factor 3	0.1078	6	Average floor of building, Variance floor of building, Average floor of residential, Variance floor of residential, Average floor of commercial, Variance floor of commercial
Factor 4	0.0788	5	Number of educational institution, Building coverage of educational institution, Floor area of educational institution, Average floor of educational institution, Variance floor of educational institution
Factor 5	0.0706	5	Number of recreation building, Building coverage of recreation, Floor area of recreation building, Average floor of recreation building, Variance floor of recreation building
Factor 6	0.0688	3	Number of infrastructure building, Building coverage of infrastructure, Floor area of infrastructure building
Factor 7	0.0678	4	Variance of buildings density, Number of industrial, Building coverage of industrial, Floor area of industrial
Factor 8	0.0501	4	Average floor of mixed use, Building coverage of religious institution, Floor area of religious institution, Variance floor of religious institution
Factor 9	0.0461	2	Average floor of industrial building, Variance floor of industrial building
Factor 10	0.0444	2	Building coverage of commercial, Floor area of commercial
Factor 11	0.0342	2	Average floor of infrastructure building, Variance floor of infrastructure building
Factor 12	0.0330	3	Average distance station to canal, Area of roads, Variance floor of mixed use

Table 5. List of 14 representative stations having development potential for being connecting areas from canal to rail

Station	Type of Station	Group	Total score
Saphan Kwai Station	A2	1	0.348
Bang Wa Station	A1	2	0.286
National Stadium Station	A1	3	0.391
Ramkhamhaeng Station	A1	4	0.301
Siam Station	A1	5	0.285
Bang Na Station	A2	6	0.246
Saphan Taksin Station	A1	7	0.355
Bang Phai Station	B1	8	0.325
Phetchaburi Station	A1	9	0.349
Sanam Chai Station	B1	10	0.400
Victory Monument Station	A2	11	0.350
Hua Lamphong Station	A1	12	0.457
11th Infantry Regiment King' Bodyguard Station	B2	13	0.216
Kamphaeng Phet Station	A2	14	0.213

Remarks: Type of station A means Existing station, B means Under construction station, 1 means Canals with navigation potential, 2 means Canals to be improved for navigation

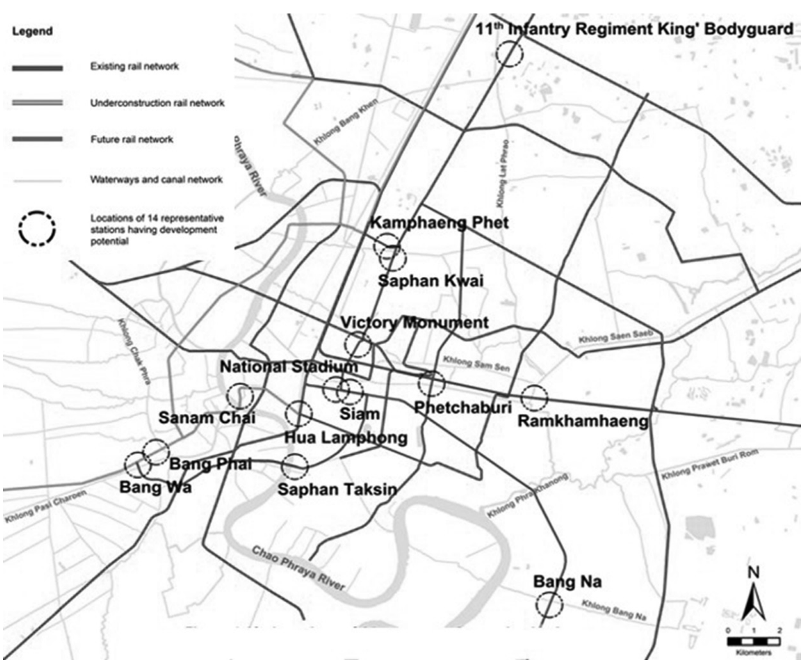


Figure 13. Locations of 14 potential canal networks and mass rapid transit lines.

The aim of cluster analysis technique is to evaluate each connecting area and then group areas that share the same characteristic (Mooi & Sarstedtl, 2011). As for evaluation, total score given to all stations came from multiplying normalized value from 12 factors which derive from the result of factor analysis, with weight of each factor. Rail stations were classified into 14 different clusters through the filtering of twelve factors and the list of 14 selected stations which represent the highest potential to be connecting areas from canal to rail of each cluster (Table 5) and overlayed as illustrated in Figure 13.

5. Discussion and Conclusions

This research has been conducted in concurrence with recent public concerns in the potentials of canal transit, the central government and BMA have a vivid policy on water transportation as transport option to alleviate traffic. Towards that end, there are certain prerequisites, mainly the navigability of transport routes, the construction of embankment and walkways, improvement of piers and boat services, measures for encroaching prevention. After the existing Khlong San Saeb, Khlong Lat Phrao will be the first canal targeted to be launched with a new boat service after a trial on Khlong Phasi Chareon. In addition to opening up new canal lines, a new transfer node from canal to Metro rail has been constructed at Ramkhamhaeng Metro ARL station. It remains to be seen what effects this new hybrid node will produce in the overall canal-rail connectivity.

Accordingly, in proposing a new city-wide hybrid canal-rail network, the researchers are fully aware of intrinsic and enduring problems of the initiative. The assessments of success of this research are thus focused on understanding the potential hybrid canal-rail transfer transit system in a city-wide connectivity. The transit-oriented development (TOD) is to create compact, attractive and sustainable communities planned for rail transit systems. In this research on "Hybrid Canal-Rail Connectivity: Linking Bangkok's Canals Networks to Mass Rapid Transit Lines," the emphasis is essentially on proposing a new plan of Bangkok – a city-wide hybrid canal-rail network with intermodal stations and possible community development in the vicinity of the stations and along the canal transit routes. Thus, the waster based transit-oriented development (WTOD) approach is to focus on the transfer stations – a linkage of boat pier and rail station. Ideally, the mixed use community development should be located within walking distance of the stations. Furthermore, to encourage canal transit, it is justified to propose new community developments of high density living along canal transit routes.

As a whole, with both canal and rail transit systems merging together as intermodal transportation demonstrate its own complexity because it is planned according to the transit-oriented development concept. One would expect to find pleasant walkways connecting public plazas adjacent the stations for canal and rail transit, coherent development of mixed uses and activities, diversity in housing, planning for change and sustainability, ease of accessibility for all. In these instances, the Bang Wa station, located in the rather sparsely developed district of the city, would provide the best development opportunities in responding to the transit-oriented development. In particular, transit-oriented development (TOD) becomes the important part for improving or revitalizing the area nearby the station to increase compactness of space usage by increasing the variety of land use types and transportation modes. However, unlike other cities, Bangkok has its own characteristic of waterway transportation which had inherited from the past; Bangkok still has strong potential for developing an alternative mode of transportation that serves the passengers' demand while the main lines of transportation are reaching the limit of supports. Thus, canal routes should fulfill the inland transportation demands and usage. Bangkok has a canal system which could potentially develop and connect to the future projects of rail routes and stations. And it could increase the expectation of transit demand if the well-prepared connectivity between canal and rail are being made.

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