Towards spatial network multiplicity: A reference to Bangkok

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Abstract

Intense urban developments in developing countries often lead towards extensive alteration or replacement of historical spatial layouts. In most cases, this results in new spatial system being added-on as another layer in the city. However, in certain cases the development could result in some degree of abandonment of existing historical spatial network itself, though preference remains for the added-on type of network. Considering the way in which multi-layers spatial network superimposed upon each other, i.e., the historical, the existing and the future, this research asks the questions: Could morphological transformation be effectively established in cases where the abandoned historical spatial network is re-integrated into the existing and future system? And, to what extent can the findings of this re-integration offer insightfulness towards the multiplicity of the spatial network analysis?

Bangkok was chosen as the study city for exploration of these two questions. Bangkok was a water-based city, formed through networks of canals that had been abandoned for a preference of road-based city. Extensive toll ways crisscrossing throughout the city were later added to ease increasing congestions. Eventually, with the pressure of urban expansion, increased population, traffic congestions and lack of space for road construction, mass transit systems were introduced. These systems, comprising of elevated and underground rails, have since become the principle strategic urban development tool. Amid all these, almost all the canals have become inactive. Very few are used as alternative thoroughfares to roads, i.e., with operation of some limited commuter boats. This research focuses on the morphological study of Bangkok’s spatial network in four systems: the Bangkok road network; the existing Bangkok spatial network; the Bangkok road-and-canal network; and the proposed integrated network for the future. The space syntax computer program was applied as the analytical tool.

This paper places emphasis on two key issues. One is the technique used for modelling the spatial network itself — in what way can a model of multi-layered spatial network be constructed to allow for independent system analysis as well as comparative study across different models. Another is on the findings of each model studied and the comparison of their spatial characteristics. Not only were the patterns of urban transformation found to be finely differentiated when the historic, existing and future spatial networks are integrated as a single studied model, it also indicates the opportunity of multiplicity for spatial network usage. As much as the latter may be unique to Bangkok, it offers an alternative projection into the future of historical city development. It could be said that the findings provide a conscious warning to planning differently in the future.

Keywords

Bangkok, spatial network multiplicity, canal network, water-based city, urban transformation.
1. Introduction

Intense urban developments in developing countries often lead towards extensive alteration or replacement of historical spatial layouts. In most cases, this results in new spatial system being added-on as another layer in the city. However, in certain cases the development could result in some degree of abandonment of existing historical spatial network itself, though preference remains for the added-on type of the network. Considering the way in which multi-layers spatial network superimposed upon each other, i.e., the historical, the existing and the future, this research asks the questions: Could morphological transformation be effectively established in cases where the abandoned historical spatial network is re-integrated into the existing and future system? And, to what extent can the findings of this re-integration offer insightfulness towards the multiplicity of the spatial network analysis?

In the attempt to answer these questions, Bangkok was chosen as the study city for three major reasons. Firstly, Bangkok was a water-based city, formed through networks of canals and a major river, the Chao Phraya. Plenty of historical records had noted Bangkok as ‘Venice of the East’. Unlike Venice, however, most of Bangkok canals have long been abandoned for the everyday spatial routes, such as pathways or roads. There are, of course, a few exceptions: Chao Phraya river has crossing and express boats, one of the canals has express boats (Saen Saeb Canal), and two other canals with rush hour boats (Bangkok Noi and Phasicharoen canals). Currently, Bangkok has 2,284 km worth of canals, and a total of 4,7000 km for roads. (BMA, 2010).

Secondly, there is a clear change in spatial preference from the water-based to road-based city. Two strong evidences can be given here. One is the filling in or the covering up of canals for road construction that had occurred extensively throughout the city for alleys or arterial roads. Another is construction of new roads parallel to some major canals, along which vast numbers of linearly developed settlements had been established (Kasemsook, 2003). This type of development turns the original canal-facing settlements into the back-alley accessing neighbourhoods, some of which are still inaccessible by car today and as a result had become run-down (Kasemsook and Subsus, 2001). The emphasis on road network preference can also be seen from later addition of elevated toll ways. The lack of planning to combine canals and roads as a single spatial network, in turn, makes the canals themselves into natural barrier for the integration of road system. The canals end up blocking road connections and extensions. In that sense, syntactically, the canals add, to some degrees, the segregation to the Bangkok road network system (Kasemsook, 2007).

Lastly, continuation of urban expansion, increase of city population and lack of available land for road construction had led to severe traffic problem. This subsequently pressured the city and central government to develop several mass transit systems. The proposed mass transit systems cover several types of rail and bus rapid transit (BRT) systems. There was a comprehensive study by Thailand’s Office of Transportation and Traffic Policy and Planning (OTP) for the cohesion of various mass transit systems and the road networks, i.e., intermodal connections either at station or ground level between the rails, the bus or the boat. However, the resulting connections are limited as well as difficult to access.

To summarise, despite having three different spatial and transportation systems, they appear to operate independently in Bangkok. This raised a critical question mentioned earlier: how can the multimodal spatial structure of Bangkok be established when these independent systems are integrated? Furthermore, to what extent have the canal network and mass transit system spatially affected the road network?

2. Multimodal spatial systems

Spatial network can be constructed that will allow for independent system analysis as well as comparative study across different models. Another issue is the findings from each model studied and from their comparison. Four study models were proposed: the Bangkok road network, being the reference system; the existing network with the inclusion of roads, operating mass transits and operating boats, being asserted for the current situation; the Bangkok road-and-canal network,
being investigated for the spatial change by the impact of canal inclusion into the road network; and, the proposed integrated network in the future, being evaluated for the policy impact.

The framework for assessing the findings is Hillier’s foreground and background networks, the normalisation and the to- and through- movements (Hillier et al, 2012). According to Hillier, two key measurements of the syntactic analysis are: ‘integration’ and ‘choice’. Integration measures the distance from each spatial elements to all others in a system, corresponds to mathematical closeness and represents to-movement. Choice measures the quantity of movement passing through each spatial element on the shortest or simplest trips between all pair of spatial elements in a system, corresponds to mathematical betweenness, and represents through-movement (Hillier et al, 2012: 156).

The to- and through- movements (integration and choice) can be normalised for the comparison across system. The maximum values of the normalised integration and choice will represent the foreground grid characteristics, while the mean values of the normalised integration and choice will represent the background grid characteristics. The mean and max value of normalised integration will show the ease of accessibility of the foreground and background grids. The mean and max value of normalised choice will index the degree of structure in the system, i.e, the background and the foreground structure of continuous or disrupted grids (Hillier et al, 2012: 170). These measurements and spatial characteristics will be further discussed in the following sections. Furthermore, the findings of the multimodal spatial system of Bangkok will be compared to the spatial systems studied by Hillier, to some extent.

3. Syntactic models of Bangkok - a spatial analysis approach

As mentioned earlier, the space syntax theory provides analytical approach of spatial explanation and represent its structure as a network with colour ranges and mathematical values, embodying each spatial accessible performance as a part of the whole. The spatial network of public space is constructed as a configurational model, which has been drawn upon city map as spatial alignments called axial lines. The axial line network represents the public street network that any urban inhabitants can perceive and access through urban spaces. According to Hillier and Hanson (1984) the axial line represents the potential of angular movement through most possible connected convex spaces -- static and fattest public space.

In this way, a structure of axial lines conceptualises the urban settlement’s syntactic model of space available for public good. DepthmapX application calculates the spatial performances of each axial line regards to the whole system. This includes topological and metric (proximity and distance) analysis to explore the geometrical properties of urban morphology in relation to its configuration of the street network. The accumulation of effects of the structure of the network will in turn affect patterns of urban movement flows and influence, through its effect on movement flows, the land use patterns and neighbourhood settlement (Hillier et al, 1993; Penn et al, 1998; Hillier and lida, 2005). Globally, the form of settlement is conceived from the model through the degree of dual urban network: foreground and background network, of spatial relationship between the integration cores and patchwork of local areas in which they are linked by choice networks as so called local-to-global elements (Hillier et al, 2010).

As mention earlier, there are two different types of movement syntactically: integration or to-movement and choice or through-movement. While integration is implemented as the destination of urban centrality by the effect of grid intensification, choice plays an important role to capture the efficient route to travel in the city. These different interpretations are crucial in the ways in which this paper conceptualises the relationship between actual spaces and the intervening of transportation routes. The more advance spatial investigation is held by a segment analysis, which considers not on the whole axial lines but on every segment that approximates the least angle change and is intersected to the other segments. Then choice and integration of the segment analysis are normalised in order to adjust the effect of total angular depth of each segment and leave the pure choice and integration measures to be compared independently on system’s size (Hillier et al, 2012).
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There are four main values used in spatial structure interpretation. The mean values of NACH (normalised choice at radii) and NAIN (normalised integration at radii) represent the to- and through-movement potentials of background network, which forms the majority of urban spaces in the city. The maximum values of NACH and NAIN stand for the to- and through-movement potential of foreground network or the main linear spatial alignment. Whilst the mean and max NACH indicate the form of urban structure in which explicitly direct to its morphology, the mean and max NAIN demonstrate the degree which foreground and background networks connect to each other. By this, these measures are used to explore the extent in which the structure of transportation layers of Bangkok on the spatial network changes when adding those multi-layers, and how we can understand the effect of true changes on urban morphology. The relations of change by different models when transportation layers are added are shown here. It then discusses the direction of morphological change of Bangkok by these variables.

There are four constructed syntactic models of Bangkok made up from different modes of public travelling in the city.

I. The Bangkok road-network model, a reference model, is made up of pedestrian network which had been enlarged and revised from the one constructed by Thai scholars since 2005. The main enlargement is to cover more areas in western part of Bangkok in order to accurately reflect the contemporary urban development and sprawls in that area. The main revision is to add a number of lines of developments within the major blocks, which are few steps away from the main stripes. The revised model has 115,594 axial alignments, increased from 93,810 axial alignments (increased approx. 23%) and 261,162 segments (Figure 1).

II. The existing-network model combines multi-transportation modes, which present the contemporary scenario of the ways in which people commute in the urban area. It includes pedestrian network, canal transportation routes (excluded Chao Phraya river-crossing boat services) and mass transit systems. There are four mass transit systems serving the central area of Bangkok which are: 1) the Bangkok Mass Transit System (BTS or the Skytrain), an elevated rail-based system (2 routes/ 34 stations/ 36.45 km.); 2) the Metropolitan Rapid Transit (MRT), an underground rail-based system (1 route/ 18 stations/ 20 km.); 3) a bus rapid transit system (BRT; 1 route/ 12 stations/ 16.5 km); and 4) the Airport Rail Link, an express and commuter rail providing an elevated airport rail link from Suvarnabhumi Airport in the east of Bangkok to Phaya-Thai station (a BTS station) in central Bangkok (1 route/ 8 stations/ 28.6 km). Each system and routes are connected at the station location and/ or the interchange station by added line(s) to link them together.

III. The model of Bangkok road-and-canal network is a combination of the Bangkok road network with canal transportation routes. The canal transportation routes are categorised into two phases. First is the existing boat routes, currently consisting of four lines routes: Chao Phraya river express (4 routes/ 34 piers), local Chao Phraya river-crossing boat services (31 routes/ 62 piers), Saen Saeb Canal boat service (2 routes/ 28 piers) and Phasischaroen Canal boat service (1 route/ 15 piers). All canal transportation routes connect to pedestrians at pier locations by added line(s) to link them together. Second phase is the selection of canals with high potentiality of becoming canal transportation service routes. These are chosen based on feasible width and depth of the canals for operation of long-tail boat services, i.e., a local boat with a body length from 4-17 meters, a width of 1.5-2.5 meters, and a depth of 1.5 meters. However, as these routes are the projection, approximated distance and location of piers are based on average distance of piers on the Saen Saeb Canal boat service, which is at 500-1,000 metres. They were also placed based on proximity to community centres such as temple, school, node of community, which are features also commonly found for the existing piers on the Saen Saeb Canal.

IV. The integrated-network model is a combination of existing roads, canals and river, and project future mass transits system. In addition to the roads, the model covers three types of operating transportation systems. These are: 1) rail-based mass transit services, which include BTS, MRT, Airport Rail Link and their extensions which are expected to be completed by 2019 (10 routes/ 293 stations/469.5 km.) (OPT, 2009); 2) road-based mass
transit service, BRT (1 route / 12 stations / 16.5 km); 3) feasible canal and river transportation (Figure 2). The integrated network is constructed by merging the multiplicity of network layers into one map. Unlinks between layers are then calculated for their geo-reference coordination which will be used to analyse the actual connections in depthmapX (Figure 3). This multimodal system has 267,801 segments in total.

Figure 1: Axial model of road network of Bangkok
Figure 2: Axial model of integrated network of Bangkok

Figure 3: Axial model of integrated network of Bangkok and unlinks between networks

4. Spatial structure of Bangkok — differentiation and changes

Let us first look at the grid pattern of the Bangkok road-network model as it is a reference system here and then move on to the comparison across the four models studied. Figure 4 and 5 show that Bangkok does not have a strong geometrical grid form, i.e., rectangular, square, oval or circle. The city’s edges form some kind of irregular shape piercing out from the centre. The maps also display that the model has two clear grid patterns between the global and the local. The global pattern is
mainly formed by the ring and arterial roads, which create big blocks. Within these blocks are the local grids, most of which are formed by much shorter roads than those form the global pattern. The local grids themselves have two different patterns concerning their location within the city. Those located near the city centre, i.e., the centre of the map, are more likely to be the quasi-orthogonal grids, while those located near the edges are more likely to be the broken grids.

In terms of the normalisation choice and integration values of the segment analysis, the Bangkok road-network model has the mean NACH at .652, max NACH at 1.636, mean NAIN at 1.081, and max NAIN at 1.821 (Table 1), at radius N. These values are within the range of the 40-cities index studied by Hillier et al (2012). For example, Bangkok has more or less similar max NACH to Chicago, at 1.65. Comparing these four values to the average values of the 40 studied cities, Bangkok has higher max NACH (1.636) than the average max NACH, but lower mean NACH (.652), mean NAIN (1.081) and max NAIN (1.821). Average values of the 40-studied cities at radius N are: mean NACH at .919, max NACH at 1.187, mean NAIN at 1.250 and max NAIN at 2.764 (Hillier et al, 2012).

Having lower mean NAIN and max NAIN values than the average tells us that comparing to other cities Bangkok has a less-integrated system. This is an indication to the low degree of accessibility for both the foreground and the background grid. In the other words, moving from all origins to all destinations in Bangkok seems to be more difficult than such average moving in the other cities.

As for NACH, the lower than average mean NACH confirms our observation of the broken up nature of the city’s background network: local grids of Bangkok are highly discontinuous. They tend to be broken up and form sub-areas, particularly in the recently developed areas towards the edges of the city. This therefore helps explain why Bangkok has higher max NACH than the average. It is because Bangkok needs to have a strong structure in order to connect these discontinuous local grids together and to work as a whole city -- the weak area-to-area connections and their relations of the background network depend on the strong foreground network. In the other words, Bangkok is an extremely fragmented city.

The other three studied models show similar pattern of the normalisation choice and integration values (Table 1) to those of the Bangkok road-network model. Their values are, in fact, almost the same. They could possibly be indexed within the 40-studied cities at the same rank. However, this poses two serious questions. Are the canals so insignificant to the background and foreground network that their current abandonment is justified? And, does the mass transit system have so few effects on the Bangkok road network? For if this is the case, should the city continue in despair with its traffic problem?

In order to answer these two questions, correlation matrix was carried out to identify the values differentiation between the reference system and the other three systems. There are strong association for the values of the same category when every model is correlated with the reference model, but the r-values of the correlation are not the same. Between NACH and NAIN, NACH has stronger correlation to each other at different radii than NAIN has. Of the different radii of NAIN, the correlation is stronger at the global radii than at the local radii. We therefore focus on the comparison of the percentages of change of the r-values between each of the three models and the reference model (Table 2). The comparison across models on NACH and NAIN values at radii and the percentage changes in r-values are summarised as followed (Tables 1 and 2 and Figure 8):

- Overall, the values of the mean and max NACH and NAIN of each model are quite similar. However, among the four models, the mean NACH of the integrated model is the highest, then the mean NACH of the road-and-canal model, the mean NACH of the exiting model, and the mean NACH of the road-network model.

- Of the same decreasing order, the max NACH of the road-and-canal model is the lowest, while the max NACH of the road-network model is the highest. With the max NACH, the value of the existing model and the integrated model are equal and ranked in the middle.

- The ordering patterns are similar between the mean NACH and the mean NAIN value. For the mean NAIN, the decreasing order of the values form high to low is: the integrated model, the road-and-canal model, the exiting model and the road-network model.
• Interestingly, the max NAIN has the decreasing order of values as similar to those of the mean NACH and NAIN. The order is: the integrated model, the road-and-canal model, the exiting model and the road-network model.

• These trends are more or less the same for the normalisation values at different radii.

In spite of the similarities in every radius of the values of the four models, value differentiation could be identified. As mentioned, we are looking at the percentage of change in the r-values, whether it is in the positive or negative change (Table 2) -- the higher the percentage, the greater the difference. The patterns are:

• Overall, although the value differentiation against the reference model is less pronounced, the trend is that the value differentiation is greater at the NAIN than at the NACH. Against the reference model, the value differentiation of the integrated model is the greatest, then the road-and-canal model and the exiting model.

• For the mean NACH, the value differentiation can be found at every radius and greater at the global radii. With the mean NACH at radius N has the greatest difference for every model compared with the reference model.

• Value differentiation of the max NACH is only found at the global radii with different trends, i.e., positive or negative change. Unlike the mean NACH, the value differentiation of the max NACH at radius N is not the greatest, but that of the radius 4000 m or radius 5000 m is.

• Comparing the differentiation of the mean and the max NACH, the differentiation of the mean NACH is greater than that of the max NACH.

• The trends continue with the value differentiation of NAIN. First, the differentiation of the mean NAIN is greater than that of the max NAIN. Second, the value differentiation can almost be found at every radii of the mean NAIN, while it can be found at the global radii of the max NAIN.

• For the mean NAIN, the value differentiation is greatest at radius N with the positive change in every comparison. However, the road-and-canal model has negative change in value differentiation at every radii, while the existing model and the integrated model has the negative change at the local radii and positive change at the global radii.

• As for the max NAIN, the greatest value differentiation is found at radius 4000 m or 5000 m instead of radius for every comparison.

As the integrated model tend to have high NACH and NAIN values of all the four models studied, how exactly do the mass transits systems work in the spatial map? Figures 6 and 7 show the segments of the mass transit systems of the integrated model that are picked from their values of NACH and NAIN at radius N. The patterns are similar for both. The segments of the rails tend to have higher values than the segments of the canals have.

Let us try another test to identify the foreground structure of the integrated network. Figure 9 displays the segments, which have high max NACH value at radius N. Segments with value at 1.6 are the lateral roads connecting two edges, the north and the west, with the city centre. Segments with value at 1.5 form the radial system; and, segments with value at 1.4 and 1.3 continue to complete the radial system with different rings. Segments with value at 1.2 tend to depict significant sub-centres.
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Figure 4: The NACH pattern at radius N of integrated network of Bangkok

Figure 5: The NAIN pattern at radius N of integrated network of Bangkok
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Figure 6: The NACH pattern at radius N of transportation network superimposed on unanalysed segments of streets of Bangkok

Figure 7: The NAIN pattern at radius N of transportation network superimposed on unanalysed segments of streets of Bangkok
Figure 8: Graph of correlation efficiency of values between models

Figure 9: Map of NACH range pattern at radius N showing foreground structure of Bangkok
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Table 1: comparison of NACH and NAIN values between models in different radii

<table>
<thead>
<tr>
<th></th>
<th>Road network model</th>
<th>Existing network model</th>
<th>Road-and-canal network model</th>
<th>Integrated network model</th>
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<td>Mean</td>
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<tr>
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<tr>
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<td>1.821</td>
<td>1.085</td>
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The comparative study of the four spatial models of Bangkok shows four key findings. First, due to the closeness of their values and value differentiation, the road-network and existing models are almost spatially identical which, suggests that a few mass transit systems and canals have such limited impact on the spatial morphology of Bangkok. This is understandable considering that there are too few spatially systematic alterations of the existing from the road network. We should therefore focus on the road-network, the road-and-canal network, and the integrated network.

Second, the addition of the canals and the mass transits to the road network affects both the foreground and background grids, seen from the changes in value and value differentiation. However, the canals have more impact on the background grids than the foreground one, i.e., marked change in the NACH and NAIN values and value differentiations. This means that the canals help connect the fragmented background grids and make the grids more continuous.

Third, despite of this continuity, the canals do not help little to increase the ease of accessibility of the background grids, i.e., increasing in the mean NAIN value with the negative change of value differentiation. The ease of accessibility of the background grids markedly increases when all the mass transit systems are added, i.e., increasing in NAIN values and their positive change in value differentiation. This points out that the spatial role for the background of the mass transit systems is similar to that of the canals.

Fourth, the Bangkok road network is slightly more structured on the foreground grid than the road-and-canal and the integrated network, i.e., having the decreasing trend of the max NACH from the road network toward the integrated network and having negative change in value differentiation of the max NACH.

The meanings of these findings are as followed. The canals seem to work best to pull back the discontinuous local grids to connect together even though the canals’ role in helping to ease their accessibility is still somewhat limited. Nevertheless, it is clear that the canals help continue the background network and generate the through-movement among and within the background network. Syntactically, their signification is confirmed, and they should be reused.

The whole mass transit system works by continuing the background network and increasing the ease of accessibility for the to- and through- movements across the city and within the urban areas. They also form part of the foreground network together with the road network as seen from there the colours of their segments which are similar to those of the main road segments that they align to. This suggests that the rail system works subtlety. The rails increase the accessibility of the main roads along which they align first, and then together with the roads they make the urban areas more accessible.

Let us now come back to the two emphasised issues posted in the beginning: the validation of the making of the spatial models and the insightfulness towards the multiplicity of the spatial network in the case of Bangkok.

On the construction of the spatial model studied, the addition on a line/segment for a connection between different spatial models added at the location of linkage is sufficient and efficient for establishing the spatial characteristics and comparability of the four models studied. However, it is crucial that the number of lines needs to be consistently added in terms of the quantity of lines, which should reflect the steps of movement in the same way, as there are spaces to pass through to get from one system to the others at different levels. An extreme comparison case also occurs with

<table>
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Table 2: comparison changes in NACH and NAIN values between models in different radii

5. Discussion
the interchange nodes. The lines just simply connect to each other without any other lines added on alignments. The reason behind this process is that we try to minimise the unnecessary and uncertain lines since there are a large number of provisional linkage in the integrated model. The consistency adding up only one or two crossed line(s) to connect different system together refers to the entrance into other systems without any obstacle but focuses only on the process to commute between multi-modes of movement.

On the insightfulness, the urban transformation of Bangkok can be finely established and differentiated among the historic, the contemporary and the future spatial network. Bangkok seems to spatially work better when the canals and the overall mass transit systems are included within the road network. The multiplicity of the spatial network usage is the forward direction for Bangkok, no doubt. This is useful for the future planning management and decision. On the one hand, the integrated model could be a platform for the management of journeys in different distances and combined modes of transportation as suggested by Gil and Read (2013) for multimodal transportation network – the Randstad city-region’s people have preference for modes and routes of transportation and grid characteristics for short, medium and long journeys. On the other hand, the integrated model could become an assessment for the future mega transportation project development. It could evaluate the degree of efficiency of the spatial addition on the improvement of the movement with in the city, which in turn affect the other dominant land-use developments. As for Bangkok, if anything, reviving the (historical) canals being feasible for boat services now is surely help and may be much less expensive, until the mass transit systems of the rail complete.

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**References**


