Using Axial Analysis to Examine the Effectiveness of Reserved Road Development in Tainan City, Taiwan

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Abstract: The aim of this study is to investigate the effectiveness of reserved road construction in the city plan of Tainan using axial analysis. Tainan has a history of 400 years. Its urban fabric is an overlay of the street patterns from different periods. The post-war city plans have reserved many urban spaces for road developments, which have not been constructed for reasons such as difficulty in acquiring properties, or redundancy in the traffic networks. To investigate the necessary of these reserved road constructions, axial analysis was employed to examine the configurations of the reserved road constructions using local integration. A total of 41 reserved road sections grouped into four areas were tested in an overall analysis. The area with most reserved road sections, 15, were tested in different development scenarios to understand the best number and order for construction. The results show that the way a reserved road cross the existing networks is the key factor for integration value improvements. The marginal measures in different development scenarios are also examined. The results provide a perspective for decision makers and practitioners to resolve the debate of reserved road constructions.

1. Introduction

Tainan has a history of 400 years and used to be the ancient capital of Taiwan. Its urban fabric is an overlay of the street patterns from different periods, i.e. Qing dynasty rule (before 1895), Japanese rule (between 1895 and 1945) and post-war periods. The modern networks of Tainan are based on Japanese rule city plans, which were designed mainly for vehicular circulation purpose (See Figure 1). As a result, the Japanese rule networks split the Qing dynasty rule networks into small sections. In addition, the vehicular based networks block the Qing dynasty pedestrian based alleys from connecting as a whole network.

The post-war city plans have reserved many urban spaces for road developments, which were supposed to complete the modern traffic networks. The roads rank higher in the hierarchy of roads such as arterials and collectors have gotten priority to be constructed. Those rank lower which have not been constructed till now are named as 'reserved roads'. In addition to low ranks in the hierarchy of roads, the reserved roads have not been constructed for decades due to difficulty in acquiring the properties. Also, these reserved roads might be redundant due to overlaying with the historical street patterns, which already provide the same connecting functions in the networks. Moreover, the mode choice options in Tainan are using scooters and walking

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as a major choice in short trip. Such traffic does not need wide road and high speed and thus reduce the necessity of the reserved roads. Hence, to evaluate the effectiveness of the reserved roads construction is a crucial step to resolve this dilemma.

There are 18 reserved roads in the Tainan downtown area, and they can be divided into 41 sections (see Figure 2). All these reserved roads are categorized as local roads in the hierarchy of roads by its length, width and importance in the networks. They can be largely grouped into four areas according to the characteristics of the network patterns and distributions. Most of them are overlaid with the old constructed-road network patterns. Each area has its own characteristics, such as correlation between reserved roads, intersect angle of road sections and complexity in networks.

Space syntax is employed to examine the configurations of the reserved road constructions. This analytical method has been proposed as a new computational language to describe spatial patterns of modern cities (Hillier & Hanson, 1984). By using this method, various morphological parameters can be derived for the analysis of an urban structure, including the connectivity, control value, local and global integration (Jiang & Claramunt, 2002). Space syntax consists of many analytical techniques, in which the technique of axial analysis is used for the present study.

The axial line-based representation of an urban structure is the earliest approach of the space syntax (Hillier & Hanson, 1984). This technique is based on axial map, which constitutes the least number of longest axial lines (Hillier & Hanson, 1984). An axial line is a vista space that is small enough to be perceived from a single vantage point of view (Jiang & Claramunt, 2002), which is suitable for analyzing linear spaces system.

There are several methods to define an axial line. Batty and Rana (2004) suggested that the definition of an axial line should be broadened to include a range of differently specified sets of lines to be studied for their own interest. Axial maps based on centerlines may be more applicable than traditional axial maps (Dalton, Peponis, & Conroy-Dalton, 2003). The primal and dual representations are identical from the point of view of morphological analysis (Jiang & Claramunt, 2002). Street-based topological representations are superior to conventional axial maps via traffic prediction (Jiang & Liu, 2009). Road-centre line networks produce better correlation with observed vehicular flow than both standard axial analysis and metric distance measures

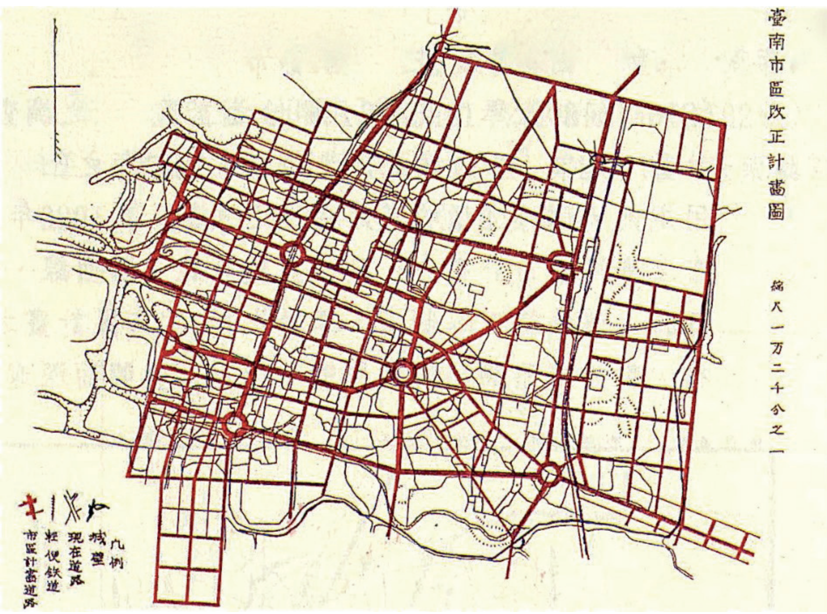

Figure 1. *Tainan Urban Plan in 1911. Source: Tainan Prefecture (1911).*

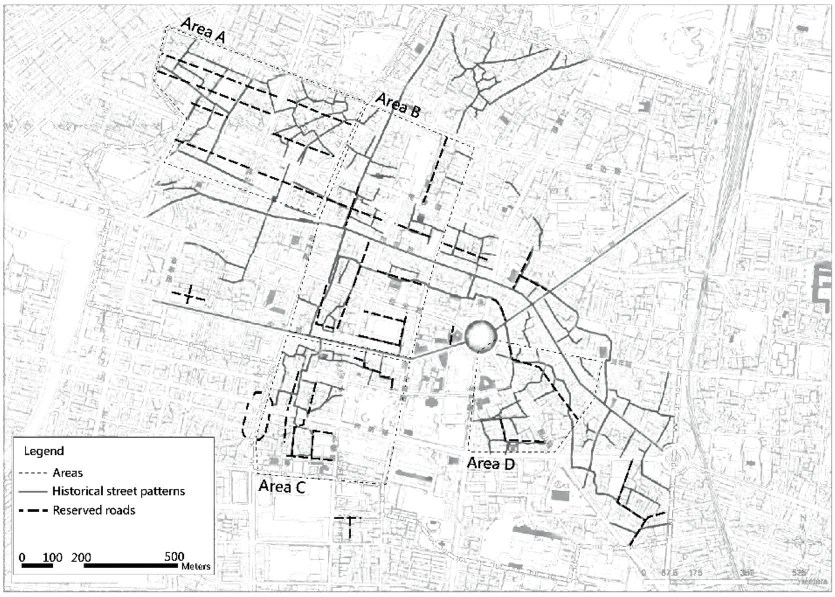

Figure 2. *Reserved road sections distribution map.*

(Turner, 2007), and thus have higher representation of vehicular networks. Hence, the present study used the road-centre line technique to construct the axial map for space syntax analysis.

This study is structured as follows: the Methodology section describes the methodology used in this research. Then, the Results section presents the results. Finally, the Conclusions and Discussions section presents the conclusion of this study.

2. Methodology

The aim of the present study is to use axial analysis to examine the effectiveness of reserved road development.

The evaluation process can be divided into two phases. First is an overall evaluation of the impact on the effectiveness of an area after all the reserved roads have constructed. Then, a subtler experiment is designed to evaluate the effectiveness improvement of the networks under different reserved road development scenarios.

2.1. *Study area*

The downtown of Tainan City, Taiwan was selected to be the empirical study area (see Figure 2). There are 18 reserved roads in this study area. The lengths of these reserved roads are shorter than average in the networks, ranging from 80m to 950m. These roads can be divided into 41 sections. The development of each section is evaluated independently. The reserved road sections scatter around the study area, overlaying with the historical pattern. Hence, the historical pattern would be split into smaller sections after the road constructions. This makes the evaluation of development effectiveness difficult.

2.2. *Phase 1: Overall analysis*

The reserved road sections in the empirical study area can be largely grouped into four areas (see Figure 2. Reserved road sections distribution map.). These areas have different characteristics such as network patterns, intersection angles and the extent of complexity. The local integration values before and after all the reserved road sections construction are calculated. The effectiveness of reserved road sections in the four area can be compared by the improvement on the average integration value and the change rate.

2.3. *Phase 2: Development scenario*

An experiment for evaluating the effectiveness of reserved road construction is designed as the following process.

- Step 1: the integration value difference of the network before and after each single section construction was calculated. Given the area has *n* reserved road sections, a total of *n* integration value differences were calculated.
- Step 2: the reserved road section with maximum integration value difference was constructed.
- Step 3: under the condition of Step 2, the integration value difference of the network before and after each remaining single section construction was calculated.

Repeat Steps 2 and 3 until every reserved road section has been constructed. Hence, the marginal integration value difference of each road section can be calculated to investigate the improvement of network effectiveness under the scenarios of constructing 1 to *n* sections.

In the present study, Area A is chosen to demonstrate the results of effectiveness evaluation in Phase 2, as this area has the highest number, 15, of reserved road sections. This area is called the Old Five Channels Area, which used to be the ancient ports and commercial streets in Qing dynasty. The networks pile up in different ages, following different patterns such as river, channel, or coastal line. Based on the use of different ages, the networks have been improved for many times in the history. This background allows the observation of configuration changes under different circumstances.

2.4. *Tool*

The integration value calculated by using road-centre lines is employed to represent the effectiveness of the reserved road construction. In space syntax, different representations have the advantages on describing different spatial configuration characteristics, in which the road-centre line is employed to investigate the networks configuration in this study. Road-centre line represents one road segment between two junctions. Road-centre line is an appropriate way to interpret the segment of the network which is similar to the driving intuition. It is superior to conventional axial maps via traffic prediction (Jiang & Liu, 2009). This setup makes it suitable for describing vehicular linear spaces.

The main variables are numbers of road development and combination sets of road development. Then the parameters such as *MD*, *Rn*, *R3* are tested to evaluate the improvement after the development in different scenarios. *R3* value would be more appropriate to describe the local integration value of reserved road sections in a small scale. It is employed to evaluating process as the main parameter for calculating the impact around the reserved road sections.

The mean depth (MD) is calculated as follow:

$$MD_i = \frac{\sum_{j=1}^{n} d_{ij}}{(n-1)}$$

The integration value is actually a measure for relational asymmetry and it is measured with either Relative Asymmetry (RA) or Real Relative Asymmetry (RRA). These two variables are calculated as follows:

$$RAi = \frac{2(MD_i - 1)}{(n-2)}$$

$$RRAi = \frac{RA_i}{(D_n)}$$

The global integration value (Rn) can be calculated as the reciprocal of RRA. Where n=3, the Rn comes out to be local integration value (R3). The variable is calculated as follow:

$$Rn = \frac{1}{(RRA_i)}$$

2.5. *Data processing*

Data processing started with vectorization axial maps. The network was defined by using the Traffic Network Digital Map from Ministry of Transportation and Communications, Taiwan. In addition, the data were refined by using other data source such as Google Map, ancient map and cadastral map.

The data processing focused on three parts, including generating axial line based on road-centre line, constructing different development scenarios on the axial map, and calculating with different parameters. The axial line generating process focused on vehicular access, which were supposed to have a higher improvement after the road construction.

After mapping out the correct linear space pattern, the software Autocad was used to convert axial map, which could be imported into DepthmapX 0.6.0 for calculating parameters value. Different axial maps were generated according to different development scenarios, and then the effectiveness of reserved road constructions in different scenarios can be evaluated.

3. Results

This section reports the results of evaluation of effectiveness improvements of reserved road constructions. Firstly, the overall effectiveness improvement in four areas were compared. Also, the marginal effectiveness of each reserved road section construction in the Old Five Channels Area was analyzed.

In Phase 1, before and after all the reserved road construction were simulated for the four areas (see Figure 3). Within these four areas, the integration values of the scenarios before and after the reserved road constructions were evaluated. A higher integration value indicated a more convenient local network. The results show that the average local integration value after the reserved road construction of areas A, B and D increased slightly, whereas that of area C remained the same (see Table 1).

Areas A, B and D have their local integration values (*R3*) slightly increased after all the reserved road constructions. These three areas share a common ground, i.e. the constructed-networks and the reserved road networks intersected with each other. In other words, the constructed roads were split more sections after the reserved road constructions. However, in Area C, all the reserved roads are the extension of existing constructed roads. This means that the network pattern remains the same after the reserved road constructions. Hence, the system had no improvement in the average integration value.

The results show that if the reserved road splits the constructed networks into more sections, a higher integration value improvement is expected. The reserved road networks crossed the constructed networks at right angles would cause small integration values. Also, a reserved road overlaid with a constructed road will not increase the integration value when the connecting relations do not change.

In the urban transportation planning conventions, the roads rank higher in the hierarchy of roads have less dense intersections. In this analysis, more intersections represent a higher integration value. This means that this approach might be suitable for evaluating the effectiveness of local street network circulation, and might not be suitable for evaluating that of arterials. Given that the reserved roads are defined as local streets, this approach is suitable for the present study.

Figure 3. *Average R3 value before and after road construction (a. Before construction; b. After construction).*

Table 1. *Comparative measures of the construction R3 value.*

Area	R3 value before construction	R3 value after construction	The rate of change
Area A	1.873	1.901	1.5%
Area B	1.765	1.787	1.2%
Area C	1.746	1.746	0.0%
Area D	1.753	1.755	0.1%

In Phase 2, the reserved roads in Area A were examined further. In Area A, reserved roads intersected with the existing network by in a certain degree, generating a large number of intersections, and splitting the existing streets into small sections.

Figure 4 presents the best reserved road section construction priority and the effectiveness improvement of each section. The horizontal axis lists the reserved road section in the order of construction priority calculated by the approach described in the Methodology section. The vertical axes present the marginal and overall effectiveness improvements to the network after a reserved road section has been constructed, given that the other higher priority reserved road sections have been built.

The results show that the average integration values increase and the marginal measures decrease for the first seven sections. These sections overlay the existing networks with more complex patterns than other sections do, and hence get higher value in effectiveness improvements.

The effectiveness improvements of other sections constructions are more complicated. The integration value of the network might not increase by a section construction, i.e. some of the marginal measures of section construction are negative (10^{th}, 12^{th} and 13^{th} sections), which are caused by the sections not intersecting with the existing networks. In addition, the marginal measure rebounds for some particular reserved road section construction (8^{th}, 9^{th}, 11^{th} and 14^{th} sections). These rebounds are mainly caused by the synergy those sections create, i.e. these sections bridge the existing networks.

4. Conclusions and Discussions

The present study examined the effectiveness of reserved road development in Tainan City, Taiwan by using the axial analysis techniques of space syntax. Axial maps were employed for facilitating axial analysis, which were drawn based on road-centre line, which is suitable for describing the linear spaces for the vehicle user.

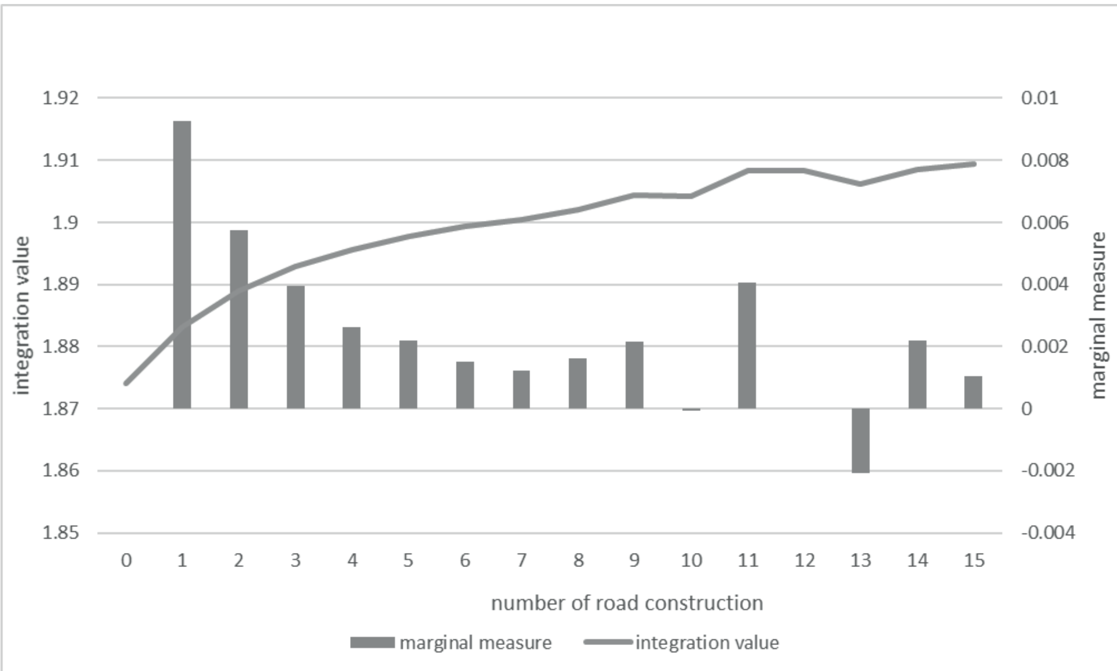

Figure 4. *The effectiveness improvement by each reserved road section construction.*

The results from Phases 1 and 2 show that the angle of overlaying between the constructed and unconstructed networks plays a crucial role in the improvement of integration value. The angle affects the manner of intersection generation when two network systems overlay to each other, which affects the connection relationship of the network and thus affects the integration value. As a result, the improvement of average integration value depended on the degree of networks overlaying. Generally, each construction of reserved road section would cause the average integration values increase. Moreover, the marginal measures decrease for an additional construction. However, some specific reserved road sections which bridge the networks can bring great improvements to the network effectiveness due to the synergy. All this show that the order of the reserved road section constructions and the design of the network pattern are important to the network effectiveness. Based on the analysis, the strategies for reserved road construction can be suggested

In addition to the above conclusions, this study finds that the local integration values (*R3*) might be able to define the hierarchy of roads in the networks as this index is linked to the density of intersections. Also, the approach used in this study might be able to prove that some of the reserved roads are redundant, which might be the reason why these reserved roads remain unconstructed.

5. Acknowledgements

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