Configurational Accessibility Study of Road and Metro Network in Shanghai

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Abstract

Accessibility determination has become one of the key issues to interpret the relationship between urban form and travel pattern in metropolitan areas. Although the use of urban planning and design and associated accessibility influence travel makes intuitive sense, researchers have found it difficult to provide clear evidence of the influence of urban form. At the same time, it is generally recognized that land use patterns and transportation patterns are closely related to each other through accessibility change. The spatial organization of human activities creates a pattern of personal travel and goods transport, thus influences the mobility behaviour of actors such as households and firms. Conversely the availability of infrastructure makes certain locations more or less accessible. This paper identifies spatially desegregated micro-macro configurations of structural flow derived from accessibility analysis and their relationships with urban block size, road and metro-line network design, metro stations and bus stop locations, commercial land use locations distribution and station usage in Shanghai, China. Using GIS and spatial Design Network Analysis (sDNA) software to perform multi-level accessibility analysis of each link in each network, this revealed that **most of the metro stations, bus stops and commercial land use are co-located on parts of the road network with the highest level of micro to macro accessibility. This indicates a 'coupling multiplier effect' between metro stations, commercial land use and multi-level multi network structural flow derived from accessibility analysis. Moreover block size is revealed as an important variable.** These findings suggest the possibility of strategically appraising the impact of block size and land use planning on micro-macro accessibility change due to transportation system change and thus further the potential for systematically guiding transport oriented development planning and design place making.

The objective of this paper is to identify the spatial configuration and composition details of multi-modal networks using micro-macro relative accessibility and the derived structural flow to understand configuration and composition of urban block size, road and metro-line network design, metro stations and bus stop co-locations, commercial land use co-locations distribution and station usage in Shanghai. Using GIS and spatial Design Network Analysis (sDNA) software to perform multi-level accessibility analysis of each link in each network, we found that **most of metro stations, bus stops and commercial land use are co-located on the part of the road network with the highest level of micro to macro accessibility, indicating a coupling multiplier effect between metro stations,**

commercial land use and multi-level multi network structural flow derived from accessibility analysis. Moreover block size is revealed as an important variable.

These findings suggest the possibility of evaluating and appraising strategically the effectiveness of block size and land use planning in relation to micro-macro accessibility change due to transportation system change and thus further the potential for systematically guiding transport oriented development planning and design place making.

Keywords: accessibility, transportation system, metro system, network, land-use, urban block

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1. INTRODUCTION

Major cities in China, most notably Beijing and Shanghai, are building and expanding rail transit systems as a strategy to reduce the negative environmental and social consequences of fast-paced motorization. Transit systems play an important role in urban public policy. They are increasingly seen as an essential element in policy packages that aim to reduce congestion, make more efficient use of road space, reduce pollution, and keep the lid on increasing energy consumption in the transportation sector and as a counter-measure to automobile-driven and automobile-dependent suburbanization.

Between 1993 and 2013, the high-capacity metro network of Shanghai has expanded very rapidly and played a major part in the sustainable public transportation system. In this short period, the major change in accessibility introduced by the metro system kept pace with massive increase in population and land use intensification and diversification of the urban form. For urban planners and designers, a better configurational understanding of the relationship between travel pattern and the 5Ds: public transport networks, public transport access point accessibility, land use location as destination accessibility and urban form as pattern of street and urban block is becoming important for interpreting the relationship between urban form and travel pattern in metropolitan areas. However, most previous TOD empirical studies relied on discrete variable descriptions using large geographic scale, few of them focused on the detailed analysis of public transport access point co-location configurations and compositions.

Objectives of this paper

This paper identifies spatially desegregated micro-macro configurations of structural flow derived from accessibility analysis and their relationships with urban block size, road and metro-line network design, metro stations and bus stop locations, commercial land use locations distribution and station usage in Shanghai.

Structure of the paper

The paper is organized as follows, in the next section, we set out the literature context of the present paper. In the subsequent two sections, we introduce the methodology, the data and software. In section 4, the road network accessibility and urban block size is computed. The relationships between road network accessibility and commercial land use, between road network accessibility and metro stations, bus stops are then presented in Section 5 and 6. Regression analysis is applied in Section 6 to discuss the interaction between the above systems. In the last part, we discuss and contextualize the analysis results.

2. CONTEXT AND LITERATURE

The relation between Built Environment and travel pattern

A recent meta-analysis of more than 200 studies of the built environment–travel pattern literature (Ewing & Cervero, 2010) and empirical studies (Ewing, et al., 2014) found that of all of the environmental variables considered, none on their own has a significant impact. Still, the combined effect of several such variables on travel pattern could be quite large. Consistent with prior work, it was found that "vehicle miles travelled is most strongly related to the measures of accessibility to destinations and secondarily to the street network design variables. Walking is most strongly related to the measures of land use diversity, intersection density, and the number of destinations within walking distance. Travel by bus and train use are equally related to proximity to transit access points and street network design variables, with land use diversity a secondary factor." Surprisingly, population composition and densities were found to be only weakly associated with travel behaviour once these other variables were controlled for. We can identify a set of key urban design indicators: road network design variables such as intersection density i.e. urban block size, non-residential land use location diversity and clustering as destination, destination accessibility, and public transport service access point accessibility. In Shanghai, studies of travel behaviour and built environment (Pan, et al., 2009; Zacharias , 2005) and suburbanization (Cervero & Day, 2008) corroborate the meta-analysis. These indicators seem to be usable in Shanghai. However, these studies did not make an attempt to assess the accessibility evaluation methods or the details of urban layout configurations.

The relationships between transport networks, land use and accessibility

The impact of transport on land use is well recognized (Hansen, 1959; Banister, 1995; Giuliano, 2004; Wegener & Furst, 1999; Geurs & van Wee, 2004; Borzachiello, et al., 2010). While accessibility change due to new infrastructure is instantaneous, despite land use planning anticipatory coordination, it is obvious that land use with much longer investment cycle lag in taking advantage of these accessibility changes. Exactly how developments in the transport system influence the locational behaviour of landowners, investors, firms, and households is less clearly understood as other influences such as planning, take a longer time to have an impact. Understanding their configuration changes and cycles over time is important.

The idea of the **"land use transport feedback cycle"** (Giuliano, 2004; Meyer & Miller, 2001; Wegener & Fuerst, 2004) is often used to illustrate the complex relationship between land use, transport and change in accessibility. In this cycle, land use and accessibility patterns both influence each other. Land use patterns are partly conditional on accessibility advantage, which causes the locational sorting of human urban activities such as living, working, shopping, education, and leisure; in other words, the distribution of human activities reflect the different requirements of and competition for accessibility advantage while pursuing benefiting of urban agglomeration economies. The transport system changes the pattern of accessibility by overcoming, with different level of ease, the distance between the locations where these activities take place. The increase and clustering of activities create new travel demand and, consequently, a need for transportation services, whether in the form of new infrastructure or more efficient operation of existing facilities, e.g. change in level of service which in turn change accessibility. The resulting increase in accessibility co-determines the

location decisions of landowners, investors, households and firms and so results in changes of the land use, starting the cycle again. This process continues until a (provisional) equilibrium is reached or until some external factor intervenes (Meyer & Miller, 2001). A key to understanding the cycle is understanding change in accessibility configurations and the co-variation of land use density and diversity co-locations.

Beyond TOD, exploring Node-Place effect of Metro Stations in Shanghai

In Shanghai, the first metro line opened in 1993. In 2014 there were 14 metro lines and 329 stations with an operating route length of 538 km making it the longest in the world. The ridership was 2.5 billion in 2013. On a normal weekday over 8 million people use the Shanghai metro. At the end of 1993, the population of Shanghai was 13 million; in in 2013, it was estimated to be 23.9 million[1]. The metro system has radically changed the accessibility pattern of the Shanghai metropolitan area. As noted by a number of researchers, transit oriented development (TOD) has become widely adopted in China (Cervero & Day, 2008; Pan & Ren , 2005; Thomas & Deakin, 2008). Pan et al. (2011) reviewed the origination and development of TOD in the USA, studying the case of Songjiang District in Shanghai. In a recent publication, Zhang (2007) explored a specifically "Chinese edition of transit-oriented development". He argued that most of the TOD performance standards developed in the United States were not applicable directly to China. In their place, he presents a modified TOD model derived from the experience of urban development around transit in Hong Kong and Taipei, Taiwan. This modified model was characterized by such key features as Differentiated Density, "Dockized" District, 'Delicate' Design, Diverse Destination and Distributed Dividends. The set is called the 5D[2] (5D squared). 'Differentiated density' refers to a desired "upward-sloping density towards the station". The upper and lower bound vary according to the station location (main centrality - higher vs sub-centrality – lower). The idea is based on bid-rent theory which is a sound theoretical grounding yet, as recognised by the author would need further elaboration and empirical research to be operationalised. Such empirical work has emerged in the UK and China it shows that accessibility analysis is for example well related to property prices (Chiaradia, et al., 2013; Xiao, et al., 2014). 'Dockised District' relate to the extent of spatial delineation of the TOD district defined by people willingness to walk. This is affected by walking level of services, for example the distance and ease of walking to the metro station such as perceived safety, security, street scene, pedestrian-scale lighting and amenities, and presence of other pedestrians – the factor that impact on both willingness to walk and pedestrian route choice preference. 'Delicate Design' is used here to stress the importance of high standards and fine details of environmental design in the TOD area beyond being pedestrian friendly. 'Diverse Destination' concerns the functional composition of TOD at both the local and the regional scale. It relates to the embedding of the metro station both in the metro network and other transport networks, the networks configuration and design but also the intensity composition of density. 'Distributed Dividend' is the principle of capturing part or all of the added value due to improvement in accessibility to properties surrounding the TOD. Excluding the Distributed Dividend, which is an important point in financing public transport policy, most of Zhang's points (2007) have a focus on place design: (Dockised District and Delicate Design) complementing the 5Ds identified by Ewing & Cervero in (2001); Density, Diversity (Land Use),

[1] http://worldpopulationreview.com/world-cities/shanghai-population/

Destination Accessibility, Design, Distance to public transport elaborated further in 2010 (Ewing & Cervero) and empirically corroborated in 2014 (Ewing, et al.).

Parallel to the TOD tradition in the USA and its adaptation in China, a Node and Place model was developed in Europe (Bertolini, 1996; 1998; 1999; Bertolini & Spit, 1998; Trip, 2007). A Node and Place approach enables a multi-scale spatial approach in relating station and station surroundings, land use mix and intensity, accessibility and the urban buzz of place.

Within the Node and Place frame, the rail station emerges as a new central place in metropolitan cities. It becomes both a hub of networks due to their high accessibility by different modes of transport mirrored by a broad range of users and also one of the very few places in the contemporary city where the participants in its increasingly heterogeneous communities still physically meet (Bertolini, 1996). The fact that all these people pass through public transportation nodes does not necessarily imply, of course, that people are also interacting with each other there. However, these intense and diverse flows of people do have the potential of translating into equally intense and diverse patterns of human interaction. If the right conditions are met, social, cultural and economic activities still requiring physical proximity can thrive in these areas. Moreover, this potential can be realized in a relatively sustainable way, as it can be coupled with environmentally more effective transport, land-use patterns and urban structure and design. More importantly these locations appear to be the locus where the micro-foundations of urban agglomerations conceptualized as "matching, learning and sharing" (Duranton & Puga, 2004), have a great potential to unfold.

The Node and Place model follows the reasoning of the transport land use feedback cycle outlined above. This feedback pattern is mediated by planning regulation and development conditions fuelled by increase in property value around transit station that are well documented in the US, China (Pan, et al., 2014) and in the UK (Network Rail, 2011). In Shanghai, exploratory studies are showing a similar pattern (Pan & Zhang, 2008; Pan, et al., 2014). The metro station, which is the transport service's access point, together with its surroundings, are the interface which produces and attracts movements of significant magnitude, and therefore constitutes opportunities for mixed use and commercial development. This has been documented as a dynamic coupling process (Pan & Ren , 2005).

Lastly, the Node and Place model is also elaborated within an economic framing of competitive advantage of place (Porter, 1985; Florida, 2000). This is relevant to Shanghai as it is transitioning from industrial to service economies and the rise of creative industries and urban place competiveness (Florida, 2000; Storper & Venables, 2004).

Toward operationalizing node and place in Shanghai

Florida (2000) and Storper and Venables (2004) used a range of indicators of 'place' at metropolitan scale to monitor policy effectiveness, but these are not usable by urban planners and urban designers (Trip, 2007). Zhang (2007) while giving guidance, does not provide a set of indicators to operationalize an adapted TOD model in China. In the most recent node and place model study (Chorus & Bertolini, 2011), the 'node' value of a station is evaluated with transport mode frequency and range, proximity to CBD by metro, bus stops and lines from the station; that is, the transport networks accessibility position of the station. The 'place' value is evaluated by population and job

levels around the station, and mixed use clustering – the functional position of the station. The functional diversity and intensity dimensions – also found in Zhang (2007) as differentiated density and diverse destination – while part of place-making and useful to urban planner, remain much less operational for urban designer but much more relevant to architect. An important point to note is that if population composition and density are dynamically coupled with station accessibility levels, this would clarify why these variables may become less significant in the meta-literature review (Ewing & Cervero, 2010) as population composition and density will be highly co-linear to level of accessibility and connectivity of the station itself.

Beyond accessibility, what will differentiate the stations will be their place value. A review of place literature and the related aspects of development form while relevant to this discussion is beyond the scope of this paper. Aspect of development forms that embed place ontologies can be categorized as follow: 'place as visual attributes', 'place as product', 'place as process', 'place as values' (Arefi & Triantafillou, 2005). Briefly stated according to these authors Place as visual attribute relates to the configuration of image, townscape, picturesque, visual excitement, contradiction/complexity, iconography, and visual layering. Place as product relate to iconic architecture, new urbanism, morphology, experience economy, staged sets, street scene and theme parks. Place as process relates to "being and becoming," uneven development, spatial political economy of place, social, cultural, environmental economic production of place. Place as meaning relates to Sense of place, sacred and the profane, mythical and real place, "betweenness of place," phenomenology, territoriality, and liveability.

For an introduction to a detailed discussion of the analysis of quality of place around station see Trip (2007, pp. 67-83) which echo Zhang's "delicate design" (2007) that stress the importance of high standards and fine details of environmental design in the TOD area. Zhang's last dimension, 'value capture' has been widely researched in the UK. In the UK, a growing body of seminal research investigated the economic value of urban design. The research ranges from the value of street public realm improvement (CABE, 2007; Transport for London, 2011), to the social and environmental value of park and public space (CABE Space, 2003), the value of green space (GLA Economics, 2003; 2010; Dunse, et al., 2007; Rogers, et al., 2012; CABE Space, 2009; Jim & Chen, 2010), the value of blue space (Garrod & Willis, 1994; Fisher, 1999; Rouwendal , et al., 2014; Goetgeluk, et al., 2005), the value of station investment (Network Rail, 2011), the value of housing and urban layout (CABE, ODPM, Design for Homes, 2003; The Prince's Foundation for the Built Environment, 2007; Chiaradia, et al., 2013), the value of mixed use street (Jones, et al., 2007; Chiaradia, et al., 2012), the value of urban design (CABE, UCL, DETR, 2001; British Council for Offices, 2006), and more recently resilient urban form, governance and the creation of long term value (Grosvenor, 2013). All of these studies link "delicate design" characteristics of the built environment to economic value. They investigate the relationship between physical configuration or condition (e.g. layout, perceived street quality, etc.) to economic value and in some studies, the social and environmental economic value. They also employ various methodologies in answering these questions, drawing on different data sources in different ways. However, they all link "urban design" with "value" through inferring relationships from a small sample to large population. A variety of methods are used and there is an explicit recognition of design value. Overall they are more robust and detailed than earlier research examining the "Value of Urban Design" (CABE, UCL, DETR, 2001). Within these studies and along

several literature review on urban design value have been published (CABE, 2003; Ministry for the Environment, NZ, 2005; McIntyre, 2006). While the results are fragmented, some of these conceptualization and assessment techniques of good design, correlates against economic value findings and economic underpinning. While yet to be consolidated by further research, they have been integrated and operationalized by consultancies (CBuchanan, 2008; Tribal Urban Studio, CBuchanan, 2008; Amion Consulting; Taylor Young; Donaldsons; University of Liverpool, 2007) advising local authorities on capturing the value of public investment in good urban design (Chiaradia, et al., 2015). Following Zhang (2007) we doubt that these studies are directly transferable to Shanghai; more research is needed. While there are similarities between TOD, Zhang's adapted TOD model (2007) and the node and place model (Bertolini, 1999), it is the node and place model that here provides the basis of a systematized approach.

Station areas are, ambivalently, both 'nodes' and 'places' (Bertolini, 1996). They are (or may become) important 'nodes' in both transport and non-transport (e.g. business, consumption) networks. Conversely, station areas also identify a 'place,' a both permanently and temporarily inhabited area of the city, a dense and diverse conglomeration of uses and forms accumulated over time, which may or may not share in the life of the node. Any successful development strategy for station areas needs to deal with this complex, node-place dynamics. Insight into the characteristics of such dynamics, its underlying factors, and the possibilities of influencing it, would seem a necessary precondition for effective action (Bertolini, 2008). The underlying idea is the land use transport feedback cycle mediated by accessibility: "By improving transport provision in a location will, because of improved accessibility, create conditions favourable to the further intensification and diversification of land uses there. In its turn, intensification and diversification of land uses in a location (or increase in its place-value) will, because of growth in the demand for connections, create conditions favourable to the further development of infrastructure there. The emphasis on 'conditions' is important, as it implies a distinction between existence of a development potential and its actual realisation, which will by and large, depend on factors other than transport and land use" (Bertolini, 2008). The node-index is a measure of the accessibility of the station area. Intensity and diversity of transport supply are the key criteria (train, metro, tram, bus, car, and bicycle). Surprisingly, the place-index is only a measure of the intensity and diversity of activities in the station area.

In this paper which is the first part of a detailed study on the synergy between the 'node' and 'place' functions of metro stations and their surroundings, in Shanghai. Our analytical focus and contribution is on 'multi-level accessibility' characteristics including pedestrian and aspect of development form that are structural to metro station as central place. Shanghai's metro stations are located in the metro network, in the bus network, in the street network in urban areas with varying urban block size, block form and street network layout, resulting in multi-scale accessibility. Our focus in this paper is on configuration of the co-locations of all the Ds components subject to their dynamic constraints. The importance of urban block size in relationship to central place i.e. central business district has been studied in the American and Australian cities (Siskna, 1990; Siskna, 1997) and was singled out by Jane Jacobs (1961). Our research questions in relation to metro stations and their surroundings are as follows:

- What are the relations between metro network accessibility position in the metro network, structural flow and station usage?

- What are the relations between the metro stations and bus stops co-locations?
- What are the relationship of the metro station location, bus stops location, and commercial land use relative to street network multi scale structural flow derived from accessibility?
- What are the relationship of colocation between metro stations, bus stops, commercial land use locations relative to street network multi scale structural flow derived from accessibility?
- What are the relationship between street network micro-structural flow derived from micro-accessibility and urban block size?
- Are there any desirable or undesirable consequences which result from the choice of block sizes and form, street layout, multi-level layout?

Urban block size and form dynamics and accessibility measures

The city block and their configuration, shaping and shaped by the street network are fundamental elements of the physical structure of urban areas. It is a key urban planning and design component. As Siskna (1997) notes it might be expected that the properties of different sizes and shapes and configuration of block would be well and documented. Surprisingly, this is not the case. There is still little knowledge about the properties and performances characteristics of different block sizes configuration in terms of circulation, land use, building forms and others aspects. Siskna's (1997) study revealed that block size and form in American and Australian city centre have crucial and predictable effects on evolutionary urban patterns. Extensive alterations to the original layout can occur through successive modifications often by un-coordinated actions that might lead to optimal collective patterns over time, yet this is not always the case and there is a need for better coordination of block size and layout. Two main dynamic processes are observed. In cities with small and medium initial block sizes, the street and block layout has remained intact whereas in cities with large initial blocks the layout has been considerably modified by addition of street and alleys, creating smaller block and sub-blocks. Smaller medium blocks are more suitable than larger blocks for the general functioning of the centre, which are areas of intense pedestrian activity as they produce and permit fine meshed circulation, affording better change in travel direction which is a good indicator of ease of movement and thus accessibility; small blocks increase dispersion, reduce congestion and enable better level of services. This principle can also be seen applied within department stores and shopping malls, a stacking strategy, where on each floor small display islands minimize distance between each island while maximizing display surface by providing a greater length of island perimeter. Contemporary development has included the commercial centre, multi-level shopping and entertainment mall directly connected to station. While these developments have often high internal permeability they often encapsulate this increased permeability within a building which itself acts as impermeable superblock. The "Delicate Design" and node and place model can be improved by including an assessment of the urban block for accessibility of the station and its surroundings, whether of its size and form, or as multi-level complex environment.

In the past decades, various definitions of the accessibility as well as indicators have been developed and used to describe accessibility (Reggiani, 1998; Geurs & van Eck, 2001; Geurs & van Wee, 2004), most of them derived from the seminal work of (Hansen, 1959), which first defines accessibility as "the potential of opportunities for interaction", formalised as:

$$A_i = \sum_{\substack{j=1 \\ j \neq i}}^{n} S_j \, exp(-bs_{ij}) \qquad \textbf{area i = 1, 2,..., n} \qquad (1)$$

where the accessibility A at area i varies directly with the sizes S of the other locations j, and inversely with the spatial separation s between i and j. This is akin to a gravity model. Size is measured with respect to quantities such as retail floor area, population, employment, retail sales, etc., while spatial separation is measured with respect to distance, travel cost, travel time and other similar, spatial distance variables. This is a field accessibility between areas.

If we recognize the co-determination of accessibility and land use and want to identify the role urban block and size impact on street network layout configuration in shaping accessibility, we need to use indices of accessibility that are not weighted by land use to begin with. The alternative to Hansen's weighted version of accessibility (type 1) is an unweighted accessibility measure (type 2) which omits the size variable (Ingram, 1971).

$$\boldsymbol{A_i = \sum_{\substack{j=1 \\ j \neq i}}^{n} S_{ij}} \qquad \textbf{area i = 1, 2,…, n} \qquad (2)$$

Ingram (1971) notes that "The use of average distances, rather than sums of distances..., facilitates comparison with the literature on area 1 moments" (Ingram, 1971) does not define n explicitly but clearly intends it to refer to the n-1 distances to each single j, rather than the n points.
This focuses on the spatial separation variable (Pooler, 1995). Spatial separation is easy to understand and calculate. This is of particular interest in intra-urban situations to disentangle the role of accessibility in the potential for interaction between land use diversity and intensity which are thickly and continuously intertwined with transport service access points.

On network, the first unweighted definition of accessibility can be found in Shimbel (1953). Within the context of network analysis using graph theory, Shimbel defines the unweighted accessibility of a network vertex with respect to the sum of the distances at that vertex:

$$A_i = \sum_{\substack{j=1 \\ j \neq i}}^{n} d_{ij} \qquad i = 1, 2, \ldots, n \qquad (3)$$

where d_{ij} is the shortest path from vertex *i* to vertex *j*.

In order to measure the overall network dispersion, Shimbel defines another elementary measure:

$$A_i = \left(\sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} d_{ij}\right)^{-1} \qquad i = 1, 2, \ldots, n \qquad (4)$$

Equation (3), representing the simple sum of the distances, is described usually as a measure of the compactness of network relative to each vertex.

Equation (4) measure the overall "network dispersion". This is the mean shortest path length on network. Christaller (1933-1966) and Reilly (1931) were also early pioneers of "mean shortest path length".

Shimbel (1953) defines "stress" on a vertex k as the "count of all the minimum paths which pass through site k, then we have a measure of the "stress" which site k must undergo during the activity of the network. In transport this is also called 'path overlap'. This is a definition of structural potential flow in route assignment through the network sampling each link origin as all or nothing to link destination (Pooler, 1995). Shimbel's (1953) work on network was applied later in transport network

analysis (Kansky, 1963), and by geographers for the analysis of networks geography. For an extensive review see Haggett & Chorley (1969).

More recently, analysis on spatial network have invoked centrality measures from social network analysis such as closeness and betweenness centrality analysis (Cutini, 2001; Porta, et al., 2006; Newman, et al., 2006; Borzachiello, et al., 2010; Xiao, et al., 2013). Closeness is referenced in Social Network Analysis studies (Bavelas, 1950) as is Betweennness (Freeman, 1977). The **farness** of a node *x* is defined as the sum of its distances from all other nodes, and its closeness was defined by Bavelas as the reciprocal of the farness:

$$C(x) = \left(\sum_{y \neq x} d(y,x)\right)^{-1}$$

Thus, the more central a node is the lower its total distance from all other nodes, its **closeness.** It is also called spatial separation (Pooler, 1995)**.** **Betweenness** centrality quantifies the number of times a node acts as a bridge along the shortest path between two other nodes. It was introduced as a measure for quantifying the control of a human on the communication between other humans in a social network by Freeman (1977). We can see that closeness and betweenness centrality are the same than Shimbel's accessibility and "stress" also called path overlap or structural flow (Pooler, 1995). In the reminder of the paper we will use respectively accessibility and structural flow. The foundation of such analysis is by the mathematician Euler who, in 1736, solved analytically the "first travelling salesman problem" for Konigsberg, inventing at once network codification, graph theory and transport network analysis (Coupy, 1851). Euler also showed that network layout can make certain travel route patterns impossible.

The classic spatial interaction model (Wilson, 2000)estimates the flow of people, material or information between locations in geographic space. Factors can include origin propulsive variables such as the number of commuters in residential areas, destination attractiveness variables such as the amount of office space in employment areas, and proximity-accessibility relationships between the locations measured in terms such as distance or travel time. Spatial interaction models are usually aggregate and top-down: they specify an overall proximity-accessibility governing relationship for flow between locations. This characteristic is also shared by urban models such as those based on mathematical programming, flows among economic sectors, or bid-rent theory. Traditionally accessibility analysis is seen as such a top-down aggregate approach. An alternative modelling perspective is to represent the system at the highest possible level of disaggregation and study the bottom-up emergence of complex patterns and relationships from behaviour and interactions at the individual level. This bottom up approach is deployed in two modelling traditions: the use of Cellular Automata (CA) and Agent Based Modelling (ABM). CA modelling imposes a fixed spatial framework such as grid cells and specifies rules that dictate the state change over time. The cell spatial notation loose the spatial specificity that urban block size and configuration requires. ABM focuses on agents that have purposeful behaviour and can react, interact and modify their environment while seeking their objectives. Unlike the cells in CA, ABM can allow agents to be mobile over actual spatial spaces with their specific geometries. Although these models are valuable for assessing opportunities for encounter at a microscopic level, their usefulness becomes compromised when insights into broader spatial trends are needed. We are suggesting a third way

based on combining generic micro-economic behavioural route choice preferences and desegregated spatial notation through the use of the detailed spatial network. Research findings on route choice preferences of driver, cyclist and pedestrian (Hill, 1982; Bovy & Stern, 1990; Golledge, 1995; Verlander & Heydecker, 1997; Raford, et al., 2005; Chiaradia, 2007; Menghini, et al., 2010; Hood, et al., 2011; Broach, et al., 2012) suggest that that driver, cyclist and pedestrian share behavioural sensitivity to the effects of distance and turn frequency i.e. angular change frequency. Each mode also has more specific sensitivity. For example, cyclists are sensitive to slope, intersection control (e.g. presence or absence of traffic signals), and traffic volumes (Broach, et al., 2012). For the purpose of this paper, such micro-economic behavioural foundations provide an extension of the utility-theoretic framework to multi-modal accessibility analysis using spatially desegregated (link-based) and based on agents' general mobility behaviour. Complex adaptive systems theory applied to urban spatial analysis suggests that simple interactions among proximal entities can lead to intricate, persistent and functional spatial entities at aggregate levels. Patterns that can emerge from the simple interactions between network configuration and composition include land use distribution and travel pattern. We suggest to systematically simulate mobility patterns within detailed networks using such approach.

3. METHODOLOGY

In Shanghai, we propose to follow a three-step methodology described below.

We calculate:

1) Street network angular accessibility unweighted by land use to derive structural flow levels at micro, meso, and macro spatial scales for the street networks (radius at 600 m, 2,000 m, 5,000 m) within Shanghai outer ring. The radii correspond to walking, cycling for a short distance, e-bike and bus ride journey, and both short and long car trips.
2) Urban block size and show a choropleth map of block size in Shanghai within the outer ring.
3) Metro lines network topological accessibility unweighted by land use to derive structural flow levels.

We explore:

4) the relationships between structural flow level indices and urban block size, metro stations, bus stops and commercial land use location distribution in order to understand the mutual relationships between network configuration and composition i.e. the colocation of network, metro station usage, and land use using frequency distribution analyses. We do this because the circular causation nature of these relationships imply generalized spatial auto-correlations. Hence the point here is not to eliminate auto-correlation as one might in a normative statistical analyses. Instead, we want to systematically understand the profile of the auto-correlations across the different analysis which give an indication of the network coordination and synergies.

What spatial unit is used?

The spatial unit of analyses is the link. This is standard in transportation. The link is within the node/link network notation standard, the central path between two junctions. A street link has length, angularity along its path, connectivity with other links, incidence with other links at junction. The node/link principle can be extended to pedestrian and cycling path network and to complex multi-level environment.

What analytical catchment should we use?

Zhang (2007) in the section on "Dockized District" discusses the issue of choosing an analytical catchment area (e.g. 400 m) from the station. He recommend that the underlying behavioural principle should be defined by people's willingness to walk.

Calthorpe (1993, p. 53) used 600m as comfortable walking distance in his TOD theory. Studies in Shanghai showed that 500-600m is also the comfortable walking distance (Pan, et al., 2007, p. 93; Bian, 2006; Liu, 2012, p. 20). Moreover 600m is half of the median distance between Shanghai's metro stations. In Shanghai, when trip distance increases to 2,000-2,500 m, people switch from walking to cycling (Pan, et al., 2003; Zacharias, 2005). The majority of within-city trips are less than 5 km in Shanghai, and this is also the upper limit of non-motorized trips (Zacharias, 2005).

The micro, meso and macro radii are associated with different uses of the road network, 800 m, 2,000 m, 9,000-18,000 m have been used as walking, cycling, car trip distance in Wuhan (Xiao, et al., 2013). Thus we propose to use the radius (600 m, 2,000 m, 5,000 m) which related to travel behaviour in Shanghai.

However, we agree with Zhang (2007) that the willingness to walk or cycle is strongly affected by other "Delicate Design" factors affecting level of services (LOS) of walking, for example, perceived safety, security, architectural interest, pedestrian-scale lighting and amenities, and presence of other pedestrians (Krambeck, 2006). For this level detail a whole level of very detailed descriptors will be required that can be accommodated easily with the link codification (Lin & Moudon , 2010; Parks & Schofer, 2006). See for example, Link and Place model (Boujenko , et al., 2007) developed in the UK which has become part of transport planning policy (DfT, 2007; CIHT, 2010).

What analytical metrics should be used?

In using accessibility analyses i.e. mean shortest path and resulting structural flow, the underlying metric should relate to route choice behaviours for the various mode choice: walking, cycling, driving, and riding a bus. In the recent literature we found three types of metric: topological, Euclidean, and angular. Euclidean is the standard measure of 'shortest distance', often criticized because it does not account for the potential value of speed (which does not apply to walking) and is rather blind to geometry. While a topological metric captures directness, it has been criticized because it is relatively blind to Euclidean distance. Finally, the least angular metric is associated with capturing both geometric directness and the geometry of speed. Ideally it would be best to combine Euclidean and angular metrics. An angular metric associated with an Euclidean radius is appropriate for taking into account of Euclidean distance *changes*. An analysis of shortest paths in Shanghai according to these three metrics provides the results shown in **Table 1**. The results demonstrate that the angular metric is also a very good proxy for the Euclidean metric. This should be the urban design metric of choice as it is simple and provides the best account for change in design.

As shown is Table 1, for the 600 m radius, 88% of the top 30% links with the shortest angular paths are also the top 30% of the Euclidean shortest path. It is 81% for 2,000 m and 77% for 5,000 m. This is particular to Shanghai and may change from city to city, making comparability unlikely.

Table 1: TOP 30%

	R600 m	R2,000 m	R5,000 m
ANG vs EUC	88%	81%	77%
ANG vs TOPO	73%	66%	63%
EUC vs TOPO	76%	71%	65%

Repeating the analysis for the upper median (top 50%), Table 2 shows the shares of upper median Euclidean and Topological ranking of the upper median Angular ranking and similarly Euclidean versus Topological ranking.

Table 2: TOP 50%

	R600 m	R2,000 m	R5,000 m
ANG vs EUC	92%	87%	85%
ANG vs TOPO	79%	76%	78%
EUC vs TOPO	81%	80%	79%

These auto-correlations between metrics might explain why the literature is so uncertain about which metric to use. Comparison between metrics and cities is impossible before identifying these auto-correlation levels.

Data and software deployed

All the data is brought into a geo-database in ArcGIS which is used to store, compute accessibility and structural flow indices and visualize the results.

Spatial accessibility variables are computed using Spatial Design Network Analysis (sDNA)[2]. It is a set of multi-level spatial analysis techniques for urban networks. SDNA calculates unweighted accessibility and unweighted structural flow on a network with user defined radius with different analytical metrics: Euclidean, angular, hybrid, topological and custom and catchment distance as Euclidean distance/time as travel budget.

Unweighted accessibility: Mean Angular Distance (MAD)

MAD is defined as the mean (averaged per link) of the angular distance from each origin link to each possible destination falling within the network radius of the origin. It is an accessibility measure, in that lower values of MAD indicate straighter paths to destinations within the radius. Thus,

$$\boldsymbol{MAD}(\boldsymbol{x}) = \frac{\sum_{\boldsymbol{y}\in\boldsymbol{Rx}} \boldsymbol{d_\theta}(\boldsymbol{x},\boldsymbol{y})\boldsymbol{P}(\boldsymbol{y})}{\sum_{\boldsymbol{y}\in\boldsymbol{Rx}} \boldsymbol{P}(\boldsymbol{y})}$$

[2]sDNA is a plugin for ArcGIS, Autocad, and open source GIS (QGIS) it uses the Shapefile (.shp) or .gdb files and link/node standard to analyse the spatial networks design characteristics using centrality measures and other measures such as severance. It provides many control variables. The software is freely available after registration at www.cardiff.ac.uk/sdna/with full specifications.

Where MAD(x) is the MAD for link x, $\boldsymbol{y} \in \mathbf{Rx}$ is each other link y in Rx the radius surrounding x, $\mathrm{d}_{\theta}(\mathrm{x},\mathrm{y})$ is the shortest possible angular distance along a route from x to y, and P(y) is the proportion of y falling within the radius.

Unweighted structural flow: (BtA)

BtA measures the frequency with which each link x falls on the shortest angular path between each pair of other links y and z, provided the Euclidean distance from y to z is within the network radius. For **BtA**, the network radius can be regarded as a kind of maximum trip length. Thus,

$$\boldsymbol{BtA}(\boldsymbol{x}) = \sum_{y \in \mathbf{N}} \sum_{z \in \mathbf{Ry}} \mathrm{P}(z) OD(y,z,x)$$

Where BtA(x) is the structural flow of link x, **N** is the set of all links in the network, **Ry** is the set of all links within the defined radius of link y, P(z) is the proportion of y falling within the radius from y, and OD(y,z,x) is defined as

$$\boldsymbol{OD}(\boldsymbol{y},\boldsymbol{z},\boldsymbol{x}) = \begin{cases} 1, if\ x\ is\ on\ the\ shortest\ angular\ path\ from\ y\ to\ z \\ 1/2, if\ x \equiv y \not\equiv z \\ 1/2, if\ x \equiv z \not\equiv y \\ 1/3, if\ x \equiv y \equiv z \\ 0, otherwise \end{cases}$$

The ½ and 1/3 contributions to **OD (y, z, x)** handle the cases of routes which terminate on the link of interest, and routes from a link to itself. 1/3 represents the average flow for each point on a link, assuming flow is generated by the product of origin and destination link proportion, P(z) in the above formulae). All measures were computed with sDNA software (Chiaradia, et al., 2014; Cooper, et al., 2014).

4. ROAD NETWORK, ACCESSIBILITY ANALYSIS and BLOCK SIZE

Using road centre lines node/link, we represent the road network of Shanghai within the outer ring. The area within the outer ring is about 10% of the Shanghai municipality area and has more than 50% of Shanghai population. Figure 1-a, b shows the road network and the urban blocks shaped by the road network. The colour of urban blocks from blue (large) to red (small) represents the area size of blocks. As predicted by urban economic theory, the road density in the centre of Shanghai is much higher than in the suburban areas. As agglomeration increases, the increase in network density acts dispersively to mitigate congestion and increase level of proximity of a larger number of people. As people density increase faster than road density, there are economies of scale in a denser network (Chiaradia, et al., 2013).

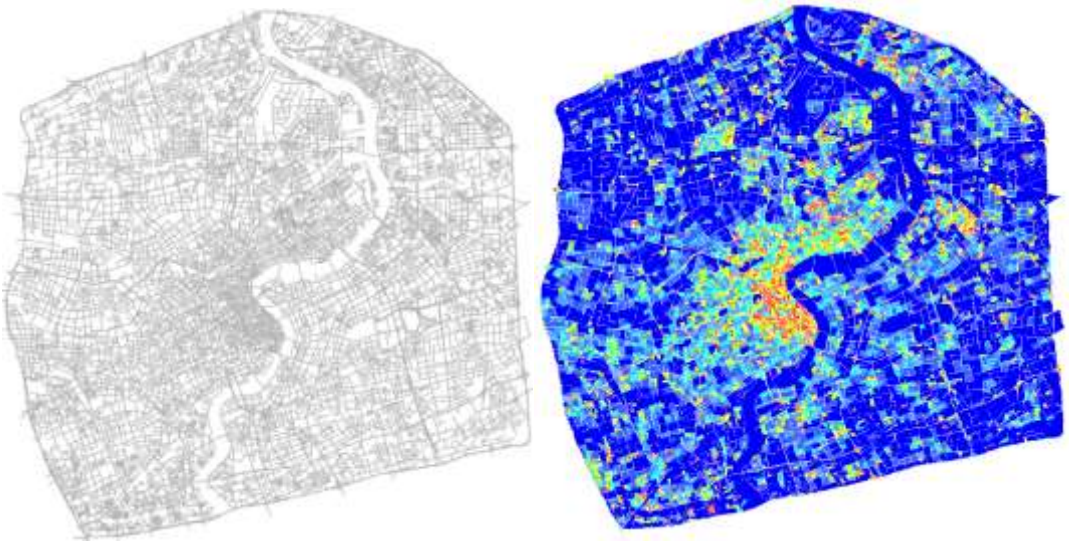
As identified by Siskna (1997) in the US and Australia, the smaller block sizes in Shanghai are mostly located in the centre, where people density is higher. High small-block density is also related to high junction density and high network density. Junction density is one of the main design variables identified in the literature relating urban form and travel pattern (Ewing & Cervero, 2010; Ewing, et al., 2014). In Shanghai, within the outer ring, the block size average is 65,900 m^2 (≈ 256 x 256 m),

the median is 22,718 m^2 (≈ 151 x 151 m), while within the inner ring (115 km2) and central Shanghai, the block size average is 36,300 m^2 (≈ 190 x 190 m i.e. -45%), the median is 15,966 m^2 (≈ 126 x 126 m i.e. -30%).

Siskna (1997) provides a yardstick in evaluating block size performance in CBD as follow:

- 60-70 m (3,600 to 4,900 m2) – very fine meshed – optimal for pedestrians
- 100 m (10,000 m2) – fine meshed – very convenient for pedestrians
- 200 m (40,000 m2) – very coarse meshed – inconvenient for pedestrians

From, the above it seems that block size are rather oversized in the central area of Shanghai (inner ring) were 85 metro stations are located (26% of the total). A further analysis shows that street network length within 500 m of the central metro stations is 648 km using crow fly and 385 km using network distance. The area covered is 61 km^2 (53% coverage of the inner ring area) using 500 m crow fly from the station and 31 km^2 (27% coverage) using street network. For central Shanghai, using a block size model we have estimated that the block size profile within 500 m of the stations is on average 200 m which is deemed to be inconvenient for pedestrian.



a b

Figure 1. Road Network (a) & Urban Block Size (b) of Shanghai in 2010

Street network, structural flow

Figure 2 shows the level of structural flow (**BtA**), from cold (blue) low level to warm colours (red), high level. **BtA** measures how often each link is used on angular shortest paths from all other links in the radius to a given link. This is the level of path overlap on each link, the level of structural flow on link (Pooler, 1995). Then all links are ranked from high to low levels. BtA is a measure of shortest path overlap on each link which indicates potential structural flow level of each link.

A high BtA at micro level (radius: 600 m) identifies links that are closely clustered i.e. short links, smaller blocks and high junction density. As the radius increases to the meso level (2,000 m), links with high level of structural flow are identified. These are the inter-neighbourhood streets and roads, which are still denser in central Shanghai. We can clearly see how the pattern of block size relate to the pattern of micro-meso accessibility in Figure 2. These relationships are somehow overlooked by urban designers and transport planners.

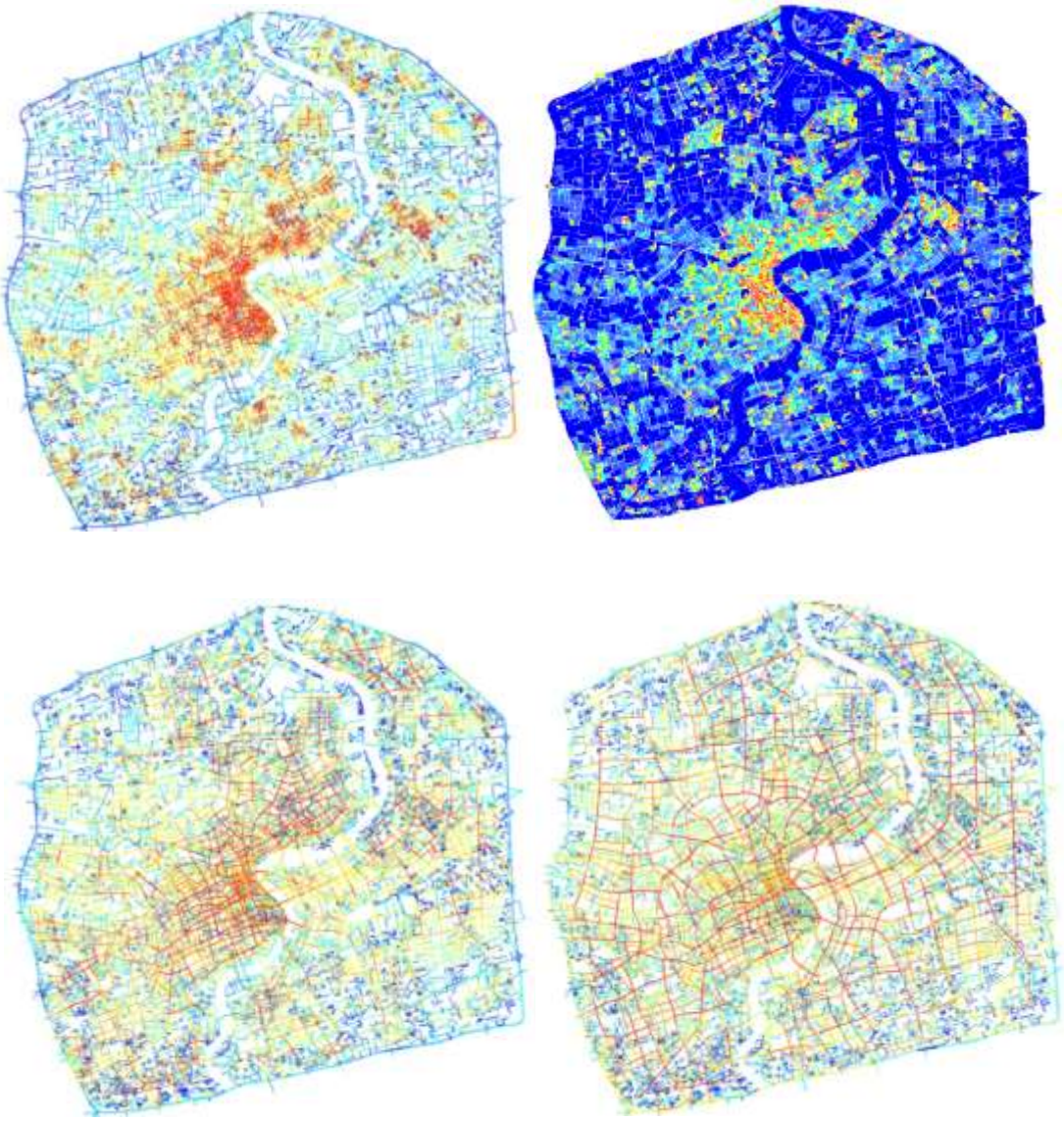


Figure 2. Shanghai road network in 2010, unweighted structural flow (BtA, radius: 600 m, 2000 m, 5000 m)

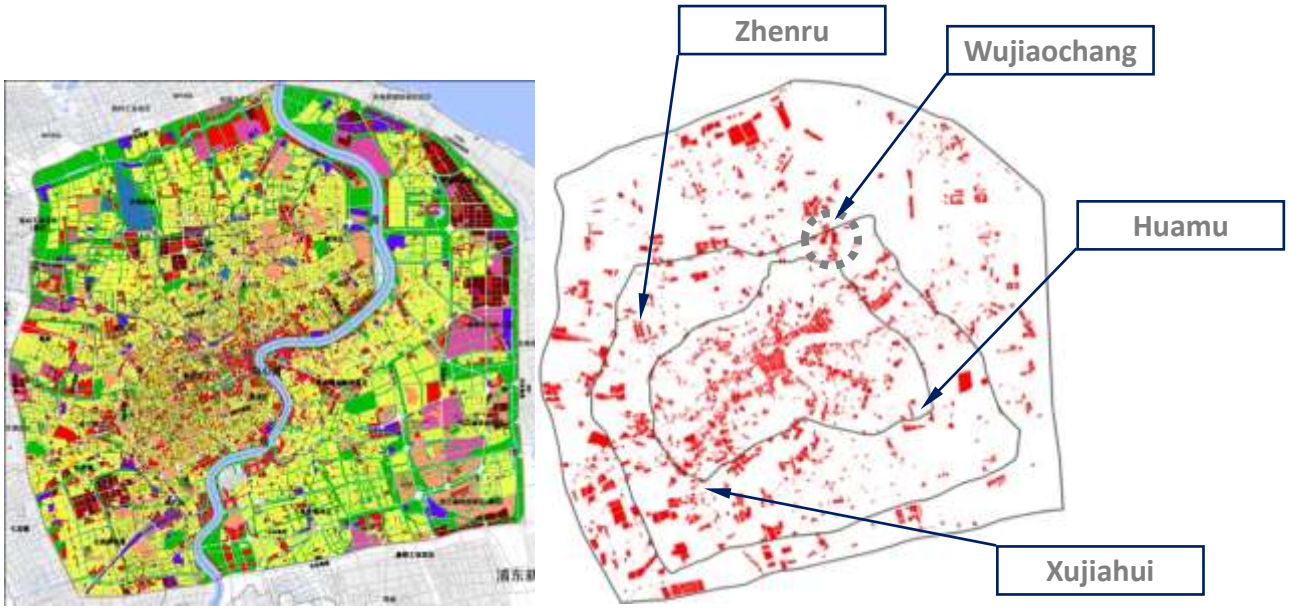
At macro level (5,000 m) the main arterial network which allow to move from one part of Shanghai to the others is identified. The arterials are evenly distributed in the whole city as they follow the national design standard used by transport planners. The arterials are about 1 km spaced. There is still a strong focus on central Shanghai. There are easily identified by transport planner and urban planner and designer.

5. COMMERCIAL LAND USE & FLOW POTENTIAL

Figure 3 shows the land-use map and commercial land use location (red) of Shanghai in 2010. The commercial designation includes both retail and office. The urban land has been planned and transformed from a “single-core” pattern around the city centre into a “multi-cores” pattern - urban land expansion around the city centre and sub-centres). The four sub-centres are known as Xujiahui,

Zhenru, Wujiaochang, and Huamu. Some large commercial clusters are also located in proximity of the ring roads.

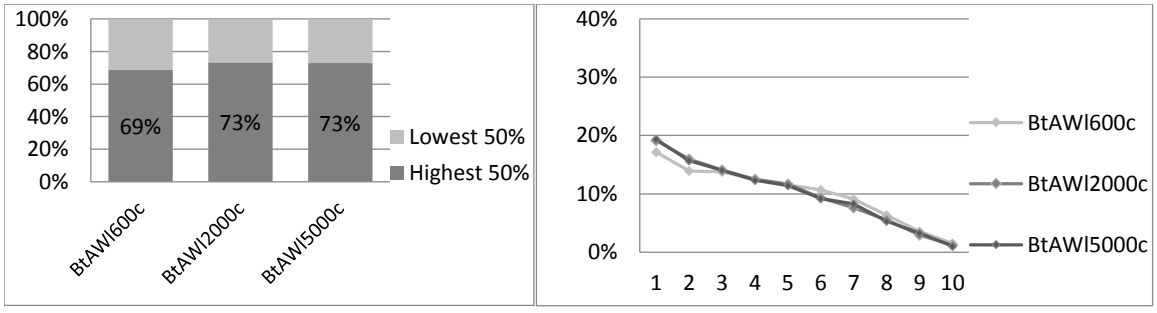
To understand the relationship between commercial land use and structural flow, we first divided the roads into 2 categories according to their structural flow levels: the roads with the 50% highest flow potential and the roads with the 50% lower flow potential, then calculated the frequency distribution of commercial block. From Figure 4-a, we can see that across radii, 72% of the commercial land use is located at the roads with highest structural flow levels. We repeat the frequency distribution analysis with deciles. Figure 4-b shows the density distribution of commercial land use location by structural flow (level 1 highest, level 10 lowest).



a b

Figure 3. Urban Land use (a) and Commercial land use location (b) of Shanghai in 2010

Commercial land use seems to maximize locational advantage from micro to macro structural flow level. 17%, 19%, 19% respectively of commercial land use locates on the link with highest 10% structural flow level at different scales (radius 600, 2,000 m, 5,000 m). Cumulatively the top 30% of the links with highest flow potential have almost 60% of commercial land use located on them.



a b

Figure 4. The density distribution of commercial land use in relation to link multi-level **BtA** (a. divide road accessibility into 2 categories; b. divide road accessibility into 10 deciles)

6. METRO STATIONS, BUS STOPS & STRUCTURAL FLOW

In 2013, there was 329 metro stations in operation[3] in the Shanghai metro system. Figure 5a shows that more than 200 of the stations are located inside the outer-ring of Shanghai representing ≈ 61% of the metro station and only ≈ 11% of municipality area. Of these 200 metro stations, 85, or 26% of the total, are concentrated in the centre of Shanghai, inside the inner-ring, which is only ≈ 2% of Shanghai municipality area. Still this is only half of the metro station density of central New York City (Manhattan) or Paris municipality. The average distance between metro stations is 1.2 kilometre with the standard deviation of 400 meters.

There are more than 4,000 bus stops inside the outer-ring of Shanghai (Figure 5-b), more than 1,000 are located in the centre of Shanghai (25% of the bus stops on 2% of the land – the inner ring is 115 km^2 and outer ring area is ≈670 km^2).

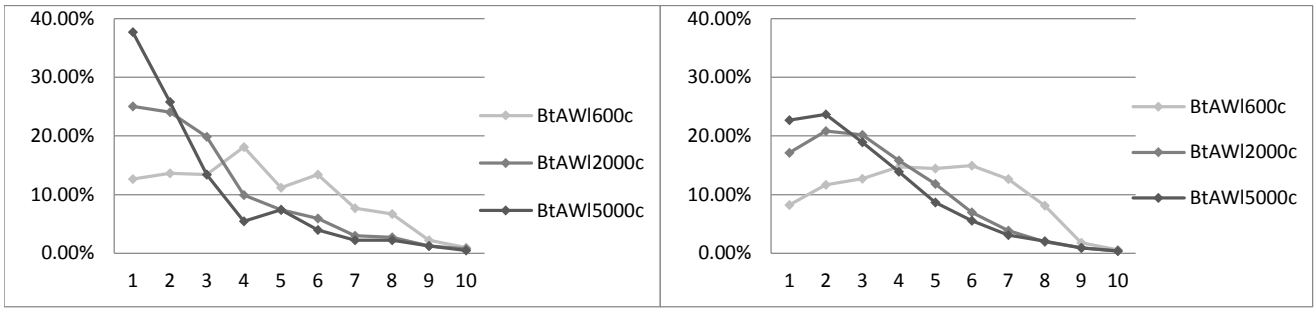
Figure 6 provides the density distribution of metro stations and bus stops in relation to link multi-level structural flow levels (divided into 10 deciles, level 1 highest and level 10 lowest).

It can be easily seen from the figure 10 that the relationship between link structural flow potential and metro stations and bus stops location profile are very different according to radius. Only 13% of metro stations and 8% bus stops locate on link with the highest 10% flow potential at radius of 600 m, which would correspond best to a very walkable neighbourhood. This is understandable as most of the metro lines have used a cut and cover construction technique thus they mainly have been located on large arterial roads. This is reflected in their name which most of the time contains a road name and only rarely a place name. An aspect that may bias the result of this analysis is that metro stations are often coupled with large shopping and entertainment malls. In addition, the detail of the permeability network of the large shopping malls is missing from the spatial network codification.

a b

Figure 5. Metro Stations (a) and Bus Stops (b) in Shanghai (2013)

[3]http://en.wikipedia.org/wiki/Shanghai_Metro



a b

Figure 6. Correlation between **BtA** and the location of Metro Stations (a), Bus Stops (b)

Bus stop locations can be explained by the fact that bus lines have to trade off proximity to patronage and service speed and thus cannot only be located on very local streets. The links with 30% highest level of flow potential, at radius 5,000 m, are where 76% of the stops are located. 64% and 38% of stops are located on links with 20% and 10% highest flow potential, respectively. These are very remarkable spatial distributions because of the asymmetry of the probability distribution. The distribution is much alike Pareto's 80/20% - 70/30%. For bus stops the links with 30% highest level of flow potential (5,000 m) are where 65% of the bus stops are located.

We can see a pattern emerging of extreme coordination between flow potential levels, commercial land use, bus stops, and metro stations locations. This coordination is best explained by circular causation presented above.

7. METRO NETWORK FLOW POTENTIAL ANALYSIS

Derrible and Kennedy (2009; Derrible, 2012) demonstrate that network topologies play a key role in attracting people to use public transit; ridership is not solely determined by cultural characteristics, city design or driven by land use demand but also by the transport supply side configuration and composition – the network of network effects. Therefore, we now turn to the configuration of the metro lines network and evaluate the network effect on entry and exit usage. A network was created to represent the metro line network topology using one link between each station. The analysis is structural flow potential, i.e. using topological distance (one link = 1 distance unit). This is taking in consideration that while comparing route choice to destination metro rider count number of stations. To model transfer between connected lines at the level of 'station', each transfer between two lines was considered as a topological distance of two thus adding two short links. This approach was taken because a limited market research showed that between two alternative routes to the same destination with changes at station level, people choose to switch to the route with the change if the difference in station number was reduced by at least two stations i.e. one change is the substitute of at least the distance between two stations. This makes the distance of line change in the model equal to two metro stops. A more elaborated model could be made by considering transfer between "virtual" station i.e. stations that are not interconnected but close enough to be reach with a short walk. In Shanghai, Metro cardholder will be able to transfer between "virtual" without incurring extra charge.

Figure 8 show the results of topological structural flow analysis (**BtT**) of Shanghai Metro network. We can see that the network configuration conform to the schematic evolution of metro network (Roth, et al., 2012); “A large `ring' encircles a core of stations. Branches radiate from the core and reach further areas of the urban system. The branches are essentially characterized by their size and their spatial extension”. The core is characterized by the connection degree of the stations and the number of station. Yet this characterisation miss the differentiation that is due to the network configuration. In Shanghai it seems that that east-west lines form a stronger core than the north south line. Figure (8-a-b) show the 2011 entry and exit usages. The structural flow levels were compared to actual station entry/exit movement rates. Correlation analysis shows that the structural flow level of metro network model for each station correlated with entry/exit r^2=0.407 ($p<0.0001$) (weekend), and r^2=0.497 ($p<0.0001$) (weekday). Given that the Shanghai metro system has grown at an exponential pace and is set to grow by almost 50% in the next 5 years, and that land use is and will obviously lag behind such a massive accessibility change, it would be important to capture this accessibility change dynamic to understand each station overall node change status in the whole system and plan accordingly.

Figure 7.Topological structural flow (**BtT**) of Shanghai Metro Network 2013. The thicker and the darker the higher structural flow and vice versa.

a b

Figure 8. Shanghai Metro Network: a. Weekday Exit/Entry; b. Weekend Exit/Entry

Figure 11 show that the metro station location relation to street network link structural flow **BtT** (5,000 m), the number of bus stops in the metro areas (600m), and the Exit/Entry movement of metro stations have similar decile distributions.

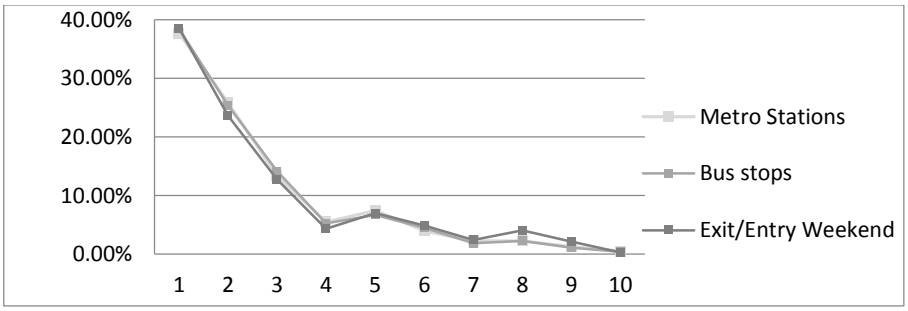


Figure 9.Relationship between Location of Metro Stations, Number of Bus stops in metro areas, Exit/Entry movement of Metro Stations and structural flow (5,000m)

8. DISCUSSION

We started this paper with a review of a meta-analysis relating urban form indicators to travel behaviour and identify particular urban form indicators including non-residential land use (diversity), distance to public transport access points, design of transport networks, destination accessibility related to these travel behaviours. Prior to 2010 this was known in the literature as the 5Ds (Ewing & Cervero, 2001). More recently transport network composition and layout were found as important factors (Ewing & Cervero, 2010; Banister, 2012; Ewing, et al., 2014). One of the surprising findings of the empirical study in 15 conurbations in the USA (Ewing, et al., 2014) is that the population

composition and density play a minor role once other urban form variables are taken into account. What play a role is employment density. Basically, those who live in highly accessible places (characterised by these five D variables) and larger metropolitan areas are better able to make do without car trips. We delineated the circular causation model between accessibility and development which in part would explain such a 'surprising' finding. Urban form has evolved from being simply measured in terms of 'density' (Newman & Kenworthy, 1989) to become understood as the 3Ds (Cervero & Kockelman, 1997), the 5Ds (Ewing & Cervero, 2001; Ewing, et al., 2014) and more recently 'the spatial distribution of activities and the composition and layout of transport networks' (Bourdic, et al., 2012), i.e. the configuration of their co-locations.

We reviewed the TOD model's adaptation to China and introduced the 'node and place' model, that extend and systematize this model's application to study Shanghai's metro stations and their surroundings as new locii of multi-scale centralities. In other words, we aimed at characterising the multi-scale accessibility profile of metro stations in Shanghai. Since local accessibility is predicated on urban block size and configuration, and studies of "traditional" centrality i.e. CBD in the US and Australia show the important role of block size and configuration, we used accessibility indicators that are unweighted by size effect to explore the role structural flow derived from accessibility mediated by urban block size and form. This was in order to better understand their co-locations configuration.

The advantage of these spatial accessibility indicators is that they constitute a unified multi-level analytical framework for strategic multi modal network design analysis i.e. at options appraisal stage. Our objective was to use these indicators to distinguish between network design effect, resulting spatial accessibility and structural flow on network in relation to a range of and land use locations in Shanghai within the outer ring. To our knowledge, no such extensive and detailed accessibility analysis in relationship to land use has been performed in such large area.

We investigated the relation between urban block size and form and network morphology using network structural flow analysis with Geometric, Euclidean and topologic metrics, settling for the geometric analysis given the overlap with the other metrics and because it effectively discriminates the morphology of the transport network design and also be theoretically interpreted as generic structural flow based on cross modal route choice preferences. We then investigated the empirical relationship between these multi-level accessibility indicators in relation to public transport access points i.e. distance to transit and commercial land use, and metro station usage.

In Shanghai we found that:

- To recapitulate: the outer ring total area ≈ 670 km^2; area within 600 m of Metro stations = 196 km^2 (29%). Total Bus stop = 4,042; bus stops within 600m of Metro stations = 1,619 (40%). Total Commercial plot area = 61,889,229 m2; Commercial plot area within 600 m of Metro stations = 27,419,968 m2 (44%).

- The frequency distribution of the relationship between multi-scale structural flow and land use are approximating a Pareto distribution the 80-20 / 70-30 which is found in many phenomena.

- Commercial land use location is strongly distributed on the road network that has high level of micro to macro accessibility, a multi-scale locational differentiation and advantage;

- Most metro stations and bus stops have location distribution that follow the same pattern: a strong location bias to macro for high structural flow level at large radii. This is the coupling-multiplier effect for land-use surrounding metro stations identified by Pan et al. (2007) and Pan & Zhang (2008).

- Following Derrible and Kennedy (2009; Derrible, 2012)we found a strong and positive relationship between metro station entry/exit usage and metro network configuration. The metro network configuration, the station location, the supply side of the metro network play an important role in the movement generating pattern. More importantly it help to understand the Node position of each metro station in relationship to the whole metro network. It is an important for planning that indicator help to anticipate and understand Node change interaction according to change in the whole metro network.

- As the metro system is set for high growth while the arterial street system is likely to remain relatively similar to its present condition, the accessibility profile of the metro stations, the node value is likely to change according to change in the metro network. These changes are metropolitan in nature i.e. global. We provided an analytical approach that can anticipate these changes. Meanwhile, the surroundings of each station, the place value might be adapted to the change in node value. These changes are most likely to be local. Given the importance of block size and its role in shaping local accessibility, urban planning and design policy maker should consider shaping the pattern of block size and shape around metro station within at least 400 to 600m. Or to put it a more flexible way to consider shaping the details of the public permeability pattern within 400-600 m of each station.

Overall our contribution through this exploratory cross-sectional analysis is to show how an intensive and dynamic structural coordination is at work between locations of commercial land use, bus stops, metro station location identified through multi-scale accessibility and derived flow potential levels. We would also argue that at the structural level the understanding the “Delicate Design” around metro station will require the understanding of the relationship between urban block size and form in relationship to local accessibility. Beyond this initial cross sectional analysis, this is also the starting point of future time series analyses.

We conclude this discussion with future research and an urban design perspective.

The node-place model of (Bertolini, 1999) provides an established starting reference to more fully adapt the TOD model to a Chinese context. The node-place model, usually used in the context of train station, could be appropriately transposed to the high capacity Shanghai metro system. The

model is of interest as it follows the reasoning of the a multi-modal transport land use feedback cycle and aims at further exploring the underlying relationships, with a focus on station areas. The basic idea is that improving the transport provision (or the node value) of a location will, by improving accessibility, create conditions favourable to the further development of the location. In turn, the development of a location (or an increase in its place value) will, because of a growing demand for transport, create conditions favourable to the further development of the transport system. This circular dynamic causation is predicated on multiple equilibrium conditions. The node-place model's emphasis on "conditions" is important, as it indicates a development potential that may or may not be realized, as other factors may also affect the outcome (Chorus & Bertolini, 2011). Bertolini (Bertolini, 1999) and Trip (2007) have emphasized the role of urban design, place making and urban quality to maximize value (Network Rail, 2011).

The node-place model distinguishes five different profiles for a station area. Each profile reflects particular relative position of a station area value on the node or place hierarchy in the urban system. Future research will investigate the detailed node-place profile of metro stations in Shanghai in relation to place quality. To this end, the development of a better understanding between block size/multi-level configurations surrounding the metro station, and the quality of place in relation to pedestrian usage will be of great importance. At local level the link-place model (Boujenko , et al., 2007; DfT, 2007; CIHT, 2010) coupled with route choice preference captured by local accessibility analysis and pedestrian environment walkability assessment methods (Kelly, et al., 2011) could provide a both a theoretical framework and operational method of interest.

At a strategic level, a new research direction could be undertaken: how should multi networks accessibility be coordinated and distributed to balance accessibility equity, congestion, quality of place and agglomeration economies?

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