Simulating urban development scenarios for Wuhan

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Abstract

With the rapid growth that most Chinese cities experience, urban and transportation planning become increasingly important in developing pathways towards sustainable development. Spatiotemporal simulation models can support understanding of urban dynamics and assessing the impact of policy alternatives by answering questions such as: What will a city look like in the future if different spatial planning alternatives are applied? How will new land use or transport investments affect the populations' access to jobs or specific activities locations in the city? How robust are planning alternatives under different assumptions of socio-economic growth?

This paper reports on work that has been carried out in a World Bank funded project to demonstrate methodologies and tools to support Chinese municipalities, such as Wuhan, in developing sound land use and transportation planning strategies based on scenarios of land use change coupled with accessibility indicators. The aspect of sustainability addressed in this study relates to the performance of transport systems and how these influence the liveability of the city, measured in terms of accessibility.

First, a land use change simulation model (Metronamica) has been set up for the central urban core of Wuhan and calibrated for the period 1994 to 2004 using historic data and expert judgement. Next, seven policy-relevant land use change scenarios have been developed, starting with a Business-as-Usual scenario, assuming a continuation of historic land use dynamics combined with current land use and transport policies. These scenarios have been analyzed to show possible future land use developments and the impact of different policy alternatives on urban development. Two activity-based accessibility indicators have been accordingly measured in a GIS environment to study the effects of the land use change on accessibility to jobs over time. In addition, eight accessibility scenarios have been linked to the land use change scenarios. The results from these scenarios showcase the 'cause-effect' relation between planning, land developments and accessibility and demonstrate the utility of the approach and methods. Such an approach combining scenario based spatial analysis and simulation can provide an added value to urban policy and practice in China and elsewhere.

Keywords: Land use simulation, Accessibility, Urban development, Scenarios planning, Wuhan, Metronamica.

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1. Introduction

The city of Wuhan, capital city of Hubei province, as many other Chinese cities, has been undergoing very rapid urbanization with urban expansion, urban redevelopment and urban renewal which is radically transforming the built environment, the supporting transport infrastructure and therefore also the distribution of population and jobs and their accessibility. The interaction between urban developments and transport is highly important for liveable cities but also complex and dynamic. Any land use change has transport implications and vice versa. Urban development generates travel, and travel behaviour generates opportunities for new facilities, which in turn affects accessibility and may attract further development.

While much attention is given in the global press to the economic growth of China, the notion of "harmonious cities" has become a guide for recent debates about the management of the on-going urbanization process. With this rapid growth that most Chinese cities experience, urban and transportation planning become increasingly important in developing pathways towards sustainable development for harmonious cities as they contribute significantly to the quality of life of millions of citizens. Tools and methodologies that can assist in making cities such as Wuhan to be harmonious are needed urgently.

Spatiotemporal simulation models can provide ex-ante support in understanding the impact of policy on urban dynamics and sustainability prior to decision making and construction by answering questions such as: What does the future look like in case we apply zoning plan A1 and transport plan B1? What is the difference between the expected futures under zoning plan A1 and zoning plan A2? How will new land use or transport investments affect the populations' access to jobs or specific activity locations in the city? How robust are planning alternatives under different assumptions of socio-economic growth? Effects of (alternative) policy options on the quality of the socio-economic and physical environment can be simulated using scientific models. With this information, awareness building, learning, and discussion can be facilitated prior to decision making and investment.

This paper reports on work carried out in the World Bank funded, Wuhan Urban Accessibility Planning Support Systems (WUAPSS) project (WUAPSS project team, 2011) to demonstrate methodologies and tools to support Chinese municipalities, such as Wuhan, in developing sound land use and transportation planning strategies. The study is based on scenarios of land use change coupled with GIS-based accessibility indicators. The results from these scenarios showcase the causal relationships between planning, land developments and accessibility and demonstrate the utility of the approach and methods. Objectives of this paper are:

- To demonstrate an explicitly dynamic land use model (the Metronamica application for Wuhan) by exploring the effects of alternative policy options for land use change in Wuhan;
- To demonstrate different types of accessibility measures to explore the effects of changing land use and alternative (transport) policy options on accessibility to jobs.

The approach does not seek to fully optimise the economic, ecological and social dimensions separately, but rather to take them into account holistically. There is a specific focus on land use development with its entailing population and job distributions, and transport system development with its effects on mobility options and patterns. Although this means losing some detail, the benefit of the chosen approach is the strong integrative and interactive nature of the resulting system, in which highly dynamic, autonomous and interactive processes play a key role and strategic insights are needed for key policy decisions related to land use and transport, two key sectors of spatial planning. Actually, it can be augmented that being comprehensive isn't needed. Instead of trying to be comprehensive, which is often neither necessary nor feasible, an "integrated" approach maintains the benefits of a systems perspective by "focusing on the key components and relationships accounting for the greatest variability in system behavior" (Mitchell, 2005 and 2006).

The remainder of this paper first provides an overview of the Metronamica land use model that has been used and its application to Wuhan city in section 2. Then various policy-relevant land use change scenarios obtained from this model are described and results are discussed in section 3. Section 4 describes the accessibility measures and scenarios that implemented in a GIS environment to study the effects of land use and transport development on accessibility to jobs over time. The last section concludes with a discussion of the work carried out and possibilities for further developments and future use of such systems in Chinese policy practice.

2. Theory on land use simulation and accessibility measures

2.1 Metronamica: modelling land use dynamics

To model land use dynamics the Metronamica[2] software has been used. Metronamica is a unique generic exploration tool for planners to simulate and assess the integrated effects of their planning measures on urban and regional development. As an integrated spatial decision support system, it models socio-economic and physical planning aspects and incorporates a mature land use change model that helps to make these aspects spatially explicit. The economic and demographic development processes operate at different spatial scales and are thus represented in the model at various spatial levels. Metronamica can be applied to any region and city.

At the global level, figures taken from economic, demographic and environmental growth scenarios can be entered. These growth figures for the different land uses are derived from historic data or policy options and entered in the model as trend lines. At the local level the detailed allocation of economic activities and people is modelled by means of a Cellular Automata based land use model (Couclelis, 1985; White and Engelen, 1993, 1997; Batty and Xie, 1994; Engelen et al., 1995). Land uses are subdivided in *features* (fixed land uses that do not change dynamically), *functions* (change dynamically as the result of the local and regional dynamics) and *vacant states* (change dynamically due to the local dynamics only). The land use functions are by all means the most important land uses in the model. Each cell has one type of land use, and together cells constitute the changing land use pattern. In principle, it is the relative attractiveness of a cell together with characteristics that cause land uses to persist or to change from one type of land use to another. This model is constrained by the demands for land for the total study area generated at the global level. Four elements determine whether a piece of land (each cell) is taken in by a particular land use function or not: the neighbourhood interaction, the accessibility to infrastructure, the suitability of the location and its zoning status (see Figure 2-1).

On the basis of these four elements, the dynamic model calculates the *transition potential* for each cell and land use function for each step in time. Over time and until global demands are satisfied, cells will change to the land use for which they have the highest transition potential. Consequently, the transition potentials reflect the pressures exerted on the land and thus constitute important information for those responsible for the design of sound spatial planning policies. The type of land use conversion will also affect the distribution of jobs and population and therefore accessibility.

Neighbourhood interaction. The most import aspect of land use allocation is the dynamic impact of land uses in the neighbourhood of a location. This models autonomous developments of land uses representing the fact that the presence of complementary or competing activities and desirable or repellent land uses can influence the potential for change. New activities and land uses invading a neighbourhood over time will change the attractiveness for activities already present and others searching for space.

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[2] Metronamica website: http://www.metronamica.nl/

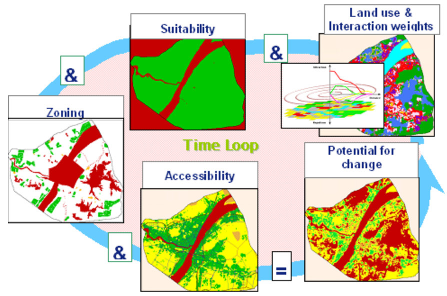


Figure 2-1 Four elements: neighbourhood interaction, suitability, zoning, and accessibility, determine the yearly land use changes that take place at the local level (cell size 1 ha)

Accessibility. General accessibility for each land use function is based on proximity to the transport networks. It accounts for the ease with which an activity can fulfil its needs for mobility in a particular location. It is an expression of the distance of the cell to the nearest link or node of each type of infrastructure element, the importance and that the type of link or node, and the need for mobility of the particular land use function. This accessibility function is only used for calculating the transition potential, while after the land use simulation a more detailed concept of accessibility is adopted to evaluate the scenarios – see section 4.

Physical suitability. The term suitability is used here to describe the degree to which a cell is physically fit to support a particular land use function and the associated economic or residential activity. It is a composite measure based on several factor maps determining the physical, ecological and environmental appropriateness of cells for development.

Zoning or institutional suitability. Different locations have different restrictions for particular land uses. Protected areas that can be facilitating for one land use, like forest reserves for the land use forest, can be restrictive for other land use functions like residential or industry & commerce. Each category in a plan needs to be interpreted in terms of their zoning status for each land use function separately. Five different interpretations used: actively stimulated, strictly restricted, weakly restricted, allowed and unspecified. The zoning map specifies for a particular period the extent to which cells can and cannot be taken over by a particular land use (i.e. land use conversion).

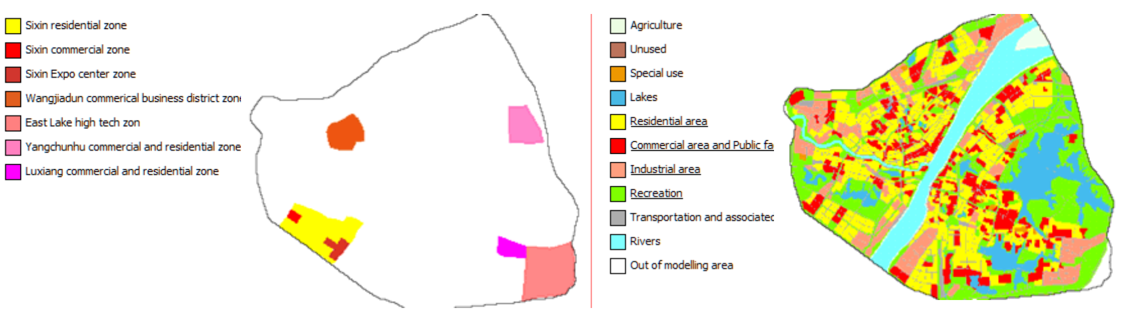


Figure 2-2 Sub-centre zones for the tenth five-year plan (left)and Master plan 1996-2020 (right)

For Wuhan city, the Metronamica application is set up for the area within the third ring road. As the study area is quite small, the Wuhan application only takes into account two levels: the global level (the whole study area) and the local level (grid cell of 100 m x 100 m). At the global level, the figures taken from economic, demographic and environmental growth scenarios for the different land uses are derived from historic data or policy options and entered in the model as trend lines. At the local level, the modelled area of Wuhan city is represented as a regular grid of 75,429 cells of 1 ha each. The land use model is constrained by the demands for land for the total study area of Wuhan city generated at the global level.

In the Metronamica application for Wuhan, the transport networks, such as road network, railways, railway stations, metro are metro stations are used as input to calculate the accessibility in the land use model and develop land use change scenarios (section 3) and accessibility scenarios (section 4). Suitability in Wuhan is particularly related to land versus water bodies. Therefore, the data on lake and water bodies are used for generating suitability maps. In order to stimulate the economic development in Wuhan city, several sub-centres (see Figure 2-2-left) planned during the tenth five-year plan. For each sub-centre, the city is prioritizing for development with a different focus: some residential, some industrial / high tech and some commercial. In the Wuhan City application, zoning played an important role as a composite measure based on the master plan 1996 – 2020(Figure 2-2-right), the sub-centre zones for the tenth five-year plan and direct expert inputs for interpretation.

The Metronamica application for Wuhan City has first been set up and calibrated based on land use maps generated from observed data at two points in time (1994 and 2004) as well as local expert knowledge. Seven policy-relevant land use change scenarios have been defined to explore land use dynamics up to 2020. The section 3 describes and analyse the selected land use change scenarios.

2.2 Activity-based accessibility measures

In a highly dynamic globalized economy, adequate access to spatially and temporally dispersed resources (consumers, jobs, suppliers, information) are vital conditions for firms and households in order to thrive or even just to survive (Castells, 1996). Accessibility is the potential for interaction between these resources and is influenced by the qualities of the transport system (reflecting the travel time or costs of reaching a destination) on the one hand and by the qualities of the land use system (reflecting the qualities of potential destinations), on the other hand (Benenson et al., 2010; Handy and Niemeier, 1997). Accessibility can therefore be used as an indicator of the integration of land use and transport. Unfortunately, often only simplified and infrastructure focused accessibility indicators are used, for reasons of easy understanding and communication. Examples of such infrastructure-based indicators are the level of congestion, travel time or travel cost, which has strong methodological disadvantages (Geurs et al. 2004).

Straatemeijer (2008) gives three reasons why planners should move away from merely focusing on such infrastructure-based accessibility indicators. First, for households and firms it is not the transport system itself that is important, but the fact that the transport system provides them with access to spatially and temporally dispersed opportunities. Second, accessibility defined in this way gives planners the opportunity to assess the effects changes in transport and land use system have on the potential for interaction. In this way, accessibility can be used as a policy design tool to generate alternative land use – transport solutions (Groenendijk et al., 2003). Thirdly, accessibility opens the floor to a more normative approach of transport planning involving different actors. For politicians, citizens and firms it might be easier to discuss the quality of access to education services and markets than it is to discuss the inefficiencies of the transport system. Based on these three points Straatemeijer (2008) rightly concludes that improved accessibility indicators have the potential to address some of the flaws of the traditional supply-driven approach to urban transport planning.

To evaluate the effects of land use change (scenarios) on transport accessibility, this study implements two activity-based accessibility measures, also called location-based measures. Such measures calculate the distribution of activities (in this study jobs) in space and the ease of reaching these activities. These measures allow us to link accessibility to people and jobs directly and to study specific accessibility scenarios based on prevailing land use change scenarios in a spatiotemporal analysis. Compared to other types of accessibility measures (see Geurs and Van Wee (2004) for an in-depth discussion), activity-based accessibility measures are comparatively easy for planners and policy makers to understand, which makes them fit for use in a policy environment (Straatemeier, 2008). They can also be used in an interactive way as quickly re-calculating changes in accessibility is possible.

In this study, contour measures and potential measures (adopted from Geurs and Van Wee (2004)) have been applied to the land use change scenarios of Wuhan. The *contour measure* (also known as an isochronic measure) indicates the number of opportunities reachable within a given travel time or distance, from a specific point of origin or a set of points of origin. This measure indicates that accessibility increases if more opportunities can be reached within a given travel time or distance. This increase can be the result of a change in the ease of reaching destinations (the transport component) and/or land use changes affecting the distribution of activities in space (the land use component). The *potential accessibility measure* calculates the potential of opportunities for interaction (e.g. residents in location A finding a job in location B). This measure discounts these opportunities over distance. As a consequence, the level of accessibility of a point of origin increases relative to the number of opportunities and is corrected for impedance (more distant opportunities provide diminishing influences). Such opportunities could be jobs or people.

To conduct the accessibility analysis a spatial dataset containing population and job information (Wuhan city transportation planning & design institute, 2009) at the Traffic Analysis Zones (TAZs) level as well as transport network databases for the different mode options (Car, bus, metro, and combination) have been used. The dynamic land use information from the Metronamica simulation served as an input (at the 100m x1 00m cell level) to the accessibility analysis through a spatial aggregation from the cells into the TAZs and calculation of population and job densities based on these results. The accessibility measures have been operationalized in ArcGIS, specifically a multi-modal network model for Wuhan has been developed in the ArcGIS Network Analyst.

3. Policy-relevant land use change scenarios

3.1 Overview of land use change scenarios

In order to develop scenarios that are meaningful and useful for policy makers to support the spatial planning for Wuhan city, it is very important that policy makers or stakeholders are involved in the process of defining them (Mahmoud et al, 2009). Seven policy-relevant scenarios have been developed together with local experts and analyzed to show possible future land use developments and the impact of different policy alternatives on urban development. These are based on a Business-As-Usual scenario that assumes a continuation of historic land use dynamics combined with current land use and transport policies (Land use change scenario 1). The alternative scenarios vary in terms of: *Spatial zoning planning* (Land use change scenarios 2 and 3); *Trend of urban development*, such as compact development versus urban sprawl (Land use change scenarios 4 and 5); *Infrastructure investment*, such as different transport networks (Land use change scenarios 6 and 7).

Scenarios have been compared against a reference scenario LU 1, which is the business-as-usual (BAU) case. Table 3-1 below summarizes the seven land use change scenarios as they have been implemented in the Metronamica application for Wuhan city. The BAU (LU 1), BAU without sub-center zones (LU 2), Compact urban development (LU 4), Urban sprawl (LU 5) and Metro Focus Extra (LU 7) scenarios will be discussed in the next paragraphs.

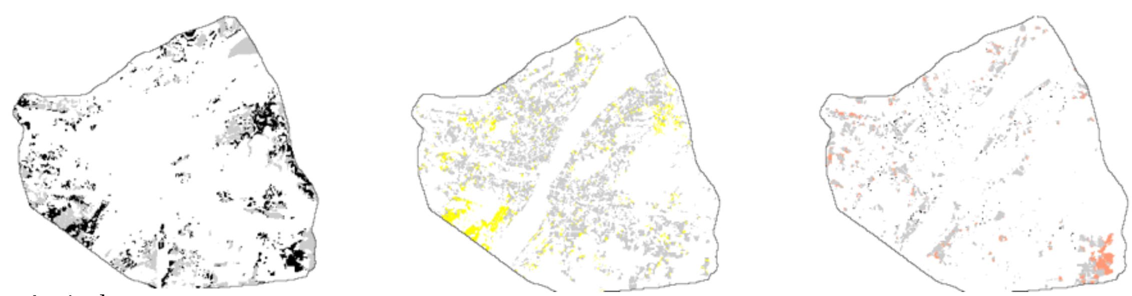
Table 3-1 Overview of the land use change scenarios for Wuhan

Components / LU scenarios	**Land use demand in 2020**	**Transport networks**	**Master plan**	**Sub-centre zones**	**Policy intervention**
LU 1: BAU	BAU: master plan 1996-2020 for urban land uses	BAU	BAU	BAU	Policy is pursued as Business-as-usual

Components / LU scenarios	Land use demand in 2020	Transport networks	Master plan	Sub-centre zones	Policy intervention
LU 2: BAU without sub-centres	BAU	BAU	BAU	Excluded	Subzone policy is not pursued
LU 3: Relaxed zoning	BAU	BAU	Excluded	Excluded	No zoning regulation is pursued
LU 4: Compact urban development	High density residential: the lowest bound of the national standard	BAU	BAU	BAU	High-rise buildings are facilitated, allowing for more development of green space
LU 5: Urban sprawl	Low density residential: the highest bound of the national standard	BAU	BAU	BAU	Less high-rise buildings are allowed in the city centre causing the development of urban sprawl
LU 6: Metro focus	BAU	No roads built after 2010; metro construction continues on schedule	BAU	BAU	After 2010 construction of infrastructure focuses on metro instead of metro and roads
LU 7: Metro focus extra	BAU	No roads built after 2010; metro construction continues on schedule; metro becomes more attractive	BAU	BAU	After 2010 construction of infrastructure focuses on metro instead of metro and roads. The metro is more attractive for urban development, e.g. due to price policy.

3.2 Land use change results for the BAU scenario

The starting point of any of the six alternative scenarios (LU 2 – 7) is the BAU scenario (LU 1), which is based on the historic development of Wuhan city (modelled after historic land use change), and assuming that the city will grow according to currently planned spatial and transport policies, thus including the zoning plans, transport infrastructure plans and land use demand estimates derived from the master plan 1996-2020. The BAU scenario provides the main input to the accessibility scenarios described in section 4. Figure 3-1 shows the land use development in the BAU scenario per land use category. These maps indicate the difference per land use between 2004 and 2020.



a. Agriculture b. Residential area c. Industrial area

d. Commercial e. Lake f. Recreation

Figure 3-1 Land use change per category from 2004 to 2020 for the Business-As-Usual scenario (grey: land use present in both years; black: land use disappeared between 2004 and 2020; other colours: land use appeared between 2004 and 2020).

From these figures it can be concluded that if the historic development is extrapolated into the future, while complying with planned developments (zoning, infrastructure, land use demand). The agricultural area (see Figure 3-1-a) will decrease rapidly over the period 2004-2020. Disappearing agricultural area is predominantly filled by urban land use (especially residential and commercial lands), and partly recreational land use (Figure 3-1-f). An increase in residential land is visible in the period 2004-2020 (Figure 3-1-b). The new residential areas are mainly allocated within the sub-centres, such as Sixin, Yangchuhu and Wangjiadun. Other minor new residential locations appear adjacent to the existing residential land and/or are allocated within the areas where the master plan 1996-2020 stimulates residential development. The commercial land use change has similar trends as the residential land (Figure 3-1-d). A lot of industry moves out of the first ring road (see Figure 3-2-a) to the urban fringe as can be seen in Figure 3-1-c. This is a direct consequence of the prevailing policy which states that it is not allowed to have factories inside the first ring road after 2000 (see Figure 3-2-b).

a. First ring road and third ring road in Wuhan b. BAU - Zoning map for industrial in 2004

Figure 3-2 Ring roads and zoning map for industrial land for the BAU (LU 1) scenario in 2004

As a consequence the same figure shows mainly an increase of the industrial area outside of the first ring road in the period 2004-2020. For example a large new industrial development is allocated in the East Lake Hi-tech zone, which is the result of a zoning regulation determined by the tenth five-year plan. Other small industrial developments are allocated along the transport networks (roads and metro stations) and/or allocated within the areas where the master plan 1996-2020 stimulates the development of industrial land. The lake area is decreasing due to reclamation (Figure 3-1-e). According to the historical land use data in 1994 and 2004, a large part of the lake area is taken over by urban expansion or reclamation in the period of 1994-2004. Land reclamation is becomes less between 2004 and 2020, because lakes more protected after 2000 due to new zoning regulations. Figure 3-1-f shows an increase in recreational land over the period 2004-2020, the new recreational land is mainly allocated along the rivers and lakes.

3.3 Comparison of results of land use change scenarios

Scenarios on spatial planning (Business-as-usual vs BAU without sub-centres scenario)

Figure 3-3 shows the comparison results of the location of commercial area and public facility in 2020 for the Business-as-usual scenario (LU 1) and the Business-as-usual without sub-centres scenario (LU 2). Comparing both scenarios we see that commercial area and public facility lands in 2020 in the BAU scenario are mainly allocated within Sixin, Yangchunhu and Wangjiadun sub-centre zones, while in the LU 2 scenario the commercial areas in 2020 are distributed more scattered, due to the omission of the sub-centres zones policy. The green patterns in the Figure 3-3 show that the facilitating policy from the master plan 1996-2020 (Figure 3-2-b) plays a very important role for the commercial and public facility development in the LU 2 scenario.

During the scenario development workshop, it was discussed whether the area within the black frame in Figure 3-3 should be stimulated for commercial activities and public facilities. Those in favour stated that it should be stimulated because it was indicated on the master plan 1996-2020 that this area was planned for developing commercial and public facility land. Those opposed stated that it should not be stimulated based on their local knowledge and the fact that in reality no development of commercial activities or public facilities had taken place in this area and that on the updated master plan map (newer than the one for 1996-2020), this area was not facilitated for developing commercial activities and public facilities.

The simulated results in the LU 2 scenario show that without the sub-centre zones, a large patch of commercial and public facility land appears in the area indicated by the black ellipse in Figure 3-3. The main reason is that on the master plan map 1996-2020, the development of commercial and public facility land is facilitated in this area, while the updated master plan map, without the facilitation in this area, is not incorporated in Metronamica (because the data is confidential). Without the sub-centre zones, this area will be developed as commercial or public facility.

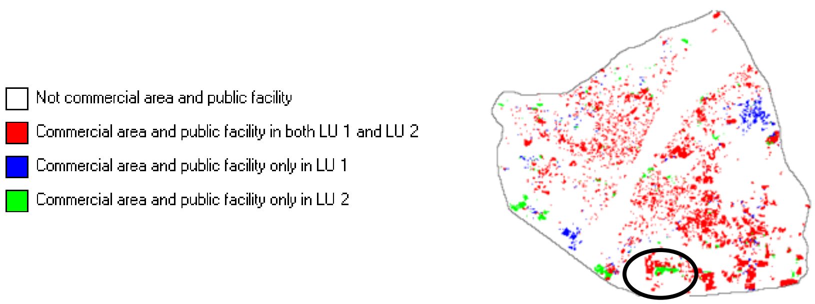


Figure 3-3 Comparison results for 2020 of the BAU (LU 1) scenario vs the BAU without sub-centres scenario (LU 2)

From this interesting argument, it can be concluded that the fact that the data was not made available for the purpose of the study led to the experts (partly) rejecting the scenario outcome. The more data and/or policy information on institutional and organizational characteristics are included as input, the simulated results will be more accurate. For instance, if by any chance, the updated master plan is used as input, even without the sub-centre zones, the simulated land use maps will be in accordance with the experts' expectations. Moreover, in both the model and reality, the effect of the zoning plan on the land use change will remain unless other policy measures overrule it. During the scenario development workshop, land use dynamics simulation was seen as a useful tool to help policy makers to explore the potential confliction on different zoning plans.

Scenarios on trend of urban development (Compact urban scenario vs. Urban sprawl scenario)

In order to explore different trends of urban development, the Compact urban scenario (LU 4) and the Urban sprawl scenario (LU 5) have been developed as well. The lower bound of the Chinese national standard for construction land (80 m^2/person) and the upper bound (130 m^2/person) are used to calculate the densities for residential construction land for the LU 4 scenario and the LU 5 scenario, respectively. The land use demands for residential area for 2020 are derived based on the densities for residential construction land and the projected population. In the BAU scenario in

2020, the residential construction land for each person is 30 m^2. For the compact urban scenario this value is set at 27 m^2/person and for the urban sprawl scenario at 43 m^2/person.

Figure 3-4 shows only few new residential cells appear in the Compact urban scenario (LU 4), while there is a large increase in residential area in the Urban sprawl scenario (LU 5). New urban development appears mainly on land previously used for agriculture, unused land and lakes. In the compact urban scenario, people move to live in high-rise buildings, which provide room for the development of green space[3] in the urban areas.

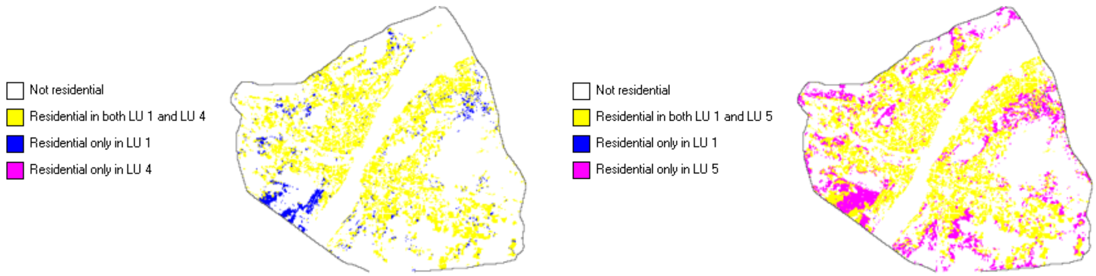
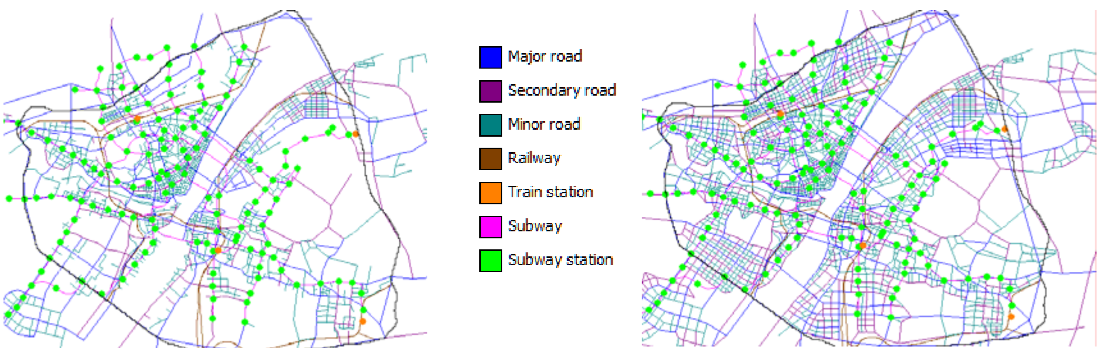


Figure 3-4 Comparison results for 2020 of the LU 1 BAU scenario vs. the LU 4 Compact urban scenario (left) and the LU 5 Urban sprawl scenario (right)

Scenarios on transport infrastructure investment (Business-as-usual vs. Metro focus extra)

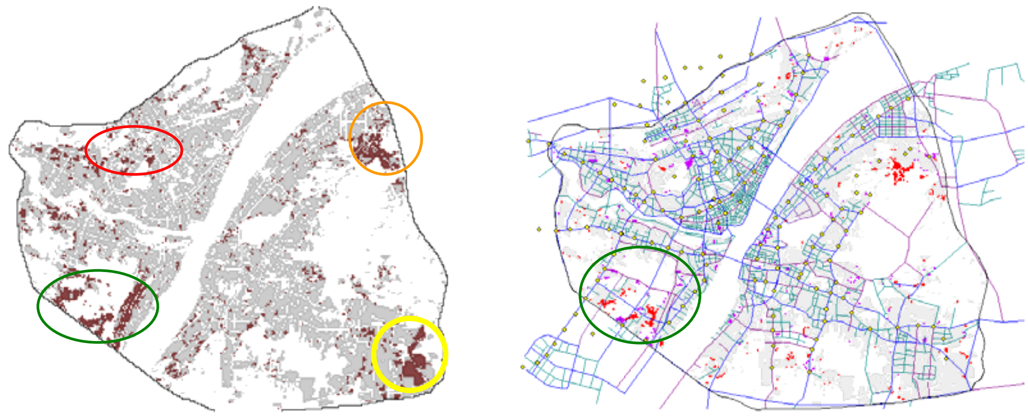
In order to explore the effect of transport infrastructure investment on land use change the scenario Metro Focus Extra (LU 7) focuses on the completion of the metro network and increased attractiveness of public transport by metro in Wuhan, e.g. through pricing policy. In this scenario further construction of the road network is stopped after 2010.



a. Metro focus+ (LU 7) - Transport network and metro stations 2020

c. BAU (LU 1) - Transport network and metro stations 2020

[3] Note that in this application of **METRONAMICA** for the city of Wuhan, green space is included in the land use category agriculture due to the available data.



b. Metro focus+ (LU 7) – Urban development (red: new urban in 2020)

d. LU 1 vs. LU 7 – Urban in 2020 (grey: urban in both; red: urban only in LU 1; purple: urban only in LU 7)

Figure 3-5 Transport networks, metro stations and land use maps in 2020 for the Business-as-usual (LU1) scenario and the Metro focus extra (LU 7) scenario

In Figure 3-5, urban land is a combination of residential, commercial and public facility land and industrial land. In LU 7 the new urban lands are mainly distributed in the Wangjiadun zone (red circle in Figure 3-5-b) and the Yangchunhu zone (orange circle in Figure 3-5-b), which is partly due to the metro system and the incentive to use this system. Figure 3-5-d shows that in the BAU scenario, the urban land (in red) is mainly allocated close to the new road segments built after 2010. Compared to the BAU scenario, the urban land in purple which appears only in LU 7 is mainly allocated around the existing road networks, which is partly because there are no new roads built after 2010 in this scenario. The figure shows that there is a clear difference in allocation of urban development between the BAU and LU 7 scenarios. For the Sixin sub-centre zone (green circle in Figure 3-5-d) this is clearly in terms of location, rather than the extent of the urban development, as the locations of urban development concentrate more around the metro station areas in the metro focus scenario LU 7. The new urban land (in purple) in LU 7 is more affected by the metro system and allocated along the metro lines.

4. Impacts of land use and transport development on accessibility

4.1 Overview of accessibility scenarios

Eight accessibility scenarios for implementing the contour based measures have been defined by local experts in one of the progress workshops. Table 4-1 below summarizes these scenarios. The scenarios vary in terms of focus on: *Infrastructure investment* for road infrastructure and bus routes (Accessibility scenarios 1 and 2); *Public transport* such as development of metro lines, stations as well as operational performance (Accessibility scenarios 3, 4 and 5); *Spatial planning* which related to specific residential and / or job centres (Accessibility scenarios 6, 7 and 8).

Table 4-1 Overview of the accessibility scenarios (contour based measures)

Components **Scenarios**	**Transport networks**	**Destination locations**	**Land use change scenarios**
AC 1: Intensive investment in road infrastructure	Road network (peak and off-peak), with and without expressway	Hankou, Hanyang and Wuchang	BAU scenario
AC 2: Total infrastructure investment	Car network, bus network, metro network and combination (bus and metro)	Hankou, Hanyang and Wuchang	BAU, LU 4 and LU 5 scenarios

Components Scenarios	Transport networks	Destination locations	Land use change scenarios
AC 3: Improved operational characteristics of the public transport system	Public transport networks (bus and metro) in combination with walking and cycling	Hankou, Hanyang and Wuchang	BAU, LU 2, LU 3, LU 4, LU 5, LU 6, and LU 7 scenarios
AC 4: Accessibility of metro line no. 5	Metro	Hankou, Hanyang, Wuchang and Qingshan	LU 1, LU 4 and LU 7 scenarios
AC 5: Accessibility to the new high speed railway station	Car network, bus network, metro network and combination (bus and metro)	To the new high speed railway station	BAU scenario
AC 6: Accessibility to existing sub-centres	Car network, bus network, metro network and combination (bus and metro)	To the existing sub-centres	BAU scenario
AC 7: Accessibility to new job centres	Car network, bus network, metro network and combination (bus and metro)	To new city's centre in Hanyang district	BAU scenario
AC 8: Accessibility to new residential areas	Car network, bus network, metro network and combination (bus and metro)	To the EastLake Hitech Zone and Qingshan sub-center	BAU, LU 4 and LU 7 scenarios

Besides, two potential accessibility measures have been developed: *Potential job accessibility* is used to assess the potential accessibility of the various areas (TAZs) to jobs. The potential job accessibility for different modes is compared against population (growth) levels. *Potential population accessibility* is used to asses the potential accessibility of the various areas (TAZs) by people. The potential population accessibility for different modes is compared against the number of jobs available to indicate competition for jobs.

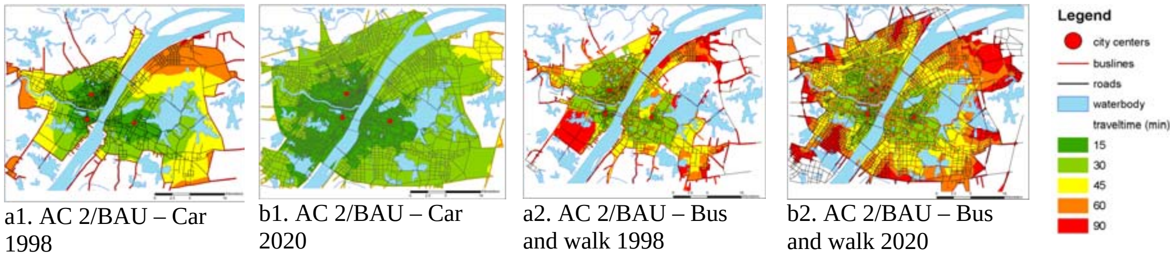
The results of the contour based measures for the total infrastructure investment scenario (AC 2) will be discussed below. In addition, the results of potential accessibility to jobs measures will be described.

4.2 Accessibility results for selected scenarios

Contour based measures for scenario AC 2: Total infrastructure investment

Scenario AC 2 focuses on the intensive investment in both road infrastructure and public transport infrastructure. Proposed investments in both public transportation (both the metro and bus) as well as road infrastructure are assessed to go to the nearest of three city centres (Hankou, Hanyang and Wuchang). Several transport modes are considered, i.e. car, bus (including walking or cycling access) and metro (including walking or cycling access). A peak hour contour based accessibility measure for 5 different travel time thresholds to travel to the nearest of the three city centres (Hankou, Hanyang and Wuchang) is derived. This scenario allows to judge whether people can leave the city in 30 minutes as the city centres are centrally located (this evacuation scheme is Wuhan's mayor's wish).

Figure 4-1 shows the results for two years and two modes. In 2020 car and bus accessibility in the central zones is almost equally good in the range of 15 to 30 minutes travel time to reach one of the Commercial Business District (CBD) points. However, towards the outskirts of the study area the difference in travel time increases (in the advantage of the car). This is partly due to lack of bus services in these areas, but may also be caused by a lack of data on (informal) public transport services in these areas. Travel time by car is improving significantly over time from 1998 to 2020, mainly due to the introduction of the third ring road and express ways in the city. As congestion effects have not been taken into account, the improvement might be too optimistic.



a1. AC 2/BAU – Car 1998
b1. AC 2/BAU – Car 2020
a2. AC 2/BAU – Bus and walk 1998
b2. AC 2/BAU – Bus and walk 2020

Figure 4-1 Contour measures for car versus bus with walking access for 1998 and 2020

These results have been combined with the zonal population estimates and linked to the BAU land use change scenario (population in the zones is distributed over the residential area cells). Cumulative scores of the number of inhabitants living within certain travel time contours to the three city centres (in this simulation peak hour speeds are used) are depicted in Figure 4-2. The results indicate that in 2010 most people (78%) could already get from the city centres to the city outskirts within 30 minutes by car, while 54% of the population could do the same using public transport, including cycling access. In 2020 this figure has improved, as 83% of the people can travel by public transport, including cycling access, to the area beyond the third ring road within 30 minutes. For public transport with walking access this is less with only 46% of the people able to get out in 30 minutes. These figures should be read with care as congestion effects (particularly when people all start moving out of the city) have not been considered.

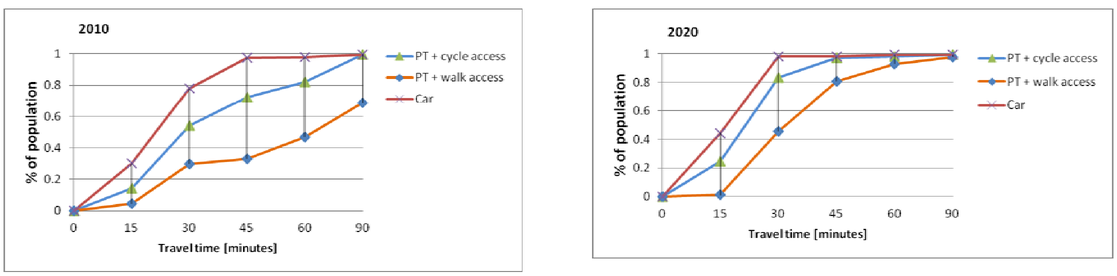


Figure 4-2 Comparison of accessibility between public transport (PT) and car for 2010 and 2020 in BAU land use change scenario

The effect of the different land use change scenarios (see section 3) for this accessibility scenario can also be assessed. In Table 4-2 the results for the BAU scenario (LU 1) as well as for two types of urban development (compact development (LU 4) and urban sprawl (LU 5) are depicted.

Land use change scenario	**Business-as-usual (LU 1)**					**Compact Development (LU 4)**					**Urban Sprawl (LU 5)**				
Contour [minutes]	**15**	**30**	**45**	**60**	**90**	**15**	**30**	**45**	**60**	**90**	**15**	**30**	**45**	**60**	**90**
Car [Cum. pop%]	44	98	98	99	99	44	98	98	99	99	40	98	98	100	100
PT + walk [Cum. pop%]	1	46	81	93	98	1	50	82	94	98	1	40	77	88	99
PT + cycling [Cum. pop%]	25	83	97	98	99	27	85	97	98	99	21	80	97	98	100

Table 4-2 Accessibility of public transport (PT) with cycling versus car in land use change scenarios Business-as-usual (LU 1), compact development (LU 4) and urban sprawl (LU 5) in terms of cumulative (cum.) percentage of people over travel time accessing the nearest of three city centres

Figure 4-3 compares the impact of the land use change scenarios on the cumulative percentage of population within certain travel time contours for public transport with walking access in 2020. Interestingly, only a small percentage of the population can reach the city centres within 15 minutes travel time. This percentage is much increased when accessing public transport by bicycle. With respect to car based accessibility the differences are only marginal. Clearly, urban development (land use change) scenarios affect public transport access more, particularly clear for travel times up to 30 minutes, as the compact development (LU 4) improves people's accessibility as compared to BAU. For the Urban sprawl scenario (LU 5) this is the opposite.

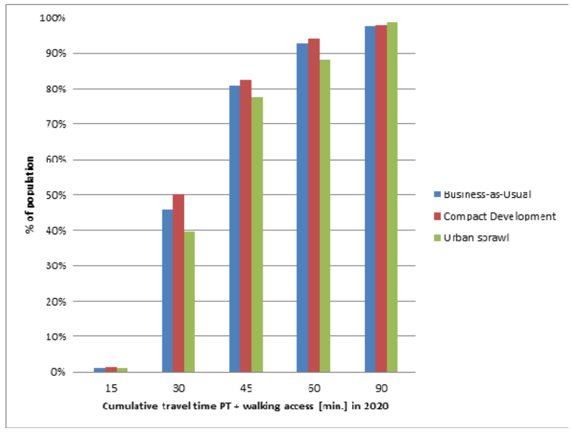
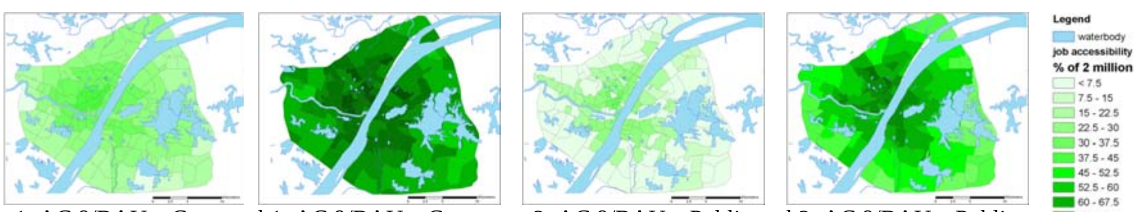


Figure 4-3 Impact of urban development scenarios on cumulative percentage of population within travel time contours for public transport (PT) with walking access

Potential accessibility to jobs (AC 9)

The potential accessibility measure explicitly links opportunities to travel impedance. In this study both population and job opportunities in Wuhan have been considered. The assessment is done for both the road network and public transport networks (with walking and cycling access) assuming peak hour conditions.

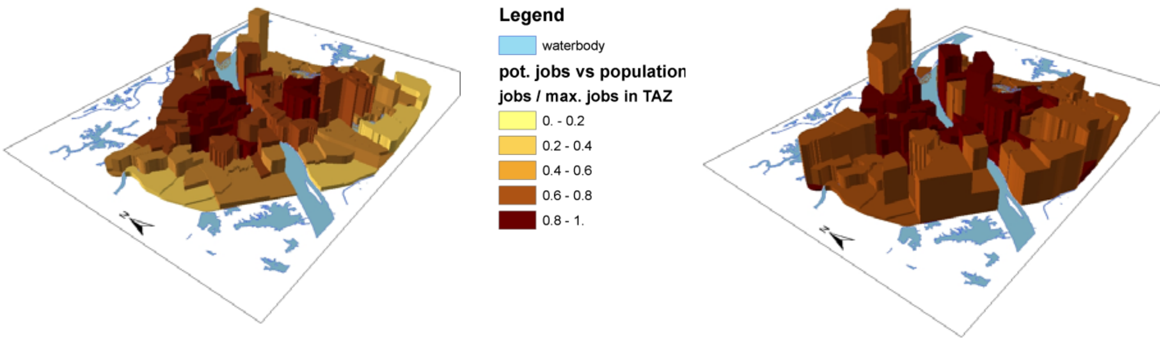
In Figure 4-4, the potential accessibility for car and public transport with bicycle access in the years 1998 and 2020 (BAU scenario) is depicted (potential accessibility as a percentage of the maximum potential value, which is around 2 million). Higher potential accessibility values indicate a higher job potential reachable from that zone. The distance decay value is based on the assumption that only a small percentage of the people are willing to travel more than 60 minutes to reach a job. The maps show that in 1998 potential accessibility by public transport was far worse than by car, but that by the year 2020 large parts of Wuhan (particularly in the central areas) have almost similar levels of potential accessibility to jobs by public transport as by car.



a1. AC 9/BAU – Car 1998 | b1. AC 9/BAU – Car 2020 | a2. AC 9/BAU – Public transport + bike 1998 | b2. AC 9/BAU – Public transport + bike 2020

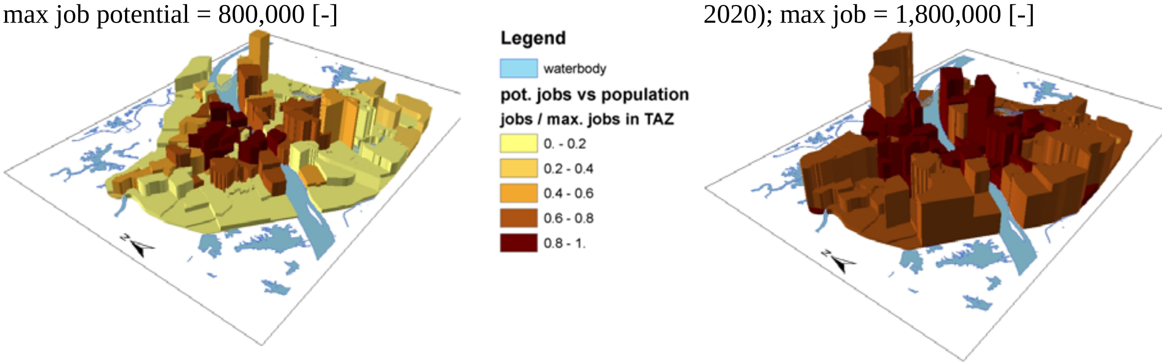
Figure 4-4 Legend and potential accessibility maps (job-based) for Wuhan 1998 and 2020, comparing car based accessibility and public transport based accessibility

In Figure 4-5, the potential accessibility maps for 1998 and 2020 are compared with the absolute number of population living in the TAZs (in 3D) that have potential accessibility to these jobs. Figure 4-5-a1 shows that in the north of the city a large peak shows there is a large population enjoying fairly limited potential accessibility to jobs (light coloured peak). This is only partly right, as local knowledge shows there is large industrial estate with a high number of jobs just across the third ring road, which is outside the modelled area. In 2020 this peak seems largely gone, as can be seen in Figure 4-5-b1, which is mainly due to the expected decrease in number of population in this area. In 2020 the overall population distribution has changed a lot, particularly towards the outskirts of the study area. Car based potential job accessibility improves in absolute terms throughout the city because of an increase in jobs and the expansion of infrastructure, however the population competing for these jobs has increased a lot as well.



a1. AC 9/BAU – Car – Population in 1998; max job potential = 800,000 [-]

b1. AC 9/BAU – Car – Population in 2020); max job = 1,800,000 [-]



a2. AC 9/BAU – Public transport with bicycle access – Population in 1998; max job potential = 600,000 [-]

b2. AC 9/BAU – Public transport with bicycle access – Population in 2020; max job potential = 1,600,000 [-]

Figure 4-5 Legend and normalized job-based potential accessibility versus number of people in the TAZs in 1998 and 2020 for Car and PT + bicycle access.

To guide the interpretation of the 3D graphs Table 4-3 can be used. Areas with relatively high number of potential jobs and a large population have a balanced job – population ratio and minimum total travel. On the contrary areas exist with a relatively low number of potential jobs, but a large population. Relatively many people compete for a relatively low number of jobs, which puts a high pressure on Wuhan's transport system. Likewise areas with a high potential jobs value and low population will require many people to travel long distances to access the available potential jobs. This implies that the more dark high peaks in the city the better. Areas with large light brown peaks or low dark peaks should be prevented. Land use – transport policies could be developed to improve accessibility to jobs or improve the jobs – population balance.

Table 4-3 Cross-table qualifying population versus potential jobs

Potential jobs / Population	**Low (light brown)**	**High (dark brown)**
Large (high peak)	Not so good: Few jobs easily accessible to a relatively large number of people.	Good: Many jobs easily accessible to a relatively large number of people.
Small (low peak)	Fair: Few jobs easily accessible to a relatively small number of people	Not so good: Many jobs easily accessible to a relatively small number of people.

5. Conclusions and lessons learned

This study has shown that technical and quantitative analysis of urban development and transport infrastructure for planning matters and could be used to stimulate debate about the impact of proposed land use and transport investments prior to their implementation. Integrated approaches to urban modelling can provide useful insights into the complex interactions between land development (land use, population and job distribution), transport infrastructure and urban policies. Historic land and transport dynamics combined with current planning policies have been used to form integral pictures of possible futures for fast growing cities such as Wuhan and to evaluate their relative value on the basis of a set of criteria. A total of seven land use change scenarios and eight accessibility scenarios (planning policies) have been simulated and evaluated, including combinations of land use and accessibility scenarios. The results from these scenarios show some of the major 'cause-effect' linkages between planning policy (zoning regulation, infrastructure and urban/city development) and future land patterns and their implications for accessibility.

Although only a demonstration project covering the city core area, some lessons learned in the study are:

1. Many factors clearly drive the interaction between land use and transport and should be considered when developing new urban policies. Transport is not the only factor that drives urban development, as more factors such as zoning regulations and other development policies, such as those for the creation of Special Economic Zones, should be considered in interaction with transport. The results from the Metronamica application for Wuhan city showed that at least 2 other sets of factors, i.e. spatial planning and urban development trends, drive land use change.

2. In order to show the potential of a dynamic land use model for the policy practice in Wuhan, additional data was collected and scenarios developed during a scenario workshop where modelling partners closely worked together with local experts. During this workshop, Metronamica was used as a tool to help participants to improve the understanding of processes, facilitate communication, stimulate discussion and explore the potential confliction on different policies.

3. The accessibility analysis further demonstrated that current urban developments and recent and planned transport infrastructure investments have significant effects on the level of accessibility to most locations in Wuhan for most people. However, the use of adjusted design speeds may exaggerate the positive results a bit. The use of real speed data and inclusion of congestion effects should be done to allow more useful assessments to be made.

4. The current study area completely falls within Wuhan's third ring road that marks the city's main urban core area. It would be more interesting and useful to apply this approach to a larger area including the urban-rural fringe so that a more complete analysis of the urban growth and accessibility can be undertaken. Furthermore, due to a lack of data on densities for residential land, it was not possible in this project to explore the intensity of land development along roads more thoroughly.

5. Since the land use change and accessibility models are loosely coupled, a true interaction between land use and transport was not achieved. A full integration of both models including direct feedback of the more advanced accessibility indicator into the land use dynamics model could make the transport factor more allow a more realistic utilization of this factor in driving the land use change.

Today's decisions on investment in urban development and urban infrastructure tie up enormous amounts of capital and will structure the city for years to come and they have substantial, long lasting effects on the lives of millions of urban residents. Therefore they should be made based on solid quantitative analyses of their distributive and environmental effects. The methods and tools used in this study have shown to be able to provide such support and insights for the local development policy making and implementation, but their practical applicability can only be fully tested in a more elaborate and spatially extensive study that is linked to actual policy practice.

6. Acknowledgement

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