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# A Study on Urban Road Networks and Their Development

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## INTRODUCTION

According to designed tasks, urban dynamic models can be divided into several groups: land-use/land-cover change, urban growth, transportation & land-use and impact assessment.

(1) Land-use models mainly evaluate the transition of different land-use types to optimize land configurations or promote sustainable development (Pullar and Pettit 2003, Silva et al 2008). The IMREL model uses destination choice as a base for locating households in Stockholm (Anderstig and Mattsson 2011). The SLUCE model was built to understand the complexity in the generation of different land use patterns and their ecological influences (Brown 2009).

(2) Urban growth models focus on urban growth phenomena. The SLEUTH model simulates the transition from non-urban to urban areas (Silva and Clarke 2012).

The Urbanism model implements a perspective on urban development via urban market dynamics (Waddell et al. 2011, 2012). The UPLAN model is based on the attractiveness of landscape features and growth constraints (Walker et al. 2012).

(3) Transportation & land-use models concentrate on the interpretation of the relationship between transportation and land use (Anderstig and Mattsson 2008, Jonsson 2008). The ILUTE model includes four main modules: land development, location choice, activity/travel, and auto ownership (Miller and Salvini 2011, Miller et al. 2010). It models eight scenarios by combining land use, economic and transportation policy factors. In transport module, activity based model is widely used as a micro-simulation approach (Algers et al. 2008).

Travel demand model is therefore an important component (Flötteröd and Bierlaire 2011, Flötteröd 2012).

(4) Impact assessment models aim to measure and evaluate the influence of simulated future status (Kwartler and Bernard 2011, Klosterman and Pettit 2012).

Actually, there is no clear distinction between the classifications of urban models above. For example, most urban growth models contain land-use modules or vice versa. The SLEUTH model is counted as an urban growth model. It however can simulate land-use transitions. The LEAM model (Deal 2011, Deal and Pallathucheril 2009) computes the growth potential of different land-use types. Meanwhile it is also used to study urban growth and consequent environmental impacts. The SLEUTH and the LEAM model share very similar functions except for the main purpose. Therefore, the urban growth model mentioned in this thesis has the same meaning as urban land-use model.

## MODELS OF ROAD NETWORK GROWTH

There is a long history of studying the temporal development of transportation systems and sustained effects have been made to analyze and model the network growth. The studies involve technical, topological, morphological, economic, social, or political aspects in broad research fields, such as transportation engineering, geography, physics, computer science, economics and urban planning (Xie and Levinson 2009).

Thanks to the availability of sufficient data and processing capacity of massive data, researchers can now study the temporal changes of transportation through statistical analyses of historical data (Taylor and Miller 2003, Levinson 2007, Levinson and Chen 2007). Transportation economists focus on various economic dimensions of network growth ranging from network pricing, ownership structures to capacity investment (Gomez-Ibanez et al. 1999, Knight

2002, Verhoef and Rouwendal 2004, Kopp 2006, Xie and Levinson 2007a).

In later 1990s, a new network science of complex networks emerged. The growth of transportation networks are interpreted with the concepts of preferential attachment and self-organization mechanisms. Recently, a growing interest of agent-based modeling is to simulate the initiatives and behaviors of independent individuals in order to investigate the dynamics of transportation networks.

Transport systems can be waterways, canals, roads, rails and airlines. The main interest in this thesis lies in the road network. The following sections will fully review growth modeling methods from the perspective of procedural urban modeling and spatial network modeling.

## ROAD NETWORK GENERATION IN PROCEDURAL CITY MODELING

In procedural modeling of cities, it is critical to generate a road network. Road networks are divided into different levels, including highways, major roads and minor roads. Highways are usually generated by linking centers with the shortest path algorithm (Teoh 2007) or population density map (Parish and Müller 2001, Sun et al. 2002). The first step to generate major roads is selecting nodes. The selection principle can be based on where users position the nodes (Kelly and McCabe 2007), the highest transition possibility (Jiang 2007, Weber et al. 2009), jobs distribution and highways location (Vanegas et al. 2009), or the difficulty of diffusing in an existing transport structure (Yamins et al. 2003). Then nodes are linked into road segments after considering elevation difference strategies (Kelly and McCabe 2007, Jiang 2007), or least-cost choice (Yamins et al. 2003).

Minor roads can be generated using the same procedure as for major roads (Weber et al. 2009, Vanegas et al. 2009) or more commonly by using road pattern templates (Parish and Müller 2001, Sun et al. 2002, Teoh 2007). Legality tests are used in the expansion process, i.e. proposed streets are checked for intersection, extension, snapping, avoidance and slope adaptation. Esch et al. (2007) and Chen et al. (2008) used user-guided tensor fields to generate streets.

Lechner et al. (2004, 2006, 2007) and Watson (2006, 2007) applied extender and connector agents to generate tertiary and primary roads. The following sections will describe road pattern templates and agent-based behavior model in greater detail.

It is necessary and desired to solve the problems of the urban road traffic safety by using comprehensive management knowledge from all sides. In the light of features of the urban road traffic safety, the analysis results achieved in the paper suggest the following: (i) on one hand, it is essential to improve the supervision and control measures of traffic safety. Urban road has been installed with advanced and modernized facilities, among which traffic control system is the key approach for urban road traffic management. The traffic control system meets the needs of traffic control, monitoring, accessibility, and communication. Under the circumstances of adverse weather and traffic jams, the system can lead drivers to the safe drive and provide traffic supervision and a control system. (ii) On the other hand, vigorous measures are adopted to develop intelligent transportation systems. Intelligent systems are the front topics in the field of transportation all over the world. Intelligent transportation systems are capable of improving traffic capacity and safety of existing networks. They represent the development orientation of traffic science. When the traffic science and technology have great breakthroughs and developments, intelligent transportation technologies can decrease traffic congestion and traffic accident, heighten the labor productivity, intensify the international competition, and increase new industry in future. By means of high-tech, computer science, and communication technology, people can improve the systematic engineering of electromechanical devices for communication, charges, and supervision and monitoring which can make intelligent urban road grow. Developing intelligent urban road can resolve traffic jams, ensure driving safety, and improve service quality. In a word, it can represent the characteristics of modernized urban road

India has a road network of over 4,689,842 kilometres (2,914,133 mi) in 2013, the second largest road network in the world. At 0.66 km of roads per square kilometre of land, the quantitative density of India's road network is similar to that of the United States (0.65) and far higher than that of China (0.16) or Brazil (0.20). However, qualitatively India's roads are a mix of modern highways and narrow, unpaved roads, and are being improved. As of 2011, 54 percent – about 2.53 million kilometres – of Indian roads were paved.

In general, roads in India are primarily bitumen-based macadamized roads. However, a few of the National Highways have concrete roads too. In some locations, such as in Kanpur, British-built concrete roads are still in use. Concrete roads were less popular prior to 1990s because of low availability of cement then. However, with large supplies of cement in the country and the virtues of concrete roads, they are once again gaining popularity. Concrete roads are durable, weather-proof and require lower maintenance compared to bituminous roads. Moreover new concrete pavement technology has developed such as cool pavement, quiet pavement and permeable pavement, which has rendered it more attractive and eco-friendly.

The National Highways are the backbone of the road infrastructure and the major roads in India. They carry most of India's freight and passenger traffic. State highways and major district roads constitute the secondary and interconnecting roads in India.

Expressways make up approximately 1,208 km (751 mi) of India's road network, as of 2013. These high-speed roads are four-lane or six-lane, predominantly access controlled. The expressways in use are:

- Greater Noida – Agra Yamuna Expressway (165 kilometres)
- Ahmedabad Vadodara Expressway (95 kilometres)
- Mumbai-Pune Expressway (93 kilometres)
- Jaipur-Kishangarh Expressway (90 kilometres)
- Allahabad Bypass Expressway (86 kilometres)
- Durgapur Expressway (65 kilometres)
- Ambala Chandigarh Expressway (35 kilometres)
- Himalayan Expressway (27.5 kilometers)
- Chennai Bypass Expressway (32 kilometres)
- Delhi-Gurgaon Expressway (28 kilometres)
- NOIDA-Greater NOIDA Expressway (24 kilometres)
- Delhi-NOIDA Flyway (23 kilometres)
- Mumbai Nashik Expressway (150 kilometers)
- PVNR Hyderabad Airport Expressway (12 kilometres)
- Hyderabad ORR Expressway (150 kilometres)
- Guntur-Vijayawada Outer ring road Expressway (46 Kilometeres) Outer Ring Road, Guntur & Vijayawada
- Coimbatore Bypass expressway (28 kilometres)

The 165 kilometre Yamuna Expressway, India's longest six-laned controlled-access, opened on 9 August 2012, and will reduce the time travel between Agra and Greater Noida from 4 hours to 100 minutes.

While the start of several expressway projects – such as the Ganga Expressway – have been delayed for 3 or more years, because of litigation and bureaucratic procedures, India expects another 3,530 kilometres of expressways to come up by 2014 from the projects under construction. The government has drawn up an ambitious target to lay 18,637 kilometre network of brand new expressways by 2022.

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