Spatial Temporal Modelling of Urban Growth and Transport: Jeddah, Saudi Arabia

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by

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Abstract

The study presented here develops a spatial temporal model of urban growth and transport for Jeddah city, Saudi Arabia. Jeddah has been facing uncontrolled land use change and consequent problems in transport such as congestion, air pollution and decline in its public transport system. Cities change over time which is influenced by factors as population, economic growth, etc contributing to the spatial distribution of locations and activities.

The present study focuses on the modelling using the Metronamica land use-transport (M-LUT) model, developed by the Research Institute for Knowledge Systems (RIKS) in The Netherlands. Spatial temporal land use and transport data were acquired from remote sensing and GIS techniques as an input for the model. The model was then calibrated using historical land use maps of 1980 and the respective transport data. The model was used to observe the spatial temporal change in the urban growth and transport in Jeddah city.

The results of the study show that M-LUT is able to reproduce the dynamics of land use and transport interaction. The transport system influences the land use change through accessibility and its impact on the transport system through congestion and the travel distance between the zones.

With a minimum dataset for the transport model, the Metronamica land use transport model simulation shows significant changes in the land use and transport network which looks promising for the future simulation. Although a high spatial accuracy was not achieved due to lack of appropriate transition rules, a full calibration of the full model is seen as an important and possible next step in the research.

Keywords: Urban growth, remote sensing, GIS, dynamic land use – transport interaction, Metronamica land use – transport model

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List of acronyms

ASCII	American Standard Code for Information Interchange
CA	Cellular Automata
DRAM	Disaggregated Residential Allocation Model
EE	Environment Explorer
EMPAL	Employment Allocation Model
GIS	Geographic Information Systems
GRASS	Geographic Resources Analysis Support Systems
ITLUP	Integrated Transport and Land Use Package
Km	Kilometers
LUCAS	Land Use Change Analysis System Model
LUT	Land Use and Transport
M-LUT	Metronamica Land Use and Transport
M	Meters
ML	Multi-Layer
OD	Origin Destination
RIKS	Research Institute for Knowledge Systems
SL	Single-Layer
SLUETH	Slope, Land use, Exclusion, Urban, Transport, Hillshading Model
TAZ	Transport Analysis Zones
TM	Thematic Mapper
TRANUS	Integrated Land Use and Transport Planning System
UC	Urbanisation Classes

1. Introduction

This thesis discusses the spatial temporal relationship between urban growth and transport. Particularly it tries to provide a better understanding on how transport is affected by urban growth in the case of Jeddah city in Saudi Arabia. This is case demonstrated by a dynamic cellular automata model that can simulate the interaction between urban growth and transport.

1.1. Background and Justification

Cities are dynamic in nature as they change over time. Cities change by various factors such as growth in the population (natural growth, in-migration), economic growth, etc. This change can also be spatial leading to new locations and intensity of activities. Therefore social and economic demand for space to perform activities change over time, resulting in existing spatial structures to change (Batty, 2005; Cohen, 2006).

The relationship between urban land use and transport is a common knowledge among land use and transport planners (Meurs, 2003). The relationship is reciprocal, which means that developments in land use are in part a consequence of the transport system and, at the same time, developments in the transport system are by large affected by land use changes.

The land use and transport relationship is a dynamic process that is driven by spatial and temporal changes. Land use changes can modify travel demand patterns and changes the transport system. On the other hand, transport creates new accessibility encouraging changes in land use at varying spatial and temporal scales and increases in land values (Priemus et al., 2001; Shaw and Xin, 2003). For example, the construction of a highway may face an increase in traffic after its completion, leading to land use changes (both in quality and quantity) in its' surrounding (Shaw and Xin, 2003).

In recent years several studies have been carried out in the development of integrated land use and transport models (Shaw and Xin, 2003).There is a need to develop land use models for use in travel demand modeling to predict how transport changes will affect land use (Landis and Zhang, 1998). There is a need to research and to develop alternative methods that will help us to explore land use and transport interaction better and easier and as such to identify potential improvements to the existing models (Shaw and Xin, 2003). The relationship has often been difficult to determine. Some researchers have examined the link between urban density and travel patterns (Crane, 2000; Maat et al., 2005). For example, people living in high-density developments will make lesser and shorter trips using public transport (Steiner, 1994; Maat et al., 2005). Others have shown that travel patterns depend on the location and type of development (Buchanan et al., 2006).

The demand for transport seems to be increasing as more people need to reach multiple destinations and achieve multiple objectives within one trip. The development of transport related strategies to respond to these needs will require accurate, reliable and readily available data (Tate-Glass et al., 2000). Remote sensing may provide such data as remote sensing imagery provides an information resource that when compared to traditional methods of data collection in transport modelling is able to supply more data with a greater frequency.

Transport planners and metropolitan organisations require up-to-date land-use information for allocating transport resources and to predict the location and type of growth within urban areas and relative increase in transport volumes. For areas where land-use changes are common, current information may not be provided by the existing geographic databases. For this purpose remotely sensed imagery can be utilised to provide information regarding current land-use (Coulter et al., 1999). The combination of Landsat TM images with GIS can provide land use and other spatial data for regional planning by image processing techniques and manual interpretation, which can be utilised by transport planners for land-use identification (Foresman and Millette, 1997). Current high spatial resolution sensor systems can fulfil this requirements of extracting urban/suburban infrastructure and socio-economic attributes (Jensen and Cowen, 1999).

Reliable data and methods are required to understand urban systems. The traditional way of collecting data is labour intensive and time consuming. Remote sensing and Geographic information systems (GIS) along with aerial photographs can provide an important data source and methods for collecting urban land use/cover information, storage, management and analysis. This urban information includes road networks, land parcels and building information for urban planners and scientists and can be used to study the quality of urban environments (Zhang et al., 2002; Carlson, 2003; Chen et al., 2007). Thus, different techniques have been used for monitoring urban land use. For extracting information from remote sensing imagery image classification, pixel based and sub-pixel classification are effective techniques which is considered the best known and widely used (McDermid et al., 2005). Remote sensing imagery can be utilized for population estimation for urban land use types. In particular, high and low land use areas for estimating zonal population using remote sensed data has long history back to the 1970s when aerial photographs where used to provide to check the census data through regression analysis(Lo, 2003). For estimating the population density, three levels of residential density were considered (Chen, 2002). Moreover, a temporal geographic information systems (GIS) design that offers exploratory data analysis (EDA) has the capabilities to examine the land use and transport interaction at user spatial and temporal scales(Shaw and Xin, 2003).

Land use and transport system changes take place in a highly dynamic system that involves driving forces such as economic development, population growth, income level, accessibility to economic centres, proximity to utilities and other infrastructures. Population, or residential, density is important because higher densities reduce the need to travel (Steiner, 1994). In general, the population density of a city decreases as the distance from the city centre increases as density is closely related to travel patterns, such as modal split and trip length (Breheny, 1996). Population density has been shown to be one of the most important land use driving factors that influences travel behaviour (Newman and Kenworthy, 1999).

A transport network model supports travel simulations by providing a representation of a city in the form of zones and a network called travel analysis zones (TAZs). Such models enable the planner to link information about activities, travel, and transport to physical locations in the study area. Zones represent the places where trips originate or terminate and each is characterized by factors such as population and employment. When identifying zones there is a desire to bound homogeneous urban activities (residential, commercial, industrial, etc.) and considering natural boundaries and census.

A trip generation model utilizes the information from land use, population, and economic forecasts as a basis for estimating the number of trips that will originate or terminate in each TAZ for different purposes (i.e., home to work, home to shopping, etc.). Trips are estimated for a zone based on several characteristics associated with the type of zone considered.

Given this trip data for each zone, a trip distribution model specifies the destination for origin and destination trips estimated in the TAZ by the trip generation model. Determination of a destination may be based on size or distance of the potential destination zones. The result is a distribution of the originating trips to match the terminations defined by the trip generation model.

In order to gauge the impact on the various modes of transport it is necessary to specify the mode of transport used in each trip (e.g., transit, public transport, private vehicle, etc.). This decision on mode choice is a function of the attractiveness of the mode influenced by such factors as the cost and time of travel, as well as the characteristics of the traveller and/or transport system. Given knowledge of the origin, destination, and mode for each trip, the path each trip uses must be determined using a traffic assignment model. Routes are determined through an iterative process to achieve equilibrium between travel demand and travel supply (Usher, 2001).

Different spatial and land use dynamics models have been developed. For example, at different scales a dynamic simulation model for land use changes was developed at the regional level in Africa (Stéphenne and Lambin, 2001), at a country level the Environment Explorer model was developed for the Netherlands (Engelen et al., 2003), the SLUETH model was established for studying the impact of planning and transport construction for Portuguese cities of Lisbon and Porto (Silva and Clarke, 2002). Two approaches are mostly used for dynamic simulation models; these are Agent based modelling and Cellular Automata (CA) (Barredo and Demicheli, 2003; Batty, 2003).

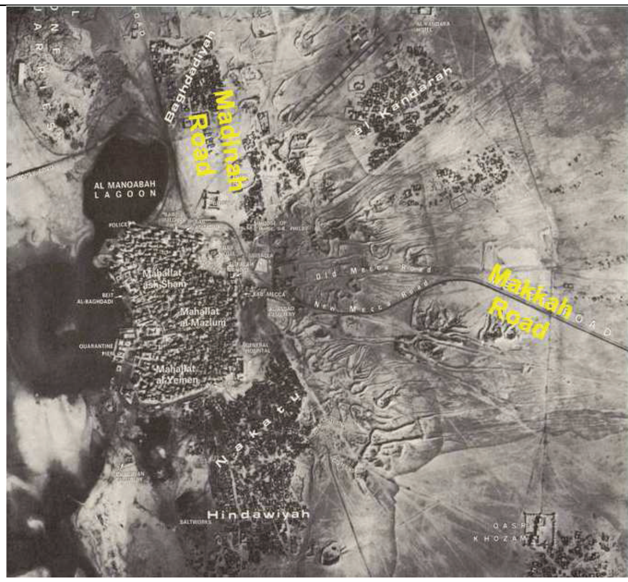
In recent years, land use change models are being developed to support policy decision making (Van Delden and Engelen, 2005). Metronamica is an integrated land use and transport framework developed with the aim to explore the effects of policy options on the socio-economic and physical environment basis at different spatial and temporal resolutions and to built awareness, learning, and discussion prior to the decision making (RIKS, 2005). Applications of METRONAMICA have shown the ability to support the analysis of socio-economic and environmental policies and their associated temporal and spatial dynamics (Engelen et al., 2003).

1.2. Study Area

Saudi Arabia, which is the biggest country in the Gulf and the first oil producing state, experiences rapid urban growth. Riyadh, Jeddah, Madinah, Dhahran, and Makkah are the major urban centers since 1973 (Mandeli, 2008). The National Population Census of 2004, shows rise in population of Saudi Arabia from 16.94 million in 1992 to 22.7 million in 2004, an increase of 5.72 million (33.8%)—an annual rate of growth equal to 2.4% (MOEP, 2004). Saudi Arabia faces high urban growth rate and transport problems. Lack of planning framework and weak city institutions that could not direct growth which led to sprawl development also the road network and utilities were rapidly extended with high financial outlays (Al-Hathloul and Mughal, 2004).

Jeddah is the second largest populated city after Riyadh (the capital), exceeding three million and considered the commercial capital of Saudi Arabia. The city of Jeddah is located on the west coast of the Kingdom at latitude 29.21 north and longitude 39.7 east of the Red Sea and surrounded on the east by Tihama plains. The city occupies 1,200 square kilometres in the Western Province on the coast of the Red Sea (Municipality, 2004).

a) Geographic location of Jeddah



b) The historic center Jeddah city (Source: Bill Hillier)

Figure 1.1: a) Geographic location of Jeddah (en.wikipedia.org/wiki/Jeddah) b) The historic center Jeddah (source: Bill Hillier)

Jeddah city started as a small fishing village within a wall. In 1947 the fortified wall of Jeddah city was destructed which lead small village growing to a modern metropolis having a population of 35,000 (Mandeli, 2008). The population increased to 150,000 in 1961 with annual growth rate of 11%. In 1982, the population rised from 1,000,000 to 1,600,000 in 1990 (Al-Hathloul and Mughal, 1991). Population of Jeddah city in 2002 was estimated as 2,560,000 with growth rate from 0.9% in 1940 to 6.3% in 2002. The strength of the economy and growth in population are increasingly straining the City's transport system. Congestion is now a common occurrence on Jeddah's streets and the duration of congestion is lengthening. Jeddah is car dominated with residents using private autos for 93% of trips (IBI, 2007).

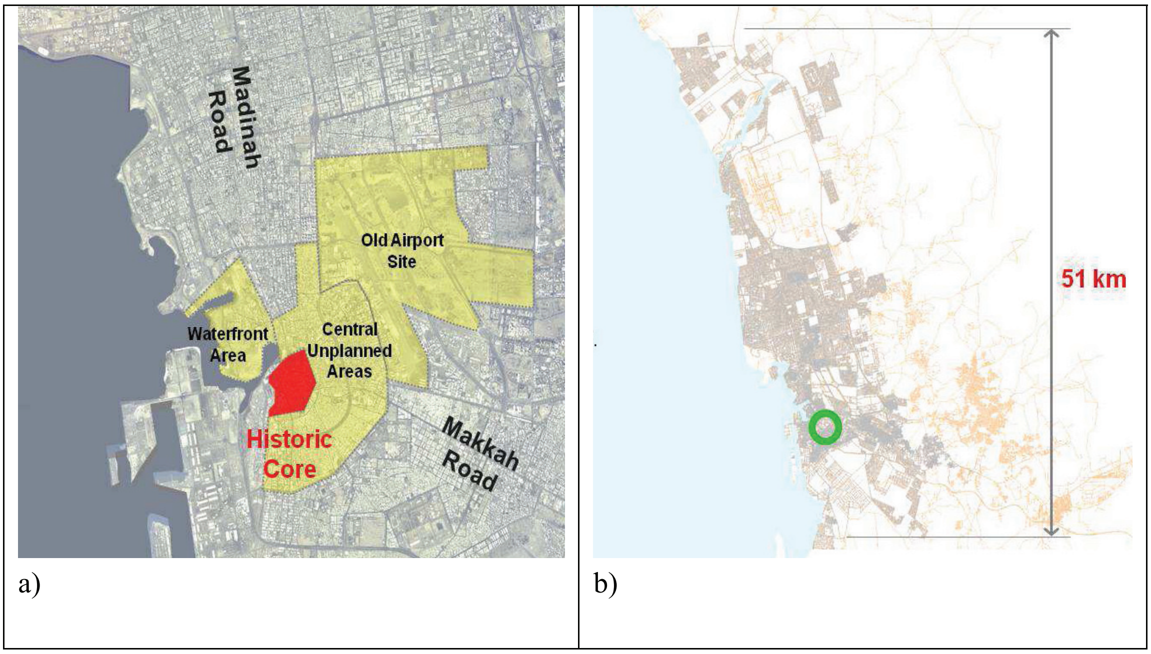


Figure 1.2: a) The current situation Jeddah city, b). The city expands 51 km north to south (source: Bill Hillier)

The main factors causing population growth in Jeddah have been internal migration, external migration, increase in economy, increase in the number of Muslim pilgrims and decrease in mortality rate (Municipality, 2004). However, the destroying of the wall was the beginning of Saudi Arabia's prosperity and turning point of the city's growth (Mandeli, 2008). It is the entry point for the pilgrims to visit the holy place Mecca and Medina. Moreover, population growth and the suburban in the Jeddah city has led to long distance travel pattern that has increased the dependence on private vehicles for commuting purpose to achieve the goal of activity.

The presence of these factors as they were and their interactions over space and time are more important in determining the growth and development of Jeddah (attained so far and the probable future pattern). These primary factors include-natural (locational) factors, economic (oil) factors, institutional factors, the role of planning, and dynamic population. The secondary factors include government foresight, commercial and housing pressure, and the influence of the urban highway system on commercial development (Abdu et al., 2002).

Urban land use data quantification is done using remote sensing in a context related to urban transport resulting from urban change. The quantification involves extraction of information about urban form (density, compactness, travel mode, etc.) and its impacts on transport. Through literature it is found that research is needed on the relationship between transport and urban change. Researches have been carried out on the causes and effects of the relationship on urban change and transport. The modelling of interaction between transport and urban change, particularly in the context of cities such as Jeddah, is a new field of research. This field will be explored in this thesis.

1.3. Research Problem

Jeddah over the past few decades has been facing uncontrolled land use change and consequent problems in transport such as congestion, air pollution and decline in public transport levels. To understand these dynamics, methods are necessary that can help in understanding this process of change better to improve urban policy making. Such modelling requires spatial and non-spatial data. This data is not readily available for which remote sensing is a suitable tool. Therefore, this research studies a model that can help in understanding these issues which is based on spatial temporal dynamics and the use of remote sensing data.

1.4. Research Objectives and Questions

Main objective

1. To develop a spatial temporal model of urban growth and transport in Jeddah

Sub objectives

1. To understand the relationship between urban growth and transport

   Q1. What are the methods to study the relationship between urban growth and transport?
   Q2. What is the potential of using Remote Sensing and GIS in quantifying the dynamics of transport?

2. To prepare spatial temporal data for transport

   Q1. How has transport infrastructure changed spatially and temporally in Jeddah?
   Q2. What are the inter-related factors between urban growth and transport for Jeddah?
   Q3. What are the exogenous factors that affect the transport in Jeddah city?

3. To setup a dynamic transport model in Metronamica

   Q1. How can transport be modelled in Metronamica?
   Q2. What are the data requirements for the transport model in Metronamica?
   Q3. How is the transport model linked to the urban CA model in Metronamica?
   Q4. What are the transport parameters in the four step model?
   Q5. How to validate the transport model in Metronamica?

4. To understand the interaction between transport and land use

   Q1. How is transport – land use interacting in Jeddah?
   Q2. What is the effect of urban land use change on transport?

1.5. Conceptual Framework

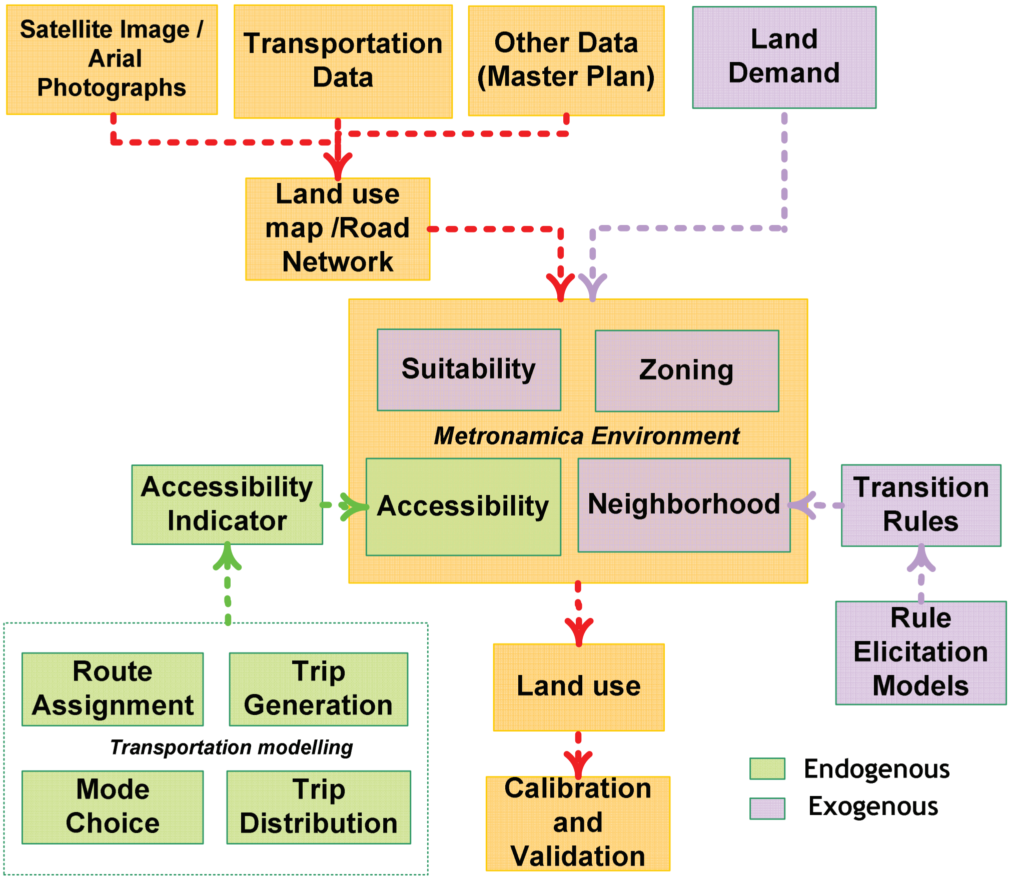


Figure 1.3: Conceptual Framework

1.6. Research Methodology

Figure 1.4 shows the procedure to be carried out for the research work in three phases. The research problem is identified through a literature review and the investigation of the real life problem for Jeddah city. To solve the problem, appropriate research objectives and questions have been defined. Different models of LU-T dynamics will be examined through literature on their temporal aspects, accuracy and consistency. The initial data available are from satellite images, aerial photographs, master plans, transport studies and socio-economic studies for Jeddah city. The list of available data is illustrated in table 1.1.

Table 1.1: Available data set for Jeddah city

Temporal T=Time	Date	Description	Built up area	Land use	Road Network	Population per District	Density per District	Road density Indicator	Accessibility Indicator	Congestion Indicator	Safety Indicator	Mode split Indicator
T1	1963	Master Plan										
	1964	Aerial Photo										
T2	1970	Aerial Photo										
	1973	Master Plan										
	1977	Thematic map										
T3	1980	Master Plan										
	1983	Thematic map										
	1983	Aerial Photo										
T4	1987	Master Plan										
T5	1993	Satellite image										
	1993	Census data										
	1994	Satellite image										
	1995	Satellite image										
	1995	Traffic situation study										
	1998	Satellite image										
	2002	Satellite image										
T6	2004	Master Plan										
	2004	Public transport plan										
	2005	Transport and Traffic plan										
	2005	Census data										
	2007	Satellite image										

Available Data

Process the Data

The secondary data available in tabular form for transport (Jeddah Transport Plan) for the year 1980, and population data for the year 1974, 1980, 2004. Socio-economic survey data for housing density (1971, 1980) with the family size, family income (1980), average dwelling size data, car ownership data for the year 1972 and 1980, total daily trips per transport mode (1980), origin destination matrix table for the year 1980.

In the second phase, the necessary data will be collected from the given data-set and processed in the data preparation stage to make it suitable for the analysis. The data will be prepared for four time steps (1964-1974, 1974-1984, 1984-1999 and 1999-2007). Several authors have described different methods for the analysis and classification of land use and road networks, for extracting information of the satellite images and aerial photographs using different techniques such as image classification, visual interpretation, object-oriented approaches which can be used for this research. The object-oriented classification can be applied for one year (base year 1964) as there is no data available for the population. It has shown that object oriented approach, using aerial photos provides greater accuracy for urban features such as roads, built-up area, simultaneously also applied in different fields such as urban environment, land use/land cover mapping, etc., (van der Sande et al., 2003; Mathieu et al., 2007; Cleve et al., 2008). These methods will be investigated and the appropriate method will be used. The transport data and the master plan are on paper which has to be prepared for the Metronamica environment. The information required will be of full structured data for the input in Metronamica.

The third phase is to set up the model for the analysis in Metronamica environment which consists of three steps. Initially, the land use data is setup, for accessibility the road network, base year land use and transport data is required which has been prepared in the previous studies. In case the dynamic land use data is not available as an input then, a simple land use model will be prepared for one time step with the available data. The second step is the input of the transport data that will interact with the land use. Finally, the input data for transport is implemented in the model to observe the interaction and to observe different land use processes affecting the transport system. The results of the model are compared and interpreted to identify the change in land use and transport. Conclusion and recommendations for the policy maker are drawn for the Jeddah city.

Context of Jeddah Land Use and Transportation (LU-T)