

Urban growth and transport: understanding the spatial temporal relationship

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Abstract

Transport and urban growth are strongly related. In fact, there is a reciprocal relationship between transport and urban growth. To understand this relationship, it is necessary to analyze urban spatial temporal changes and their related causes and effects. In this paper, an extensive evidence-based and scientific description of the relationship between urban growth and transport is presented. This relationship is specifically explored for Jeddah city, Saudi Arabia, applying spatial temporal analysis techniques from remote sensing and Geographic Information Systems. Spatial and statistical analyses have been used to analyze and relate urban growth and transport spatial temporal indicators. Results indicate a strong reciprocal relationship between urban growth and transport in Jeddah city. It is found that transport infrastructure expansion strongly correlates with population growth, spatial expansion and land use change. Results also reveal that population growth has increased urban trips and the consequent travel demand, and there is imbalance between travel demand and transport infrastructure supply which explains the increase in congestion. This study also points out a strong significant influence of transport infrastructure on spatial temporal expansion and land use change. It is found that highways and main roads have stronger influence on spatial expansion and land use change in comparison with secondary roads. Although, this study provides significant information for transport and urban development policies, further research is



encouraged to use spatial statistical analysis and dynamic modelling to study the reciprocal relationship between urban growth and transport.

Keywords: urban growth, transport, spatial temporal analysis, indicators, remote sensing, GIS, Jeddah city.

1 Introduction

In 2004, over 48% of the world's population estimated in urban areas, and by 2030 this figure is predicted to increase to 61% United Nations [1]. Accordingly, urban areas will continually witness a rapid urban growth that will impose further challenges to urban planners. Urban growth is not emerges phenomena that can be observed directly in urban areas. In fact, variety of factors trigger urban growth: transport and communication, [2–4]; internal and international migration, [5]; public policies, [6, 7] and globalization of economic activities [8–10]. Understanding urban growth, its drivers and the future impact on the urban environment is of prime concern to urban planners Al-Ahmadi *et al.* [11].

Transport plays a vital role in urban development. Transport systems provide essential mobility options for people and goods and influences patterns of growth and the level of economic activity through the accessibility it provides to land (Meyer and Miller [12]). Urban growth and transport are strongly related issues. On the one hand, transport infrastructure attracts urban development, on the other hand, urban growth and population cause an increase in travel demand and thereby an increase in the requirement for transport infrastructure. Previous studies have focused mainly on the causes and effects of transport and urban growth.

In general, there is a lack of research on the mutual relationship between urban growth and transport, while less attention has been paid to the spatial temporal aspects of this relationship. Understanding the transport and urban dynamics increasingly becomes a necessary condition for developing urban development strategies [13–18]. To provide a better understanding of this relationship, this paper analyzes this for the case of Jeddah city, Saudi Arabia. Initially, this paper provides an extensive evidence-based and scientific description of the relationship between urban growth and transport. Thereafter, it strives to relate and analyze the relationship between urban growth and transport through spatial temporal indicators using statistical and spatial analyses. These spatial temporal indicators of urban growth and transport have been developed and quantified using remote sensing and GIS techniques.

2 Literature review

Urban areas are in their nature dynamic, complex structures and are pertinent to the growth in different terms physical, economic and population which so called urban growth. Urban growth is a complex process that involves spatial temporal changes of urban areas socio-economic and physical components Han *et al.* [15]. These changes are catalyzed by many drivers and underlying factors. Among these, transport is considered one of the main factors of urban growth. Advances



in the transport system have reduced the cost of commuting within urban areas and encouraged urban scattering, [19, 20]. Equally, transport infrastructure expansion has stimulated urban growth and land use changes, [2–4, 16].

At the same time, urban growth affects transport. Urban growth patterns configure urban spatial structure and thus influence transport. Urban growth not only increases travel demand, [21–23] but also, causes infrastructure pressure and consequently traffic congestion, [16, 24, 25]. Therefore, urban growth is strongly related to transport with reciprocal causes and effects. Causality, reciprocal effects, and reciprocal causes are apparent characteristics of urban growth and transport relationship. However, the relationship could be inferred at four main interacted aspects: transport infrastructure, travel demands, population and land use change, fig. 1.

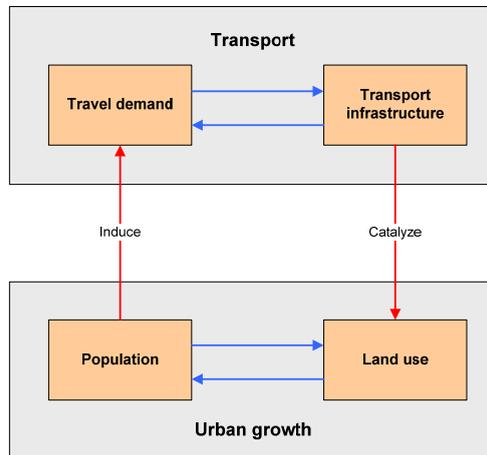


Figure 1: Conceptual reciprocal relationship of urban growth and transport.

In general, previous studies have focused only on the aspects of causes and effects of transport and urban growth relationship. However, spatial temporal processes of this relationship have not been addressed before. To address this, quantification of the spatial temporal situation of urban growth and transport has to be carried out. Integration of remote sensing (RS) and geographic information system (GIS) techniques and the establishment of appropriate indicators provide the capacity to quantify this intrinsic relationship between urban growth and transport.

3 Methodology

3.1 Study area

Jeddah is the second largest city in the Kingdom of Saudi Arabia with a population exceeding three million. Jeddah is located on the West coast of the Kingdom at the confluence of latitude 29.21 North and longitude 39.7 East, in

the middle of the eastern shore of the Red Sea and surrounded by the plains of the Tahoma in the east, fig. 2.

The city of Jeddah has witnessed a dramatic increase in population, due to out-migration from villages and suburbs to the city in search of jobs and a better living. The strength of the economy and growth in population are increasingly straining the city's transport system. Jeddah is car dominated with residents using private automobiles for 93% of trips IBI [26]. The challenges of accelerated urban expansion, population growth and traffic congestion are predominant issues in Jeddah city today. The local government of Jeddah city, its transport planning department in particular, faces challenges in managing, and planning of the transport system in view of the urban expansion.

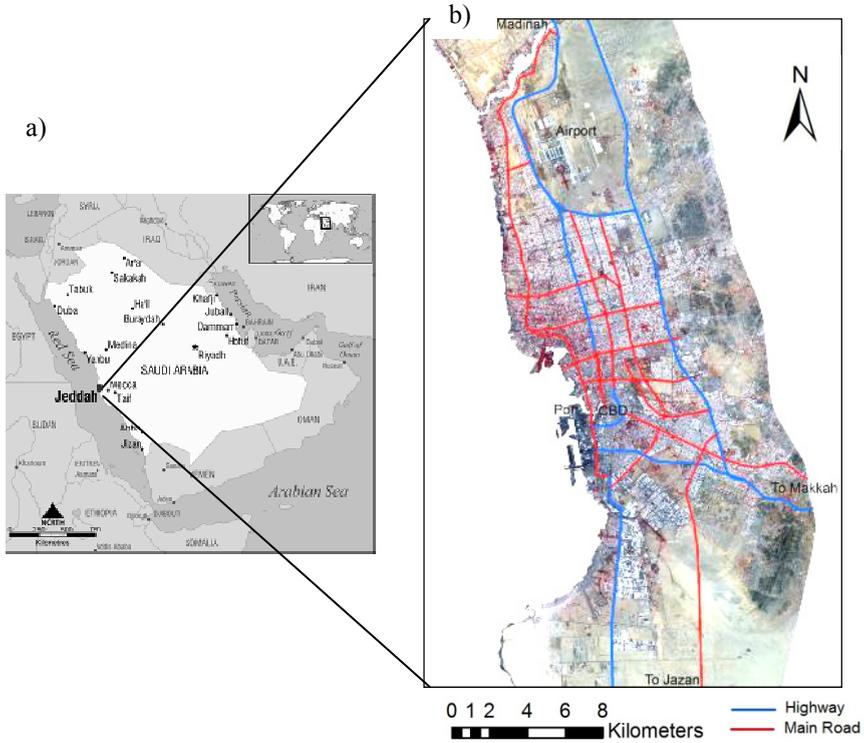


Figure 2: a) Geographic location of Jeddah (source: en.wikipedia.org/wiki/Jeddah) b) Jeddah city.

3.2 Data and image processing

This study utilizes a time series of Aerial photos and Satellite images for quantifying the spatial-temporal urban growth and transport system situation from 1964 to 2007. Aerial photos data of 1964, 1970 and 1980 have been used for the period before 1981. After that period, Spot Satellite images data of 1993,

2004 and 2007 have been used. Moreover, a variety of secondary data were collected to facilitate spatial temporal analysis of urban growth and transport in Jeddah city. These data include: Jeddah Master plans for year 1963, 1973, 1980, 1987, and 2004; Jeddah Transport Studies for year 1980, 1995, 2004 and 2007; Census data 1993 and 2005, Urban Growth Boundaries Study 1986 and Jeddah topographic maps 2000.

Firstly, image-to-image registration strategy has been adopted for georeferencing the various images using polynomial model second order function in ERDAS IMAGINE. Subsequently, a cooperative visual interpretation method is applied to quantify temporal urban land use and transport infrastructure as the main aspects of urban growth and transport in Jeddah city. The process started with unsupervised image classification to differentiate between urban built-up elements and none built-up elements using the ISODATA clustering algorithm in ERDAS IMAGINE. This process shows the spatial pattern of urban built up area in Jeddah city which facilitates a better acquaintance of the elements of built up area such as buildings, roads infrastructure and green areas. Next, land use and transport infrastructure reference data, from master plans and transport studies reports, were integrated with built up and none built images using overlay function in ArcGIS. Ten urban land use classes were specified to be extracted: residential, commercial, industrial, institutional, informal settlements, airport, port, roads, vacant lands and green areas. Thereafter, visual interpretation indicators such as pattern, shape, and size were extensively used in identifying features from aerial photographs and satellite imageries based on the field knowledge. Consequently, cooperative visual interpretation has been conducted incorporating all aforementioned process in ArcGIS v9.3 using on-screen digitizing, overlay tools and area of interest (AOI) functionality. Accordingly, land use and transport infrastructure maps of 1964, 1972, 1983, 1993 and 2007 have been obtained. Finally, accuracy assessments were performed based on a comparison of the cooperative interpretation outputs with the reference data. The average overall accuracy of land use maps produced by this approach was 90, 5%.

3.3 Statistical analysis

To examine the spatial temporal relationship between urban growth and transport, indicators represent the effective tool. Seven indicators have been developed to quantify the spatial temporal urban growth and transport situation as follows:

3.3.1 Annual urban spatial expansion index

$$AUSEI = \frac{(U_i - U_j) / (U_i \times 100)}{N_{i-j}} \quad (1)$$

where AUSEI is the annual urban spatial expansion index; U_i and U_j are the total urban areas of the study area in hectare at time i (former year) and time j (latter year); N_{i-j} is the total number of years from time i (former year) to time j (latter year).



3.3.2 Land use change index

$$LUCI = \frac{LU_{ai} - LU_{aj}}{LU_{aj}} \times 100 \quad (2)$$

where $LUCI$ is the land use change index; LU_{ai} and LU_{aj} are the total land area of land use class a in hectare at time i (former year) and time j (latter year).

3.3.3 Population density index

$$PDI = \frac{\sum P_i}{\sum U_i} \quad (3)$$

where PDI is the population density index; $\sum P_i$ is the total population at time i and $\sum U_i$ is the total urban land in hectare at time i .

3.3.4 Transport infrastructure expansion index

$$TIEI = \frac{\sum TIL_i - \sum TIL_j}{\sum TIL_i} \times 100 \quad (4)$$

where $TIEI$ is the transport infrastructure expansion index; $\sum TIL_i$ and $\sum TIL_j$ are the total transport infrastructure length of road class a in kilometres at time i (former year) and time j (latter year).

3.3.5 Road density index (area, per capita)

$$RDI_A = \frac{\sum RL_i}{\sum UA_i} \quad (5)$$

$$RDI_CAP = \frac{\sum RL_i}{\sum UP_i} \quad (6)$$

where RDI is the road density index; $\sum RL_i$ is the total road lengths in kilometres at time i ; $\sum UA_i$ is the total urban areas area in hectare at time i ; $\sum UP_i$ is the total urban population in the study area at time i .

3.3.6 Road area density index (area, per capita, residential)

$$RADI_A = \frac{\sum RA_i}{\sum UA_i} \times 100 \quad (7)$$

$$RADI_CAP = \frac{\sum RA_i}{\sum UP_i} \quad (8)$$

$$RADI_RES = \frac{\sum RA_i}{\sum URA_i} \quad (9)$$

where $RADI$ is the road area density index; $\sum RA_i$ is the total road areas in hectare at time i ; $\sum UA_i$ is the total urban areas area in hectare at time i ; $\sum UP_i$ is the total urban population in the study area at time; $\sum URA_i$ is the total urban residential area in hectare at time i .

3.3.7 Urban trips density index (per capita, residential)

$$TDI_CAP = \frac{\sum UT_i}{\sum UP_i} \quad (10)$$

$$UTDI_RES = \frac{\sum UT_i}{\sum UAR_i} \quad (11)$$



where $UTDI$ is urban trip density index; $\sum UT_i$ is the total number of urban trips at time i ; $\sum UP_i$ is the total urban population in the study area at time i ; $\sum UAR_i$ is the total urban residential area in square meter at time i .

Statistical analysis of the quantified indicators has been performed using SPSS 18 software. Pearson correlation analysis has been implemented to determine the reciprocal relationship between urban growth and transport indicators. The followings relationships have been examined:

- Relationship between transport infrastructure expansion index and various urban growth indices (population growth - spatial expansion-land use change).
- Relationship between road density index and spatial expansion.
- Relationship between road area density index and urban trip density index.
- Relationship between urban trip density index and population growth.

3.4 Spatial proximity analysis

To derive the influence of transport infrastructure in spatial temporal urban growth, spatial proximity analysis has been considered. Buffer analysis function of GIS has been used to analyze the effects of transport infrastructure in the spatial temporal urban growth of Jeddah city from 1964 to 2007. The process, depicted in figure 3, starts with extracting the temporal changes of spatial

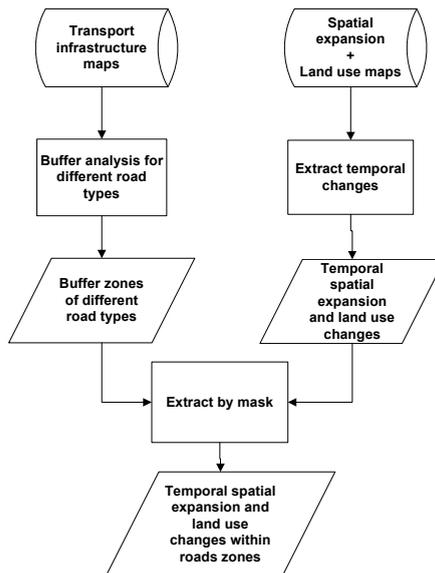


Figure 3: Spatial proximity analysis process.

expansion and land use at five periods: 1964-1970, 1970-1980, 1980-1993, 1993-2002 and 2002-2007. Conversely, buffer analysis of highways, main roads and secondary roads has been performed for the respective periods. Different buffer zones have been chronologically created as follows:

1. 400 m (highways and main roads) and 100 m (secondary roads).
2. 800 m (highways and main roads) and 200 m (secondary roads).
3. 1500 m (highways and main roads) and 300 m (secondary roads).
4. 2000 m (highways and main roads) and 400 m (secondary roads).
5. 3000 m (highways and main roads) and 500 m (secondary roads).

Subsequently, temporal changes of spatial expansion and land use have masked by the created roads buffer zones. Accordingly, the percentage of spatial expansion and land use change within different roads buffer zones can be quantified.

4 Results and discussion

During the period 1964–2007, Jeddah city witnessed a rapid population growth, spatial expansion, land use change and transport infrastructure expansion with rates of changes ranging from 0 per cent to over 100 per cent, indicating a wide variability across space, as depicted in figure 4 and table 1. Two types of urban growth can be distinguished in Jeddah: outward expansion and sprawl development.

Table 1: Spatial temporal changes.

Year	1964	1970	1980	1993	2002	2007
Spatial expansion (ha)	18315	18840	32500	40739	49700	54175
Population growth	149,000	381,000	960,000	2,046,000	2,560,000	3,247,134
Transport infrastructure expansion (km)	101	136	435	562	711	826
Transport infrastructure area expansion (ha)	510	680	2175	2560	3375	3950
Urban trips increase	-	293,370	798,430	-	5,863,475	6,051,883
Residential growth(ha)	1945	2018	8724	14921	19318	21365
Commercial growth (ha)	298	302	569	891	1355	1555
Industrial growth(ha)	26	30	1759	3793	6058	6976
Public places growth	282	678	7248	7321	8091	8244
Informal settlements growth(ha)	211	224	2137	2766	3351	4508

*- no data

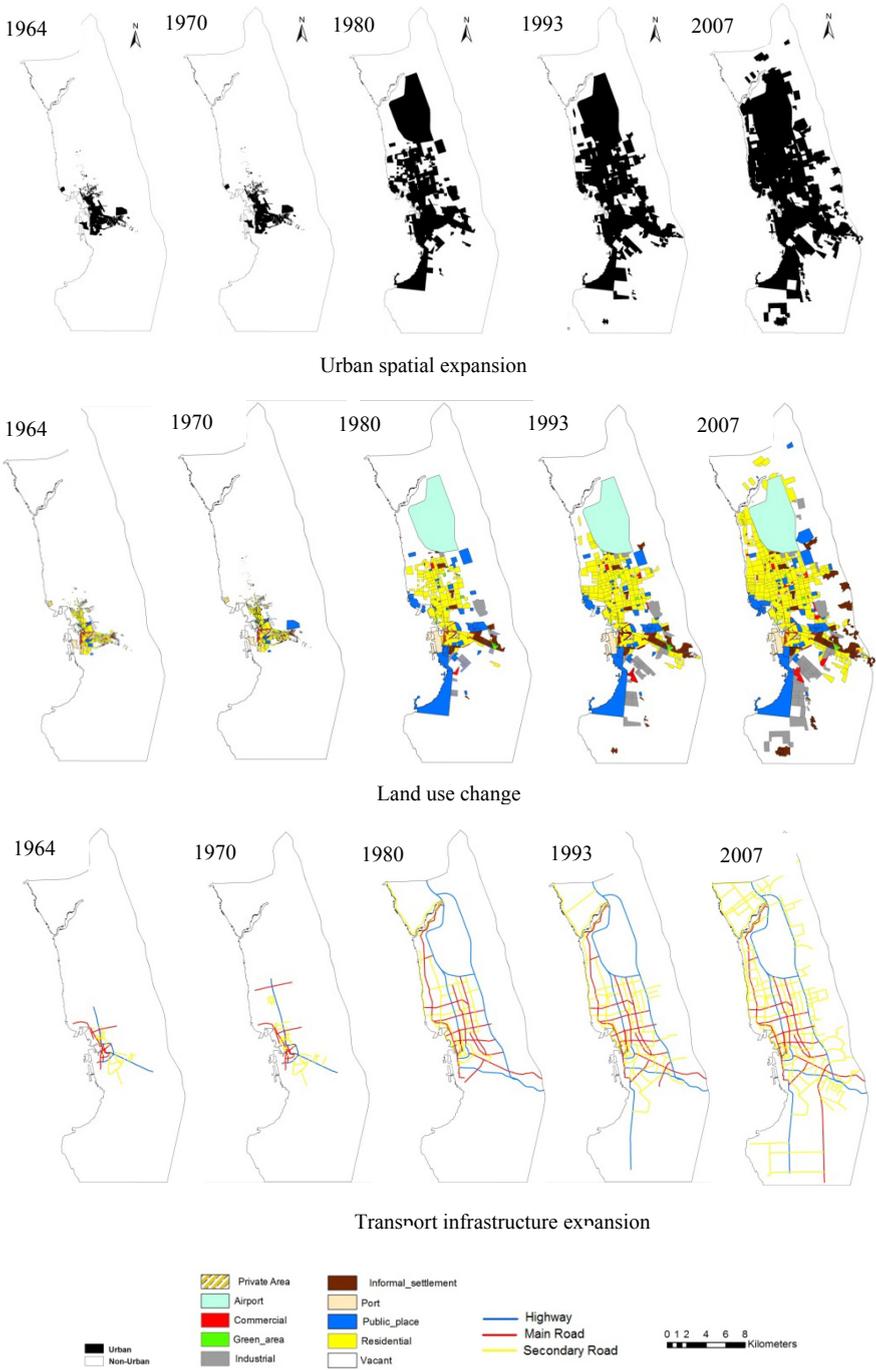


Figure 4: Jeddah spatial temporal changes.



4.1 Statistical analysis

Results indicate a strong relationship between urban growth and transport. This has been revealed by the significant positive correlation between transport infrastructure expansion and urban growth indicators, see table 2. It is found that transport infrastructure and population growth have a significant positive correlation of 0.984. Similar significant positive correlation is found between transport infrastructure and spatial expansion ($r = 0.997$) and land uses, table 2, implying that transport infrastructure expansion has promoted the various urban spatial expansion and land use change.

Table 2: Correlation between transport infrastructure and different urban growth indicators.

Urban growth indicators	Transport infrastructure expansion	
Spatial expansion	Pearson Correlation	0.997**
	Sig. (2-tailed)	0.000
Population growth	Pearson Correlation	0.984**
	Sig. (2-tailed)	0.000
Residential	Pearson Correlation	0.992**
	Sig. (2-tailed)	0.000
Commercial	Pearson Correlation	0.970**
	Sig. (2-tailed)	0.001
Industrial	Pearson Correlation	0.979**
	Sig. (2-tailed)	0.001
Public places	Pearson Correlation	0.935**
	Sig. (2-tailed)	0.006
Informal settlements	Pearson Correlation	0.995**
	Sig. (2-tailed)	0.000

** . Correlation is significant at the 0.01 level (2-tailed).

Moreover, there is a significant positive correlation ($r= 0.907$) between the road area density index (RADI_A equation7) and spatial expansion in Jeddah city. The total area devoted to transport infrastructure notably increased from 510 ha (2.8% of the total urban areas) in 1964 to 3950 ha (7.3% of the total urban areas) in 2007, wherein spatial expansion increased dramatically from 18,315 ha in 1964 to 54,175 ha in 2007, see table 1, representing an increase of 296%. This indicates that spatial expansion of Jeddah has been triggered by road density area increase. On the other hand, the increase in road area density coincided with spatial expansion. Hence, there is a reciprocal relationship between spatial expansion and road area density increase.

Correlation analysis also point out a significant positive relationship ($r=0.972$) between population growth and the number of urban trips in Jeddah city. This designates the strong relationship between population growth and travel demand. Furthermore, there is a significant negative correlation ($r= - 0.951$) between road density index (RDI equation 6) and urban trips density index (UTDI equation 11). Similarly significant negative correlation is found between the road area

density index (RADI equation 8) and urban trips density index (UTDI equation 11) ($r = -0.972$). This reflects the gap between the rapid increase of urban trips (as a result of population growth) and the expansion of transport infrastructure, table3, which reveals an imbalance between travel demand and transport infrastructure supply and the consequent increase in congestion. In fact, congestion is now a common occurrence on Jeddah's streets and the duration of congestion is lengthening, IBI [26].

4.2 Spatial proximity analysis

Results also point out the significant influence of transport infrastructure on the spatial temporal expansion and land use change. Table 4 shows that during the period of 1964–2007 about 5–84% of the total spatial expansion occurred in

Table 3: Urban trips density (UTDI), road density (RDI) and road area density (RADI) indicators.

Year	UTDI (trip/m ²)	RDI (km/person)	RADI (ha/person)
1964	-	0.00068	0.0034
1970	0.015	0.00035	0.0018
1980	0.009	0.00047	0.0023
1993	-	0.00027	0.0013
2002	0.030	0.00027	0.0013
2007	0.028	0.00025	0.0012

*- no data

Table 4: Spatial expansion percentages in different roads buffer zones.

Buffer	1964-1970	1970-1980	1980-1993	1993-2002	2002-2007	
	%	%	%	%	%	
1	400 m_Highways	6	9	16	10	12
	400 m_Main Roads	7	24	24	17	5
	100 m_Secondary Roads	5	6	8	12	12
2	800 m_Highways	12	19	29	20	23
	800 m_Main Roads	9	25	39	30	11
	200 m_Secondary Roads	7	12	17	23	25
3	1500 m_Highways	12	36	50	39	37
	1500 m_Main Roads	9	60	59	41	18
	300 m_Secondary Roads	7	17	25	32	37
4	2000 m_Highways	20	46	64	52	44
	2000 m_Main Roads	16	65	68	44	20
	400 m_Secondary Roads	77	23	33	40	48
5	3000 m_Highways	28	64	84	72	58
	3000 m_Main Roads	18	70	78	47	30
	500 m_Secondary Roads	78	27	40	47	57



transport infrastructure and spatial expansion. It is found that highways and main roads have stronger influence on Jeddah spatial expansion in compare with secondary roads in the different periods. It is noticed that the effect of roads increased with the increase of buffer size. For instance, during the period 1980 to 1993, the percentage of spatial expansion occurred in the 400m buffer zone of highways was 16%, wherein 84% occurred in the 3000 m buffer zone of highways. The highest effect of all roads types on the spatial expansion is found in the period 1980-1993 wherein 8-84% of spatial expansion occurred on different roads buffer zones. However in this period most of Jeddah roads have been constructed [table 1, 27, 28].

Spatial proximity analysis also indicates significant relationship between transport infrastructure and residential area expansion. Table 5 shows that around 7-100% of residential area expansion occurred in different roads buffer zones, which designate that transport infrastructure strongly triggered residential area expansion. It is noticed that highways and main roads have stronger influence on Jeddah residential area expansion. This is also reflected by the sprawl development of residential area in Jeddah city [27, 28].

Table 5: Residential area expansion percentages in different roads buffer zones.

	Buffer	1964-1970	1970-1980	1980-1993	1993-2002	2002-2007
		%	%	%	%	%
1	400 m Highways	32	8	17	12	18
	400 m_Main Roads	35	38	30	24	7
	100 m_Secondary Roads	31	12	12	15	17
2	800 m_Highways	69	19	33	25	36
	800 m_Main Roads	35	67	49	45	14
	200 m_Secondary Roads	42	23	23	30	34
3	1500 m_Highways	69	43	56	43	60
	1500 m_Main Roads	35	90	72	64	25
	300 m_Secondary Roads	42	33	33	43	50
4	2000 m_Highways	96	57	67	58	70
	2000 m_Main Roads	77	95	82	68	30
	400 m_Secondary Roads	66	43	44	54	63
5	3000 m_Highways	100	79	86	73	82
	3000 m_Main Roads	87	99	94	72	45
	500 m_Secondary Roads	69	51	53	63	74

5 Conclusion

Results indicate a strong reciprocal relationship between urban growth and transport in Jeddah city. It is found that transport infrastructure expansion strongly correlates with population growth, spatial expansion and land use change. On the contrary, urban spatial expansion and residential area growth are catalyzed by transport infrastructure expansion. It is noted that population growth have increased urban trips and the consequent travel demand. Moreover, results reveal imbalance between travel demand and transport infrastructure supply, which reflects the consequent increase in congestion.

This study also points out a strong significant influence of transport infrastructure on the spatial temporal expansion and land use change. It is found that highways and main roads have stronger influence on spatial expansion and land use change in comparison with secondary roads.

Although statistical and spatial analyses demonstrated significant information on the spatial temporal relationship between urban growth and transport, it provides limited explanation of the reciprocal relationship between urban growth and transport. Therefore, further research is encouraged to use spatial statistical analysis and dynamic modelling to study the reciprocal relationship between urban growth and transport.

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