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Integrated land use and transport planning in Jeddah: policy assessment and simulation

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Abstract

During the past four decades the city of Jeddah in Saudi Arabia, has witnessed a remarkable rapid urban growth. This has coincided with lack of a planning framework, weak institutional and poor policies, which have caused haphazard and interrelated land use and transportation issues. Current land use and transport planning policies and practice in Jeddah seem to focus on different visions, causing that neither land use nor transport issues are dealt with effectively or efficiently. To prevent dealing with these issues in isolation, Jeddah's urban planners require methods of integrated land use transport planning that can cope with the dynamics of Jeddah's urban growth. Dynamic land use and transport interaction models provide a rich method to deal with this. Therefore, in this study a CA-based Land-Use Transport Interaction (LUTI) model was used to assess and simulate different (proposed) land use and transport policy interventions in Jeddah city over a period of 20 years (2011-2031). The impact of both isolated and integrated policy interventions on land use and transportation were explicitly simulated in the model. The results show that the dynamic model provides a useful tool for simulating the various planning visions in the city. As such, it provides an innovative and proactive land use transport planning approach to face land use and transportation challenges in the early planning stages, and facilitates shared visions; policies and integrated strategies that in turn may provide a more sustainable land use and transport future for Jeddah city.

Keywords: Jeddah; urban growth; transportation; land use change; policy intervention; cellular automata

1. Introduction

Saudi Arabia has experienced high urban growth rates over the last six decades. Particularly, the major cities in Saudi Arabia such as Riyadh, Jeddah and Dammam have experienced rapid population increases (Al-Hathloul and Mughal, 2004). The proportion of the urban population, compared to the total Saudi population, has increased from 21% in 1950 to 58% in 1975 and 81% in 2005 (Al-Ahmadi et al., 2009). This huge population increase has created an excessive spatial expansion and consequent transportation infrastructure demand in these cities (Al-Hathloul and Mughal, 1991; Al-Hathloul and Mughal, 2004). This imposes constant and complex urban planning challenges to the local authorities.

Jeddah, the second largest city of Saudi Arabia, experienced a rapid urban growth, spatial expansion and transportation infrastructure expansion over the last 40 years with rates of change ranging from 0% to over 100 throughout the city indicating a wide variability across space and complex urban dynamics. Jeddah's population grew rapidly from 147,900 in 1964 to 3,247,134 in 2007. In contrast, Jeddah urban mass has expanded dramatically from 18,315 ha in 1964 to 54,175 ha in 2007 (Aljoufie et al., 2011). This has coincided with lack of an integrated planning framework, weak institutional and poor policies that have caused haphazard and interrelated land use and transportation issues. Jeddah's dramatic transportation infrastructure expansion has stimulated urban sprawl and lop-sided development (Aljoufie et al., 2012a). However, this expansion in infrastructure has not been able to accommodate increases in travel demand, hence causing high levels of congestion. Conversely, Jeddah's enormous spatial expansion has caused large changes in the daily share of travel modes. Current land use and transport planning practice in Jeddah municipality cannot keep up with rapid urban growth and consequent land use and transport interaction issues. Planning and policy practice focus on separate visions, causing that specific land use or transport issues are dealt with in isolation. Transport planners focus on solving transport problems and improving the transport system with little attention for the spatial distribution of land uses. On the other hand, land use planners focus on confronting urban growth and land use issues without attention for its effect on transport demand. The use of integrated land use transport decision support tools for policy intervention analysis, scenario-building and prediction in the early land use and transport planning stages may alter this situation. Yet, such integrated land use transport planning process is still absent in Jeddah municipality planning and policy practice.

Land use transport interaction (LUTI) models facilitate the study of the complicated mutual interaction between land use change and transportation and the future impact of different urban development strategies, plans and policies on the urban environment. Recently urban cellular automata (CA) models of land use are coupled with transportation models and have been integrated into larger urban simulation models (Iacono and Levinson 2009; RIKS, 2010). CA provides a dynamic modelling environment that is able to model the complex land use and transportation changes and their mutual interaction. Because of its simplicity, flexibility, intuitiveness, and its ability to incorporate the spatial and temporal dimensions of the various land use processes (Santé et al., 2010), this approach has been extensively utilized to study the spatial temporal process of land use changes (i.e. White and Engelen, 1997; Batty, 2000; Liu and Phinn, 2003; Al-Ahmadi et al., 2009). CA has the capability to mimic the spatial processes of the urban systems including land use. In this study the CA-based Land-use Transport Interaction model Metronamica-LUTI has been applied, calibrated and validated to the case of Jeddah as reported in the previous research paper Aljoufie et al., (2012b). This model has shown the capabilities to replicate historical and current urban growth, land use and transportation changes and their mutual interaction.

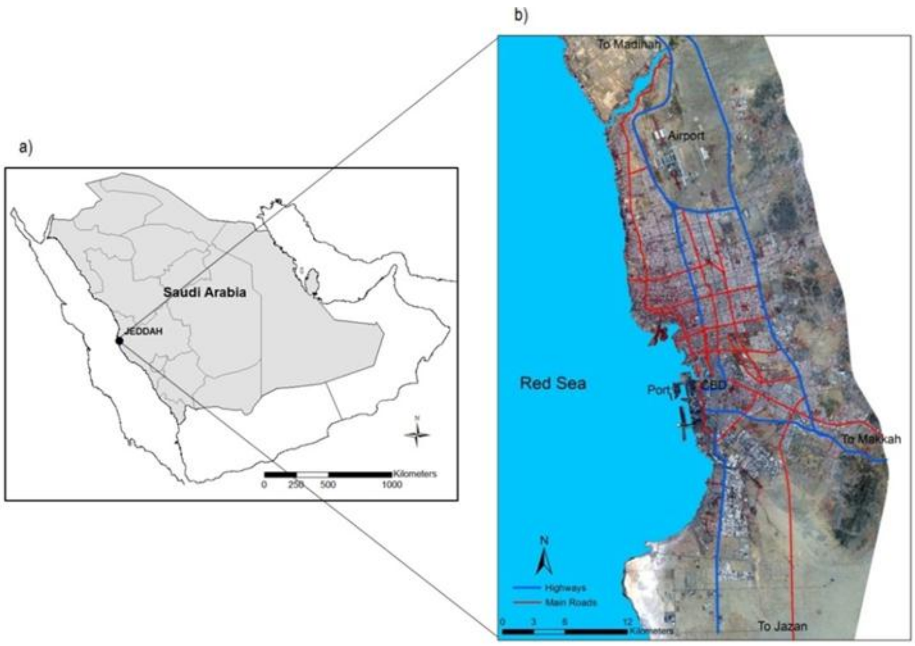
This paper introduces a pro-active integrated land use transport planning approach for the city using the Jeddah Metronamica-LUTI model (Aljoufie et al., 2012b). The paper starts with describing the challenges of urban growth, land use changes and transportation challenges in Jeddah city. Then the paper describes the methods used for pro-active integrated land use transport planning approach which encompasses: (1) Jeddah Metronamica-LUTI model; and (2) common land use and transportation policy interventions. Afterwards the paper focuses on Jeddah planner's reactions to the methods and the results based on the following criteria: (1) the plausibility of the model predictions; (2) the relevance of the indicators produced by the model and (3) the relevance of the approach to the spatial and strategic planning, land use planning, transport planning and decision making process.

2. Jeddah city

2.1. Location and Geographical context

Jeddah is the second largest city in the Kingdom of Saudi Arabia after Riyadh (the capital). Jeddah locates on the west coast of the Kingdom at latitude 29.21 North and longitude 39.7 East in the middle of the Red Sea’s eastern shore (Fig. 1). Originally, Jeddah city started as a small fishing village within a wall. In 1947 the fortified wall of Jeddah city was destructed (Mandeli, 2008) which assisted Jeddah’s growth from a small village to a modern metropolis (Figure 1).

Figure. 1. a) Geographic location of Jeddah in Saudi Arabia; b) Jeddah city



2.2. Urban growth

Jeddah has witnessed a dramatic increase in population in the past few decades. Jeddah’s population grew rapidly, from 147,900 in 1964 to 3,430,697 in 2010 with an increase of 2,320%. The total urban mass has also expanded dramatically from 18,315 hectare in 1964 to 54,175 hectare in 2007 (Aljoufie et al., 2012). Between 1970 and 1980, Jeddah has witnessed a rapid increase in urban mass, which was escalated significantly by the country’s oil boom. The spatial expansion in this period was affected by the rapid increase of transportation infrastructure, the new location of the airport and topographical factors (Aljoufie et al., 2012a). Two patterns of development can be distinguished: outward expansion and sprawl development. Thereafter, from 1980 to 1993 Jeddah has experienced a tremendous urban expansion that coincided with an economic slowdown (Al-Hathloul and Mughal, 1991). The pattern of the city's growth and development at this stage followed the changing rhythm of both the economy and the population (Aljoufie et al., 2012a). Leap-frog development and scattered development patterns have therefore occurred. Then, from 1993 to 2002, Jeddah has witnessed significant spatial expansion with a typical infill development pattern, sprawl and leap-frog development along the transportation infrastructure. After that, from 2002 to 2007, Jeddah has experienced a significant infill development pattern (Aljoufie et al., 2012a).

2.3. Land use issues

Jeddah's land use has experienced significant changes during the period 1964-2007. Residential development, the dominant land use in Jeddah city, has dramatically increased from 1945 hectare in 1964 to 21,365 hectares in 2007 (Aljoufie et al., 2012a). Residential low density land use has constantly dominated residential development in Jeddah city.

Conversely, commercial land use has notably increased from 298 hectare in 1964 to 1555 hectare in 2007, along highways, main roads and significant secondary road intersections (Aljoufie et al., 2012a). Industrial land use, in contrast, changed drastically and followed up a planning scheme that took place in the locations that had been proposed by the master plans (Aljoufie et al., 2012a). However, after 1993, commercial development has rapidly scattered in ribbon development pattern along highways and main roads creating secondary centres. Moreover, public places considerably grew and developed mostly in the locations proposed by the master plans.

The dynamics of urban growth in Jeddah has changed as the city expanded, and hence, the city expanded through the emergence of both formal and informal settlements (Mandeli, 2008). Informal settlement type of land use increased rapidly along main roads at the east of Jeddah and near the airport in the north with the sprawl pattern of development (Aljoufie et al., 2012a). This has affected spatial growth, spatial structure and transportation system of Jeddah city and inflicted enormous challenges to Jeddah Municipality.

These dramatic changes in Jeddah's land uses have posed huge pressures on transportation, public services and utilities. This has also been compounded by weak planning framework, urban management and policies. Therefore, Jeddah city faces key challenges that overshadow city growth and land development (Abdulaal, 2012).

2.4. Transportation issues

Jeddah underwent tremendous transportation infrastructure expansion from over the last four decades. Transportation infrastructure increased rapidly from 101 km in 1964 to 826 km in 2007 (Aljoufie et al., 2012a). Most of the transportation infrastructure in Jeddah was constructed during the period from 1970 to 1980 (Al-Hathloul and Mughal, 1991; Daghistani, 1993). The transportation infrastructure has predominantly been shaped around a linear grid pattern with satisfactory connectivity. However, highways and primary roads remained steady from 1980, with only minor changes in 1993 and 2007 (Aljoufie et al., 2012a).

Moreover, Jeddah's mode share has dramatically changed as a result of excessive spatial expansion and lack of dominance of highway infrastructure development. The share of daily trips by non-car modes has consequently decreased to single digit percentages only. Cars are dominating the share of daily trips by 93% in 2007, coming from 50% in 1970 (MOMRA, 1980; Municipality of Jeddah, 2006; IBI 2007). In contrast, public transportation daily trips decreased, from 19% in 1970 to 2.3% in 2007 (MOMRA, 1980; Municipality of Jeddah, 2006; IBI 2007). Similarly, the trip share of other modes, including cycling and walking trips, has significantly decreased from 31% in 1970 to 4.6% in

2007 (MOMRA, 1980; Municipality of Jeddah, 2006; IBI 2007).

The rapid population growth has increased the total number of daily trips from 293,370 trips in 1970 to 6,051,883 trips in 2007 (MOMRA, 1980; IBI 2007). Economic growth has also increased the car ownership level from 50 cars per thousand persons in 1970 to 299 cars per thousand persons in 2006 (Municipality of Jeddah, 2006). The number of daily trips per person has increased from 0.77 trips/person in 1970 to 1.86 trips/person in 2007 (Aljoufie et al., 2012a). These high mobility levels throughout the city have put a very high pressure on the existing transportation infrastructure (Aljoufie et al., 2012a). As a result, congestion is a common occurrence on Jeddah’s streets in morning and evening commuter peak periods and even outside these hours (IBI, 2007; Municipality of Jeddah, 2009). The average speed on the highways and the primary roads and traffic safety are decreasing; while transportation emissions and average trip time are constantly increasing (Municipality of Jeddah, 2009; Aljoufie et al., 2012a).

2.5. Planning and policies

Over the last five decades, several master, structure and local plans have been prepared for Jeddah (1962, 1970, 1980, 1987, 1995, and 2005). Notwithstanding the importance of these plans, the challenges of urban growth, land use changes and transportation continue. This is catalysed by the limitations on both conventional urban planning practices and lack of appropriate and coordinated policy (Mandeli, 2008).

Land grants and interest free loans policies have accelerated the spatial expansion and land use changes. Moreover, land subdivision policies and processes have led to a large-scale activity throughout Jeddah city (Abdulaal, 2012). It has favoured residential low density development which stimulated the expansion of land uses in different directions far from Jeddah city centre with sprawl patterns of development and consequently caused changes in travel behaviour. Moreover, zoning regulations and their enforcement have caused an imbalanced spatial distribution of population density. Designating and agglomerating high density zones in areas drawn to the city centre and the surrounded inner urban areas have dramatically increased traffic flow in these areas and consequently caused traffic problems such as congestion.

In contrast, transportation policies, such as the prevalent transport infrastructure provision policy, contributed to the current challenges. Even though this policy has provided a greater accessibility to different land uses; however after some time lag it induced travel demands and thus increases congestion. Moreover the mainly car-oriented policies such as the development of arterial gridiron patterns of transportation networks and lack of public transportation and non-car modes policies have contributed to the current transportation situation in Jeddah city. In fact, there is a gap between urban development policies and transportation policies. Urban development policies have not addressed the consequences in transportation. Conversely, transportation policies have not encompassed the long term effects of different policies on urban development.

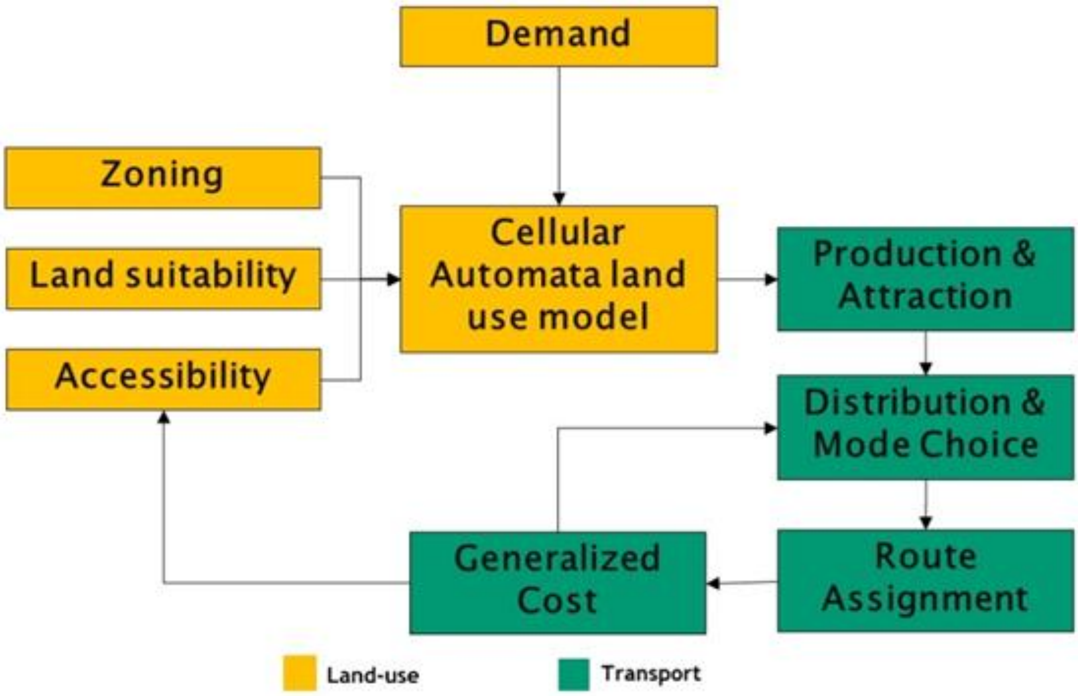
To confront these challenges, Jeddah municipality has prepared a draft strategic plan in 2009. The plan aims to confront growth and urban development challenges including land use and transportation issues till 2029. This strategic plan has recommended a sequence of sustainable smart growth, a compact urban form and transit oriented development; promotion of public transport; a connected transportation network including a new ring road in the eastern development spine and increase and decentralized the commercial and industrial development. However, as yet the future impacts of these (combined) plans have not been assessed and analysed for Jeddah municipality.

3. Simulating integrated land use transport planning

3.1. Jeddah CA-based Land-Use Transport Interaction model

The Metronamica - LUTI has been applied, calibrated and validated to the case of Jeddah in a previous research paper Aljoufie et al., (2012b). This model integrates a CA land use model and a four step transport model into one system, as shown in Figure 2. It includes a constrained CA model (White et al., 1997) that uses 3 types of land-use classes: (1) function land uses, (2) feature land uses, and (3) vacant land uses.

Figure2. Metronamica-LUT structure



Each time step, representing one year, function land uses are allocated to those locations that have the highest potential for this land use. Potentials are computed for each cell and for each land use, based on transition rules:

$$Pot_{k,i} = f(Rand_{k,i}, Acc_{k,i}, Suit_{k,i}, Zon_{k,i}, Neigh_{k,i}) \quad (1)$$

where $Pot_{k,i}$ is the potential for land use class k in cell i, $Rand_{k,i}$ is a scalable random perturbation term for land use k in cell i, $Acc_{k,i}$ is the accessibility for land use k in cell i, $Suit_{k,i}$ is the physical suitability for land use k in cell i, $Zon_{k,i}$ is the zoning status for land use k in cell i, and $Neigh_{k,i}$ is the neighbourhood effect for land use k in cell i.

Conversely, Metronamica-LUT contains a four-step transport model. Each simulation year land use change map is used as input to the production and attraction stage of the transport model. The transport model produces the zonal accessibility, which is calculated using a potential accessibility measure that quantifies for each transport analysis zone (TAZ) and for each function land use the accessibility level based on the discounted generalized costs to move from the TAZ to all other TAZs, also considering the function land use types in these TAZs. This zonal accessibility is then input for the calculation of the total cell-based accessibility which is used as one of the drivers for land use allocation in the CA land use model. More specifically, this accessibility is calculated as a function of three types of accessibility:

$$Acc_i = f(LAcc_i, IAcc_i, ZAcc_{zi}) \quad (2)$$

where $LAcc_i$ is the local accessibility in cell i, which is a function of the distance to the nearest road and the importance of that particular road, $IAcc_i$ is the implicit accessibility in cell i, which is a function of the land use on that specific location, and $ZAcc_{zi}$ is the zonal accessibility of the transport zone where cell i belongs to, which is obtained from the transport model. These three types of accessibility are combined in one single value in the range between 0 and 1 (the highest level of accessibility equals 1) for each land use and each cell, expressing the effect that the transport has on the possible future occurrence of that land use in that cell. Both the land use model and transport model use yearly time steps, and therefore each year the result from the land use model feeds into the transport model and vice versa, creating a feedback loop between both systems.

The Metronamica-LUTI model accordingly generates different spatial policy-relevant land use and transport indicators per simulated year including: land use change, spatial expansion of the urban area, accessibility maps and the level of congestion per network link. The model also generates a set of non-spatial policy-relevant land use and transport indicators including: land use statistics, average accessibility, total congestion, total number of trips, modal split, average trip distance and average trip duration.

In this study, 11 land use classes have been considered and categorized into vacant (i.e. vacant lands), function (i.e. residential low density, residential medium density, residential high density, commercial and industrial) and feature (i.e. airport, port, public places, green areas, informal settlement, and outside simulation area) land uses. In addition, 311 TAZs were considered in the transport model. Daily trips were divided over three periods: morning rush hours, afternoon rush hours and rest of the day, while four trip purposes were distinguished: home to work, work to home, work to work and others (social, shopping and leisure). Two transport modes that dominate daily trips in Jeddah have been considered in this study: private car and public transport.

The model was calibrated for the period 1980 to 2007 (t0-t1) and independently validated for the period 2007-2011 (t1-t2) using a stage-wise sequential calibration and validation framework (Aljoufie et al., 2012b). Calibration and validation results show a fitted integrated land use and transportation model.

3.2. Land use and Transport Policy Interventions Tests

In 2011, several sessions were held in Jeddah city with land use planners, transport planners, strategic planners, transport modellers and academics of King Abdul Aziz University. In these sessions the Jeddah Metronamica-LUTI model was introduced and the model and parameter settings as well as the historical trends and business-as-usual and other simulation results verified. The business as usual reference case reflects the consequences of current trends. Then, the common separate land use and transport policy interventions in land use and transport planning practice at Jeddah municipality have considered and tested over the period of 20 years (2011-2031) based on current trends of population, jobs, and land use changes. Thereafter, integrated land use and transport policy interventions have considered and tested to demonstrate the effect of integrated LUT approach. The four policy interventions tests are further explained as followings:

- Business As Usual (BAU)

This is the reference case that reflects a continuation of current land use changes and transport trends and their interactions for the period 1980 to 2011. It assumes no other land use and transport policy interventions are introduced in the future. All public places and green areas are protected from future urban development.

- Encouraging Public Transport (PT)

The promotion of public transport is a major concern in Jeddah municipality, transport planning department in particular. It is one of the main policy recommendations of both 2005 Jeddah structure plan and 2009 Jeddah strategic plan. However, the consequences of this on spatial expansion, land use changes and transport are not predicted yet. This intervention aims to reflect the consequences of transport policy interventions on the future urban growth, land use and transport system of Jeddah. It assumes an improvement in the quality of public transport and a rigorous restriction on private car use. It also includes an increase of travel cost for car that targets restricting car trips and encourages public transport trips from about 6.4% in 2011 to 30% in 2031 as proposed by the 2005 Jeddah structure.

- Transit Oriented Development (TOD)

In order to control urban growth and land use changes and to stimulate public transportation use, strategic planning department in Jeddah municipality has proposed both a compact growth and a transit oriented development (TOD) in the 2009 Jeddah strategic plan. It aims to minimise the use of expensive land, minimise additional land take outside the urban area, minimise the quantity and cost of infrastructure required to serve the city, maximise accessibility, maximise the catchment population and consequent viability and efficiency of public transport, maximise the ease and effectiveness of walking as a mode of transport. This policy intervention is designed to reflect the consequences of a compact growth and a transit oriented development as proposed in the 2009 Jeddah strategic plan. This policy intervention includes a stringent land residential development zoning for the next 20 years (Figure 3). It includes also a stringent commercial zoning into different new strategic centres as proposed by the strategic plan (Figure 4). In addition, industrial development is restricted to the eastern spine.

- Integrated Land use Transport Intervention (ILUT)

To demonstrate the consequences of integrated land use transport intervention policy, the proposed promotion of public transport and transit oriented development interventions have been included and simulated simultaneously as an integrated LUT intervention policy.

4. Planner and expert interviews

At the end of the several sessions that were held in Jeddah in 2011, land use planners, transport planners, strategic planners, transport modellers and academic experts of King Abdul Aziz University were asked to fill out questionnaires and were interviewed again to evaluate the validity of the proactive integrated LUT planning approach based on the followings criteria:

- The plausibility of the model predictions.
- The relevance of the indicators produced by the model.
- The importance of the proactive integrated LUT planning approach to the strategic planning, land use planning, transport planning and decision making process.

Figure3. Growth boundaries (Jeddah strategic plan, 2009)

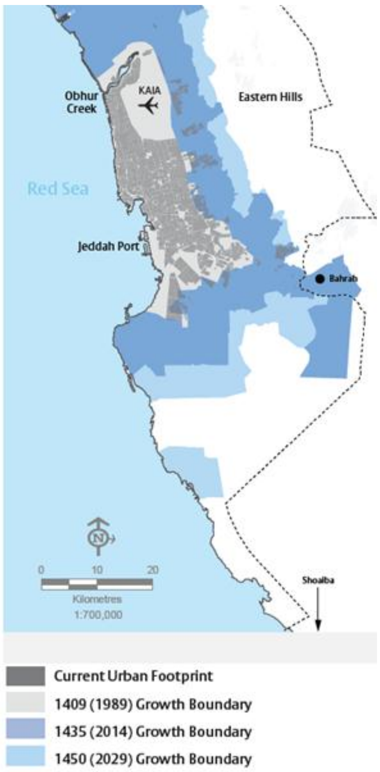


Figure4. Proposed commercial centres (Jeddah strategic plan, 2009)

Each of these criteria was divided into several questions. These questions were designed as closed-ended based on multiple choices answers. The plausibility of the model predications is based on the BAU reference case of land use changes and transportation characteristics from 2011 to 2031. Participants were asked to assess the plausibility of the predicted land use changes (pattern and densification) and transportation indicators in 2031 based on BAU reference case. Participants were given detailed results and numerical answers range between 0% and 100% (the highest plausibility equals to 100 %).

On the contrary, the relevance of the indicators produced by the model and the importance of the approach to different planning practice and decision making processes is based on the simulation of the common separate land use and transport policy interventions and integrated land use transport policy interventions between 2011and 2031. Participants were asked to assess the relevance of the indicators produced by the model to strategic planning, land use planning and transportation planning. Participants were also asked to assess the importance of the approach to different planning practice and decision making process. Detailed results of different policy interventions of land use changes and transportation indicators were given based on Likert scale answers.

5. Results

5.1. Urban growth and land use dynamic

Table 1 and Figure 5 show the simulated land use changes and urban growth patterns for the year 2031 under the four policy interventions. The results indicate that land use changes and urban growth patterns differ significantly between the various policy interventions. The BAU reference case shows a high spatial expansion, less densification and rapid changing of residential low density land use at the cost of vacant urban peripheries in the north and north eastern parts of Jeddah city. The PT intervention shows similar spatial expansion and land use changes as compared to BAU case, more spatial expansion and land use changes (24% spatial expansion for PT compared with 23.7% for BAU). This indicates that public transport encouragement stimulates more spatial expansion and land use changes.

In contrast, the TOD and ILUT interventions depict a huge densification, compactness and a lesser spatial expansion as compared to BAU and PT. The TOD intervention is expected to minimise the use of expensive land and minimise additional land-take outside the urban area. Residential low density is expected to decrease and is restricted to the 1988 urban growth boundary, while residential medium and high density residential land use are expected to significantly increase in the planned zones. As compared to the BAU and PT interventions, commercial land use is predicted to considerably increase under the TOD and ILUT interventions into the different new strategic centres as proposed by the 2009 strategic plan. Results also indicate that the ILUT intervention depicts slightly more spatial expansion and land use changes as compared with TOD intervention (14.6% and 14.5% respectively). This effect is particularly observed in the residential high density land use (106.8% compared with 106.6% respectively) and commercial land use (42.4% and 41.2% respectively). This also indicates that public transport encouragement stimulates more spatial expansion and densification.

Table 1. Predicted land use changes and spatial expansion under the four policy interventions

Land use	**2011**	**BAU 2031 change%**	**PT2031 change%**	**TOD2031 change%**	**ILUT2031 change%**
Vacant	67930	-19.94	-19.91	-12.2	-12.1
Residential Low Density	12370	40.5	41.8	-13.6	-13.6
Residential Medium Density	7041	71.8	71.9	75.3	75.3
Residential High Density	3426	47.0	48.1	106.6	106.8
Commercial	3045	7.8	7.8	41.2	42.4
Industrial	7826	20.3	20.3	20.1	20.1
Airport	9629	0	0	0	0
Port	760	0	0	0	0
Public place	8172	0	0	0	0
Green area	300	0	0	0	0
Informal settlement	4395	0	0	0	0
Spatial expansion %	**56964**	**23.7**	**24.0**	**14.5**	**14.6**

5.2. Transport indicators and accessibility

Table 2, Figure 6 and Figure 7 depict the simulated pattern of traffic flow and the characteristics of Jeddah's transport system in 2031 under the four policy interventions. The BAU case depicts the critical transport situation in 2031 with the highest congestion level, average trip distance, average trip duration and lower accessibility. The transport policy intervention in the PT shows lesser congestion and lower average trip duration as compared to BAU, but also a lower accessibility and high average trip distance. The PT scenario also shows a significant change in the modal split with a high increase of the public transport modal share to 30.3% and a considerable decrease of the car modal share to 69.7%.

Figure5. Predicted urban growth and land use changes under the fourpolicy interventions.

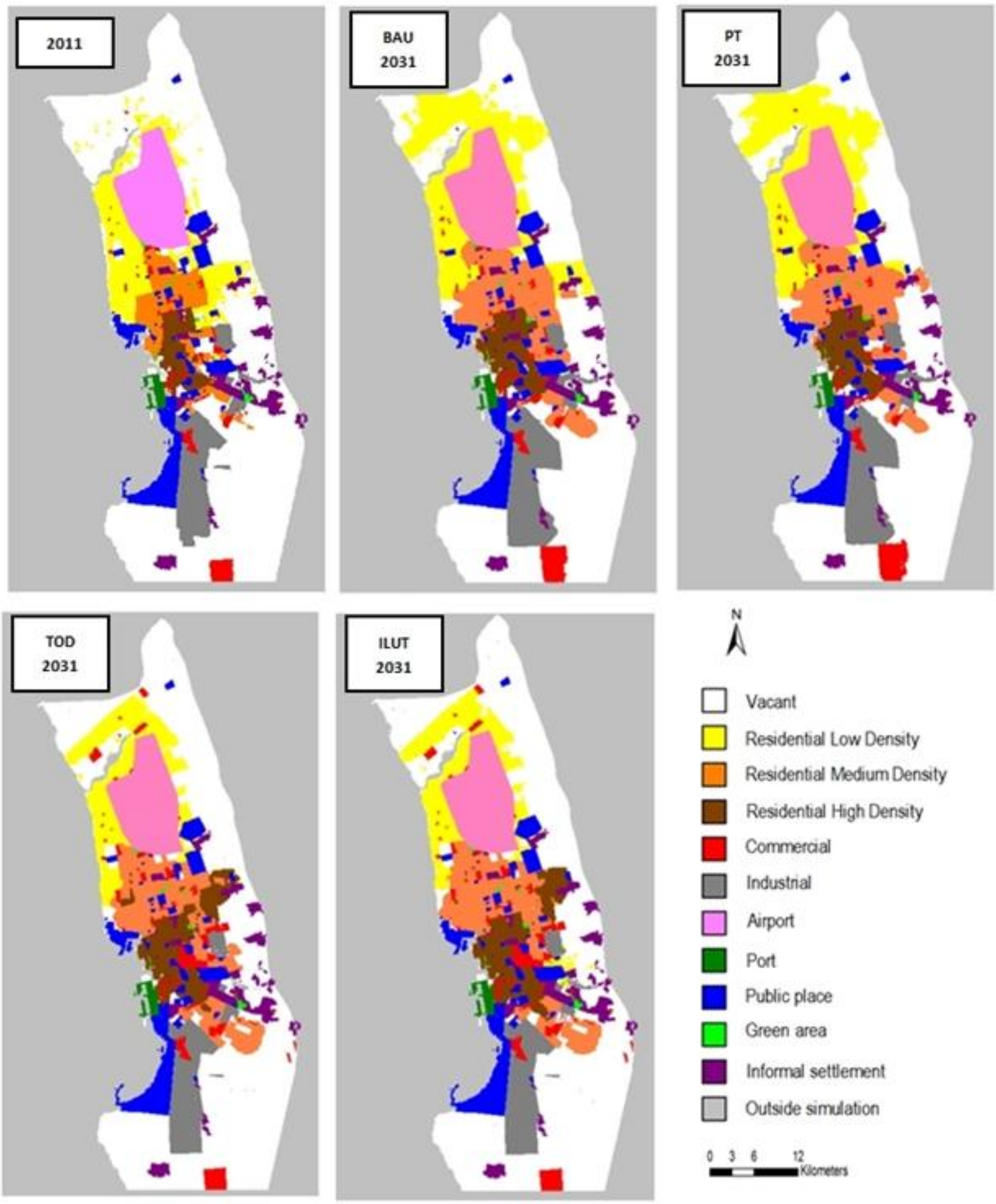


Table 2. Predicted transportation characteristics under the four policy interventions

Indicator	2011	BAU 2031	Change %	PT 2031	Change %	TOD 2031	Change %	ILUT 2031	Change %
Total number of trips	5,752,719	10,251,583	78.2	10,315,472	79.3	10,556,314	83.5	10,623,114	84.7
Car %	92.0	87.0	-5.4	69.7	-24.2	87.0	-5.4	69.0	-25.0
Public transport %	8.0	13.0	62.5	30.3	278.8	13.0	62.5	31.0	287.5
Average accessibility	0.57	0.47	-17.5	0.46	-19.3	0.56	-1.8	0.55	-3.5
Average trip distance car (km)	7.9	8.3	5.1	8.4	7.0	6.9	-12.1	7.1	-9.6
Average trip duration car (min.)	37.8	44.4	17.5	40.4	6.9	48.7	28.8	38.7	2.4
Daily Congestion (km)	556.0	825.0	24.0	723.0	30.0	690.0	24.1	627.0	12.8

Although the PT intervention relieves the severe congestion in some urban areas as compared to the BAU situation, the traffic volume and congestion levels change still critical (Fig 8).

The TOD intervention exhibits less congestion as compared to both BAU and PT interventions. The TOD intervention clearly causes a significant drop in the average trip distance (6.9 km in 2031). This stimulates the use of other sustainable transport modes such as walking and cycling. Moreover, the TOD intervention maximizes accessibility as compared with BAU and PT interventions (Table 2). The TOD case also shows no change in the modal split as compared to the BAU case. Interestingly, this indicates that transit oriented development does not directly lead to a shift in public transport in our model. This is likely caused by the absence of any restriction policy on car use, the dominant transport mode in Jeddah in this case. Accordingly, this policy intervention shows the highest average trip duration as a result of the urban densification. Therefore, TOD must be integrated with other transport interventions to have much more transport improvements. The combined TOD and PT interventions in the ILUT intervention exhibits much more transport improvements in 2031 as compared to the previous three individual cases (Figure 6, Figure 7 and Table 2). This intervention depicts a considerable decrease and change of congestion levels as a result of the transport policy intervention that is integrated with TOD. Congestion in this case is limited to the highly dense districts of urban areas only, while the intensity of severe congestion is reduced considerably (Figure 6). ILUT also shows a very notable decrease of average trip duration to 38.7 minutes in 2031. Moreover, it exhibits a significant change in modal split with a high increase of the public transport mode share to 31% and considerable decrease of car mode share to 69%.

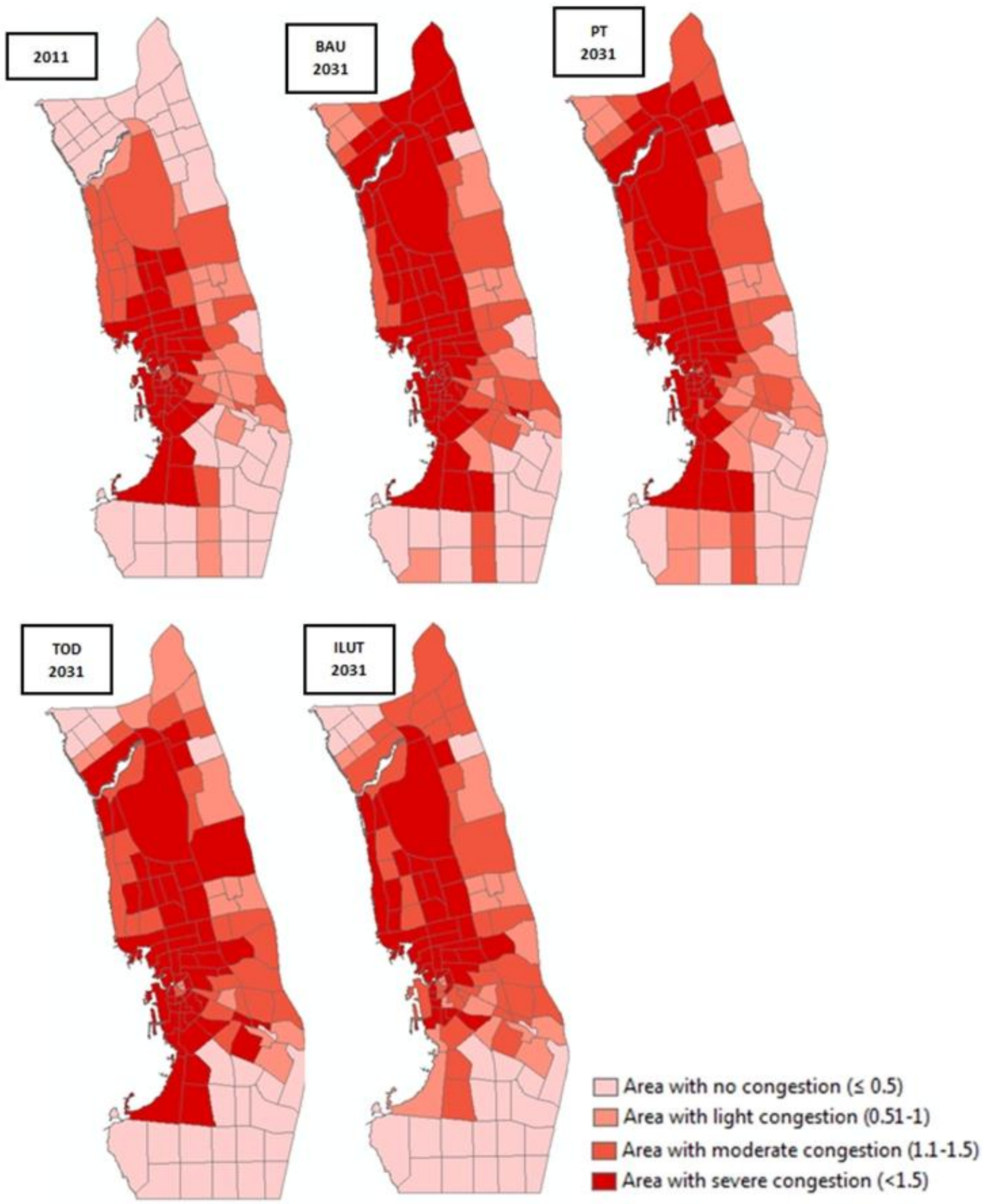
5.3 Validity of the approach

The findings of the expert group discussions indicate that they think that Jeddah Metronamica-LUTI model provides plausible changes land use and transportation over space and time. Both the land use patterns and densification in 2031 based on the BAU reference case were seen as high plausible by the participants. Some land use planners were critical about the land use pattern prediction in 2031at a very fine resolution (parcel level) in some areas of interest. Obviously, the accuracy of land use pattern decreased over time. However, the same participants were still seeing a high plausible (80%) land use pattern at the macro level.

The transportation indicators based on the BAU reference case were also seen as highly plausible by the participants. One transport planner thought that the average trip distance was less reasonable than other indicators. This can be related to the boundaries of study area hence the more far off urban fringes (or nearby cities) are not included in the model. Nevertheless, the relative distance between zones is still very reasonable as indicated by the most of participants.

Figure 6. Predicted traffic flow (V/C) change at network level under the four policy interventions.

Figure 7. Predicted congestion level change at district level under the four policy interventions.



In general, participants indicate a high relevance of the indicators produced by the model to strategic planning, land use planning and transportation planning. The ability of model to produce different indicators was considered highly relevant to policy test and assessment. Most of the participants agreed on the high relevancy of the produced indicators in land use and transport policy interventions test. Some participants thought that absolute average trip distance and absolute average trip duration is less useful as a policy test measure. Obviously, the relative average trip distance and duration (trip distance /duration frequency distribution) is more favourable and relevant.

Findings also indicate a high importance of the dynamic simulation of the integrated LUT planning approach allowing for spatial – temporal analysis of the planning tasks. The ability of the model to depict the impact of land use changes on transport and the impact of transport on land use changes was considered highly relevant. Thus, this approach is seen as very important to strategic planners, land use planners and transportation planners in order to develop shared visions, policies and integrated strategies.

6. Discussion

One of the key barriers to integration of land use and transport planning is the lack of tools that can support planners from both domains in developing shared visions and integrated strategies (te Brommelstroet and Bertolini, 2008). In this paper, we have eliminated these barriers by demonstrating the use of a CA-based Land-use Transport Interaction model in land use and transportation planning in Jeddah city. Different land use, transport and integrated land use transport policy interventions were analysed. The model has explicitly depicted the consequences of different policy interventions.

Results indicate that isolated land use and transport policy interventions in Jeddah city show a limited one directional improvement. In contrast, integrated land use transport policy interventions show an appropriate and feasible set of policy interventions in Jeddah city. Such interventions show more sustainable traffic and land use changes. These findings support the integrated land use transport planning perspective in fast growing cities.

Urban planners and policy makers require a simple measure to understand land use-transport policy implications. In particular, maps showing the differences in geographical indicators seem to help planners grasp the internal dynamics of the different policy interventions (Te Brommelstroet and Bertolini, 2008). The ability of model to produces different indicators was considered highly relevant by Jeddah strategic planners, land use planners and transport planners. The model provides explicit and simultaneous spatial indicators to understand different policy interventions implications in both land use and transport. The model produces temporal simultaneous land use map and traffic volume maps with different sets of quantitative indicators (Figures 5, 6, 7 and Tables 1 and2). It also generates other sets of spatial temporal indicators such as accessibility maps of dynamic land uses and total potential maps of dynamic land uses. Moreover, this model has a strong coupling with Geographic Information System (GIS) which facilitate a further analysis of the model outputs.

This study represents a useful case for integrated land use transport planning in Jeddah city. The ability of approach to depict the impact of land use changes on transport and the impact of transport on land use changes is highly relevant to Jeddah planning tasks. It provides an innovative dynamic land use transport planning approach to face land use and transportation challenges already at the early planning stages in Jeddah city. The minds of the planners in both domains (land use and transport) are still open in these stages, which are needed to come up with innovative ideas and shared concepts and visions (Te Brommelstroet and Bertolini, 2008). This approach is expected to relieve the conflict between land use and transportation plans and policies, and facilitates shared visions; policies and integrated strategies and thus provide a sustainable land use and transport future in Jeddah city.

7. Conclusion

Jeddah city has witnessed a remarkable rapid urban growth over the past four decades. This has coincided with lack of a good planning framework, weak institutional and poor policies that have caused haphazard and interrelated land use and transportation issues. Current land use and transport planning policy and practice in Jeddah municipality focus in on separate and isolated visions, meaning that specific land use or transport issues cannot be dealt with effectively. To actively prepare and face these issues, Jeddah municipality requires integrated land use transport decision support tools of policy intervention analysis, scenario-building and prediction that can be used in the early land use transport planning stages.

This paper therefore introduced a pro-active dynamic integrated land use transport planning approach for the Jeddah city using the Jeddah Metronamica-LUTI model. The consequences of different policy interventions on land use and transportation were explicitly depicted by the model. The results of an expert group meeting indicate that the model produces plausible results and that more appropriate (combined) policy interventions in Jeddah city should be developed, through which more sustainable traffic and land use patterns can be achieved.

Jeddah strategic planners, land use planners and transport planners, have indicated that the model provides highly relevant indictors and represents an important tool for integrated land use transport planning in Jeddah. Further research to analyse different policy interventions to examine the capability of this approach in other fast growing cities in the developing world is recommended.

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