Chapter 14

Relation Between Land Use and Transportation Planning in the Scope of Smart Growth Strategies: Case Study of Denizli, Turkey

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Additional information is available at the end of the chapter

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Abstract

In the decision-making process of planning residential areas in developing countries, importance of the commercial areas and need for a sustainable urban transportation infrastructure have generally been ignored based on several sociopolitical reasons. Meanwhile, decision-making periods of location choice and determining areal densities are conducted without quantitative spatial/technical analyses. Those urban matters bring along new planning paradigms like smart growth (SG) and new urbanism. SG is a land use planning paradigm which indicates that traffic problems should be minimized by transit alternatives, effective demand management and providing a balance between land use and transportation planning. This study aims to apply SG strategies to the land use planning process and evaluate the accuracy of land use planning decisions in the perspective of sustainable transportation. In order to reveal the effects of land use planning decisions on the available transportation infrastructure, two scenarios are investigated for 2030. In the first scenario *"do nothing"* option is considered, while the residential area densities and trip generation rates are regulated based on SG strategies in the second scenario. The results showed that the land use and traffic impact analyses should simultaneously be conducted before land use configuration process.

Keywords: Land use, smart growth, VISSIM, traffic simulation, transportation planning, spatial interaction

1. Introduction

Rapidly increasing population induces growing cities and increasing car ownership. Consequently, transportation and land use problems become significant issues due to their economical effects. Wey and Hsu [1] stated that urban sprawl and city congestion have become the inevitable development trend in the process of economic growth. Transportation and land use problems are getting inextricable issues simultaneously with the existing development trend.

Many researchers found that density is a significant factor of conversation of energy, and many studies found that access to high-capacity transit, incentives for development, balanced parking policy, mixed-use designs and jobs-housing balance are critical parameters of sustainability [2–7]. Transport-oriented problems and land use planning problems are directly interdependent fields and have a highly interrelated iterative interaction.

Interaction between land use and transportation is the basic factor for the trip generation. Transportation investments still strongly affect land use patterns, urban densities and housing prices [8]. Transportation systems primarily support sprawl [9]. To set up an effective transportation system, land use decisions have to be taken effectively and residential area densities have to be well arranged. Handy [10] stated that building more highways will contribute to more sprawl and lead to more driving. Building up a solitary transit-oriented system is not an exact solution. Conventional planning paradigm primarily builds the environment and afterwards tries to overcome the existing transportation problems [11]. Effects of land use decisions which generate strong travel attractiveness should be measured in the planning process since land use decisions acquire an irreversible characteristic after construction period. The interaction between land use and transportation should be measured and managed through traffic impact analyses.

Effects of the increasing traffic volumes should be investigated by traffic impact analyses in order to find out whether the existing link capacities are convenient or not. Conventional land use planning paradigm is inclined to generate land use decisions by evaluating social and economical parameters [12]. Whereas, traffic impact analyses should be evaluated as one of the basic elements of land use planning parameter set. Those types of deficiencies bring along new planning paradigms such as new urbanism and smart growth (SG). The rise of new urbanism brings new energy and ideas to communities that commit to manage growth. Urban design hence becomes more visible within planning since the design is incorporated into growth management programs. Comprehensive planning also begin to connect more strongly with affordable housing advocates and public health professionals, broadening their focus beyond the more traditional set of issues revolving around land-use, transportation and the environment [13]. New urbanism is synonymous with SG, but there are significant differences. New urbanism was much more influenced by architects and physical planners, while the SG was launched from a community of environmentalists, citizen groups, transportation planners and policy makers [14].

Many urban problems have led to a more intelligent and sophisticated planning trend which directly effects urban sprawl. Those problems may be stated as air and water pollution, loss of open space and increased traffic congestion. The developing planning trend has been referred to as SG [15]. To prevent unplanned sprawl and negative effects, SG strategies, which promote mixed-use development, transit-oriented development and conditions amenable to walking and biking, have been developed [16].

Objectives of the SG strategies are diverse since there are different location specifications. However, the main axes of those objectives are protection of environmentally sensitive areas, support for further development of existing urban areas and preservation of open space. Truly intelligent SG should be quantifiably superior to any other proposed land development plan. However, a quantitative definition of the SG does not exist [15].

SG strategies aim to channel new development into existing urban areas and improve the viability of alternatives to the car [16]. SG principles have been applied to integrate land use and transportation planning [17]. This approach can be applied to solve planning and design problems in order to accelerate land use efficiency and manage growth (e.g., human population control). It also advocates compact, transit-oriented, walkable, bicycle-friendly land use, neighborhood schools, complete streets and mixed-use development with a range of housing choices [18]. The planning principles which are promulgated by the SG network have gained widespread recognition.

SG strategies may be evaluated in the process of land use planning since those paradigms seek to reduce the adverse impacts of current land use and transportation patterns and practices by preserving their benefits. This study tries to develop a land use planning model where SG strategies and traffic impact analyses simultaneously take place. A main signalized intersection serving heavy traffic volumes between three major arterials in Denizli, Turkey has been selected as the study intersection. The data including travel demand and land use plans have taken from Denizli Transportation Master Plan (DTMP) [19] and two scenarios are investigated for projection year. In the first scenario, the conventional land use planning decisions are applied while the SG strategies are taken into account in the second one. VISSIM traffic simulations are utilized for providing visual analyses and quantitative evaluations of the performance indicators.

2. Methodology and study area

2.1. Methodology

The main purpose of this study is to apply SG strategies to the land use planning process and evaluate the accuracy of land use planning decisions in the perspective of sustainable transportation. In this context a four-step land use planning procedure is proposed. The flow chart of the proposed procedure is given in **Figure 1**.

As can be seen in **Figure 1** that the proposed procedure starts with the initialization of the problem parameters. Land use pattern of the study area, travel demand between all origin–destination (O-D) pairs, transportation network characteristics such as link capacities, free flow travel times and signal timings for signalized intersections are provided in Step 1.

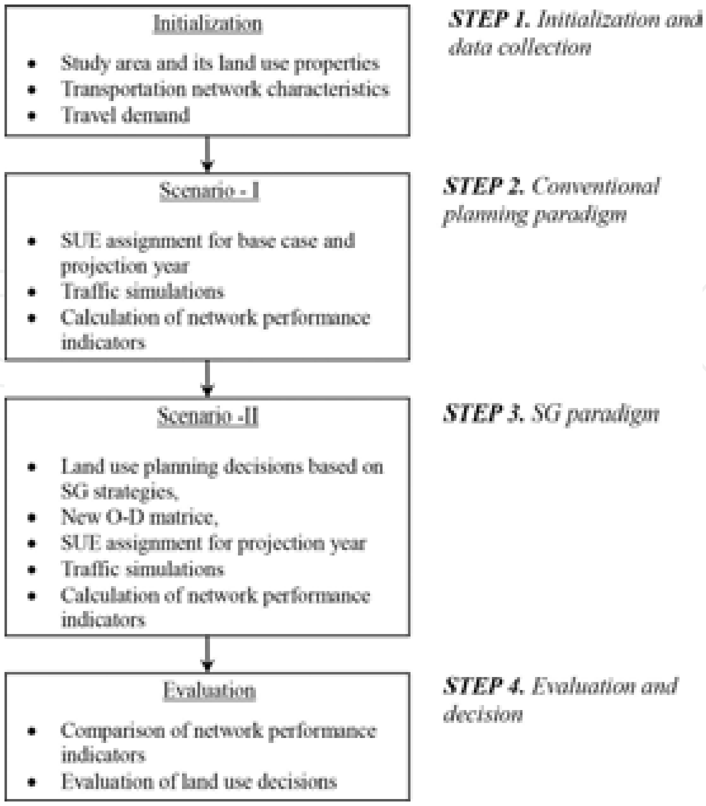

Figure 1. Four-step procedure.

In Step 2, Scenario-I that represents the conventional land use planning paradigm is analyzed. In this context, a traffic assignment is carried out in order to calculate the link traffic volumes. In the developed land use planning procedure, stochastic user equilibrium (SUE) traffic assignment is proposed since drivers' perception errors are taken into account while they make their route choice decisions.

Considering a road network with sets of nodes N, directed links A, O-D pairs W, routes P, the SUE link traffic volumes may be calculated by solving Eq. (1) [20].

$$\underset{\mathbf{v}(\psi)}{Minimise} \quad Z(\mathbf{v}(\psi),\psi) = -\mathbf{q}^{\mathrm{T}}\mathbf{y}(\mathbf{v}(\psi),\psi) + \mathbf{v}^{\mathrm{T}}\mathbf{t}(\mathbf{v}(\psi),\psi) - \sum_{a\in A}\int_0^{v_a(\psi)} t_a(\psi,x)dx \tag{1}$$

subject to

$$\mathbf{q} = \mathbf{\Lambda h}, \quad \mathbf{v}(\psi) = \boldsymbol{\delta}\mathbf{h}, \quad \mathbf{h} \geq \mathbf{0} \tag{2}$$

where $\mathbf{q}$ is the vector of O-D demands [q_w; $\forall\ w \in W$], $\mathbf{v}(\psi)$ represents the vector of link traffic volumes, $\psi$is the vector of signal timings, $\mathbf{h}$ is the vector of route traffic volumes [h_p; $\forall\ p \in P$], h_p is the traffic volume on route p, $\mathbf{y}(\mathbf{v}(\psi), \psi)$ represents the vector that consists of travel times on all routes [y_p; $\forall\ p \in P$], $\mathbf{t}(\mathbf{v}(\psi), \psi)$ is the vector of link travel times, [y_p; $\forall\ p \in P$] is the travel time along link a, v_a is the flow on link a, while $\mathbf{\Lambda}$ is the O-D/route incidence matrix [Λ_p; $\forall\ p \in P$] and $\boldsymbol{\delta}$represents the link/route incidence matrix where δ_{ap}=1 if link a is on route p and δ_{ap}=0 otherwise [δ_{ap}; $\forall\ a \in A$; $\forall\ p \in P$].

Eq. (1) can be solved by the path flow estimator (PFE) which is a traffic assignment tool using logit route choice model [21–25]. The solution procedure of PFE is given in **Figure 2**.

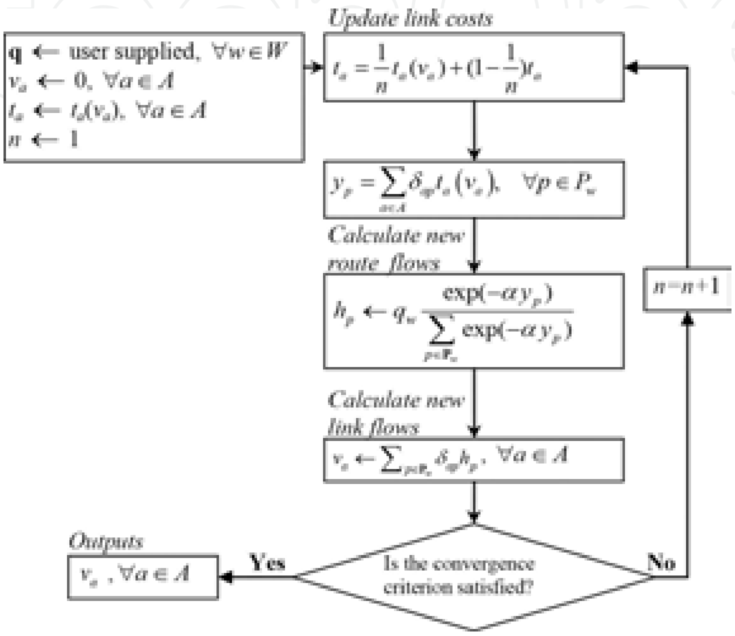

Figure 2. Flowchart of the PFE.

As can be seen in **Figure 2**, new route flows are calculated based on the logit route choice model. In this model, α is the dispersion parameter which controls the sensitivity of the route choice to the route travel times. Note that the convergence criterion κ that is based on flow similarity is used as given in Eq. (3) [26].

$$\frac{\sqrt{\sum_a \left(v_a^{n+1} - v_a^n\right)}}{\sum_a v_a^n} \tag{3}$$

In applications, the value of the convergence criterion for the PFE solution may be accepted as 0.01 [27, 28]. After obtaining the link traffic volumes, network performance indicators are calculated for base-case and projection year under Scenario-I. In this study, VISSIM traffic simulation software is used for both visual analyses of the traffic and quantitative evaluation of the performance indicators which are average delay time per vehicle (seconds), average speed (km/h), average number of stops per vehicles, average stopped delay per vehicle (seconds), total delay time (hours), number of stops, total stopped delay (hours) and total travel time (hours).

In Step 3, new land use decisions are taken based on SG strategies under Scenario-II. Then residential area densities are modified by considering the land use plan of the city. At the evaluation process, economical, social, spatial and cultural factors can be considered. Afterwards, O-D demand matrix is updated directly proportional to the new land use decisions and then a SUE assignment is carried out to calculate link traffic volumes for projection year. As it was done in Step 2, the traffic is simulated on the road network and the performance indicators are calculated for Scenario-II.

In Step 4, Scenario-I and Scenario-II are compared in terms of the network performance indicators, and the new land use decisions are evaluated.

2.2. Study area

Denizli is an industrial metropolitan city which is located at the Aegean Region of Turkey with a population of over 600,000 in central district. It is also a tourism city and consists of 80 traffic analysis zones which were the administrative neighborhood districts before new governmental regulations. The transport demand consists of mixed traffic which is supplied by private car, bus, minibus, service vehicle and taxi modes. Traffic problems increase in recent years in Denizli due to the high density of private car use [19]. The car ownership rate is about 22% which is about two times higher than the average car ownership in Turkey. The peak hour trips (07:00–09:00 a.m.) represent about 30% of the total trips which has been obtained by household surveys. The traffic analysis zones of the city are given in **Figure 3**.

Figure 3. Zonal layout.

Figure 3 shows the zonal structure of the city. Inherently, land use densities are relatively lower and the zone sizes are much larger at the outer boundaries of the city. The major traffic problems are intersection delays. Therefore, a main signalized intersection serving heavy traffic volumes between three major arterials has been selected as the field of study. The aerial pictures of the selected intersection are given in **Figure 4**.

Figure 4. Illustration of the study intersection **(a)** and queue occurrence **(b)**.

As can be seen from **Figure 4a** that the study intersection is a signalized roundabout with four entry lanes on each approach. **Figure 4b** shows the queue occurrence on an approach with three isolated lanes that join the downstream link right after the roundabout. It is obvious that the performance of the intersection will decrease and lead very high level of traffic congestion considering the increase in future travel demand.

3. Analyses

3.1. Scenario-I: Conventional transportation planning paradigm

In this section, an example application of the proposed land use planning procedure is given for the city of Denizli. Note that the data required for the application is taken from DTMP [19]. Projection year is taken as 2030 considering the 20 years projection period of the DTMP.

As it was explained in the previous section, land use pattern, travel demand between all O-D pairs, transportation network characteristics such as link capacities, free flow travel times and signal timings for signalized intersections are used to calculate the performance indicators of the road network. In this context, a SUE assignment has been applied in order to calculate the link traffic volumes for the base-case and the projection year under Scenario-I. Note that the analyses are carried out for the morning peak periods between 07:00 and 09:00 a.m. The resulting traffic volumes are shown on the road network for 2010 and 2030 are given in **Figures 5** and **6**, respectively.

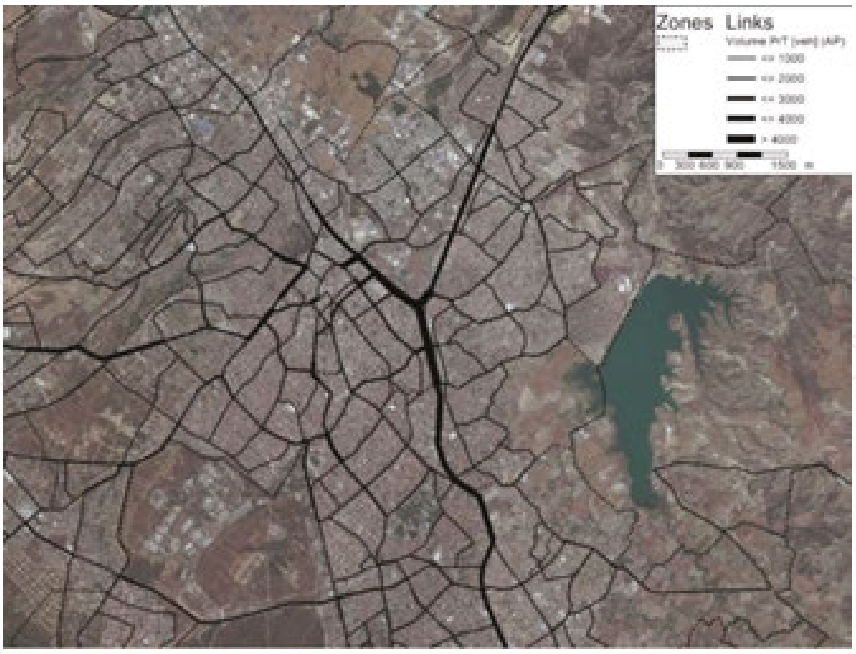

Figure 5. Traffic volumes on the road network for 2010.

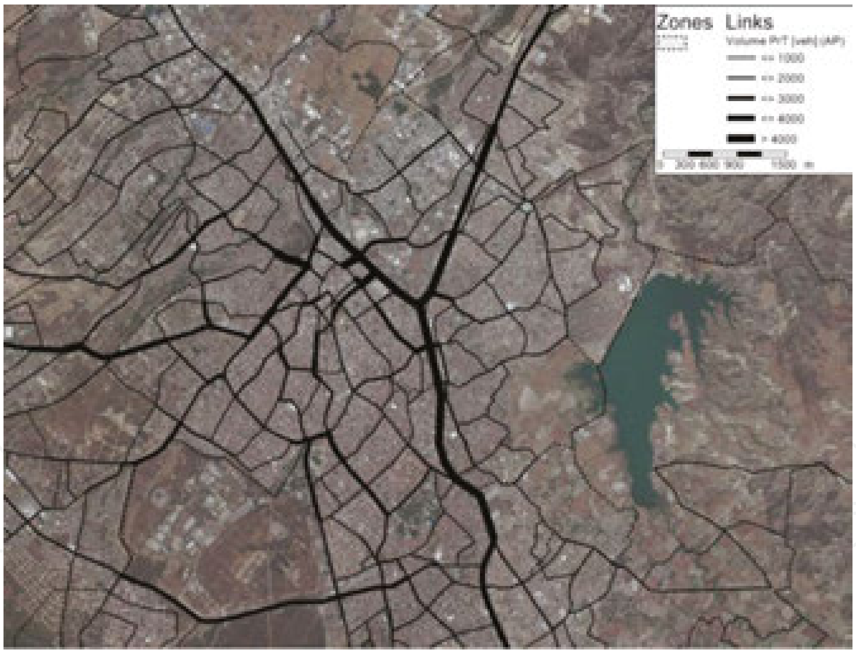

Figure 6. Traffic volumes on the road network for 2030.

As can be seen in **Figures 5** and **6** that the highest traffic volumes occur along the links meeting at the study intersection. It may also be stated that the increasing demand will lead to worse traffic conditions by 2030 considering the increasing traffic volumes through the road network. In order to investigate the performance of the selected intersection, turn movements and resulting link traffic volumes are given in **Figure 7** and **Table 1**, respectively.

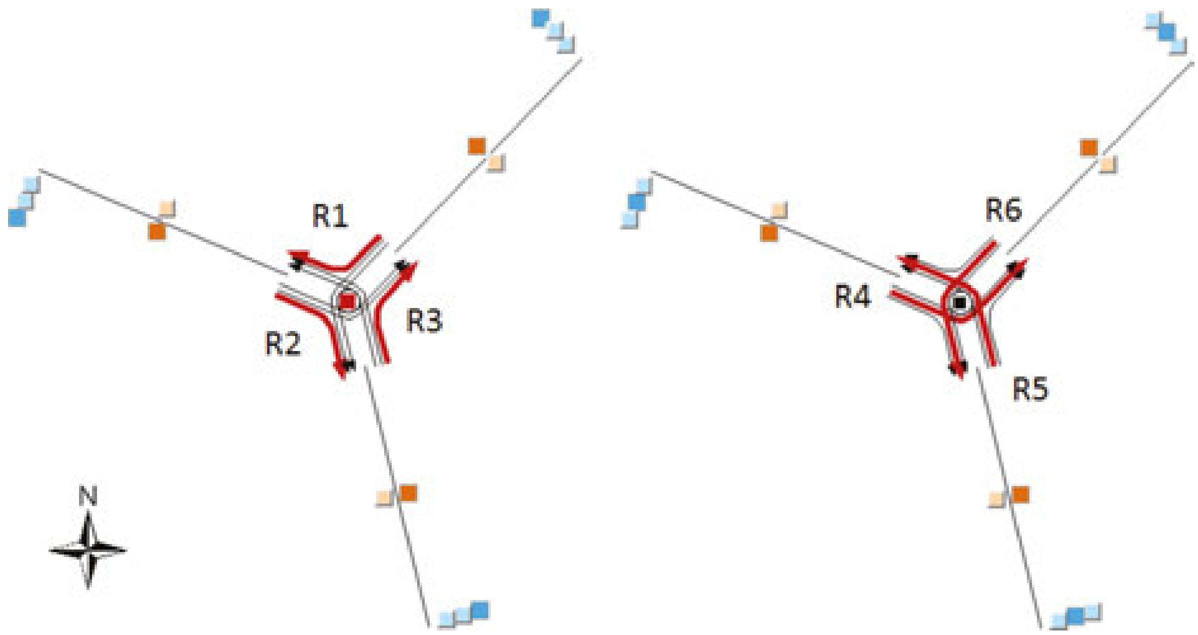

Figure 7. Turning movements in the intersection.

Movements	SUE flows for 2010 (veh/h)	SUE flows for 2030 (veh/h)	Increase (%)
R1	1549	2410	56
R2	732	1319	80
R3	433	574	33
R4	504	818	62
R5	2282	3819	67
R6	522	788	51

Table 1. SUE link flows under Scenario-I.

As can be seen in **Table 1**, traffic volumes along the approaches of the intersection are expected to increase with varied ratios by 2030. The highest increase will occur on the second movement with about 80% while the lowest one is about 33% on the third movement. At this point, VISSIM traffic simulations have been made for Scenario-I considering the traffic volumes for base-case and 2030. **Figure 8** shows VISSIM snapshots for Scenario-I.

As can be seen in **Figure 8a** that queues occur over the upstream links in a similar way to **Figure 4b**. Considering results of the simulations that represent the base-case, those queues are manageable due to the available queue storage on the upstream links. On the other hand, **Figure 8b** shows that the increasing travel demand will lead to longer queues that the vehicles may not discharge in a single green period in 2030 under Scenario-I. The resulting performance indicator values of the simulations are given in **Table 2**.

Figure 8. Traffic simulation snapshots for base case **(a)** and projection year **(b)**.

	2010	2030	Change (%)
Average delay time per vehicle (s)	85.15	166.21	95
Average number of stops per vehicle	1.55	3.08	99
Average stopped delay per vehicle (s)	60.93	128.77	111
Total delay time (h)	140.17	285.29	104
Number of stops	9210	19033	107
Total stopped delay (h)	100.30	221.02	120
Total travel time (h)	182.58	334.97	83
Average speed (km/h)	17.58	11.24	−36

Table 2. Performance indicators for base-case and Scenario-I.

Table 2 shows that the number of stops, delay times and total travel time increase over 100% by 2030 considering the traditional land use planning decisions. Meanwhile, the average speed in the intersection decreases by about 36%.

3.2. Scenario-II: Transportation planning paradigm based on smart growth (SG)

Configuring the transportation demand, which leads to traffic problems when it is assigned to the road network, may be dealt with in the SG manner. Herein, city block densities constitute the main factor which determines the trip attraction and trip generation rates. **Figures 9** and **10** show the trip generation and trip attraction increases in the city of Denizli for 2030 in zonal case [19].

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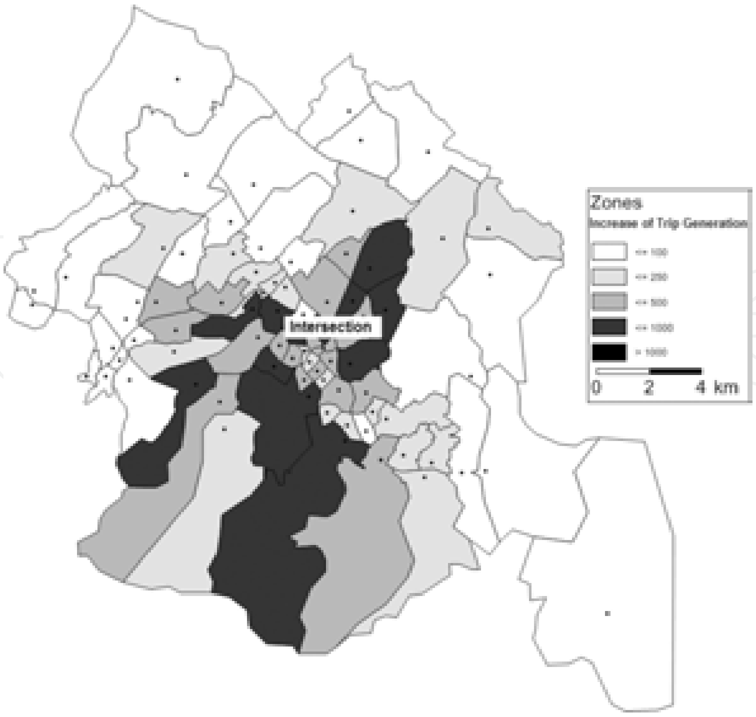

Figure 9. Trip generation increase for 2030.

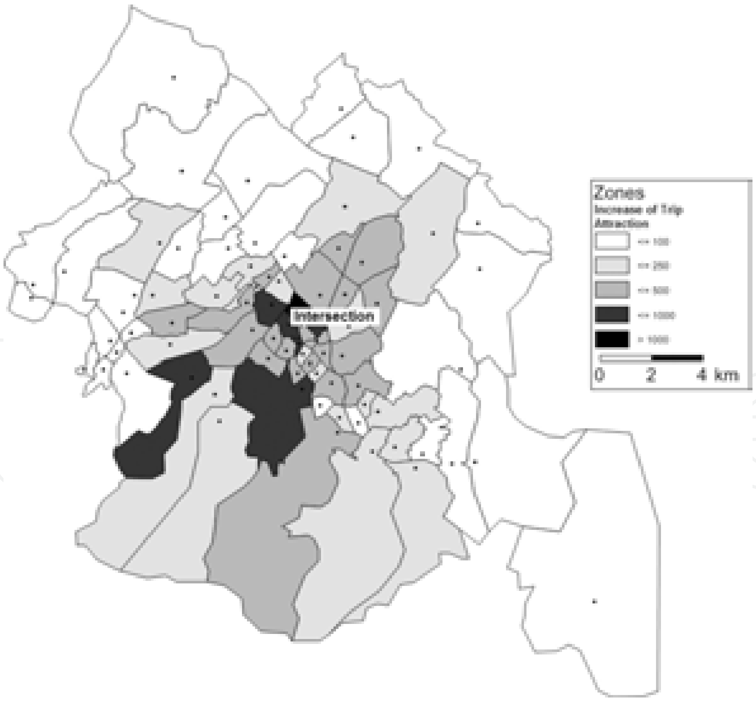

Figure 10. Trip attraction increase for 2030.

Figure 10 shows that attractive activities are clustered in the southwest of the intersection for the case 2030. The zones which have higher trip generation values also take place in the same area. On the contrary of this kind of location choice, several zones which have high trip generation values take place on the eastern part of the intersection. The zones which have attractive characteristics take place at the western side of the intersection. Note that there is no alternative access between the urban districts without using the study intersection. In this case, higher trip generation values at the eastern district of the intersection should be questioned because using intersection for access may be an obligation. To decrease the trip generation characteristics of the zones which take place at the eastern part of the intersection is an alternative land use planning paradigm for urban planners. Residential development areas on the eastern part of the intersection may be transferred to other side of the intersection in order to decrease the traffic congestion.

In the SG context, residential area densities at the eastern part of the intersection have been reduced by 50% in Scenario-II. Therefore, trip generation rates reduce directly proportional to the O-D matrices. This reduction has been applied by evaluating the land use plan of the city. Empty areas which are proper for residential development have been taken into account and all reductions and increases have been reflected to the O-D demands. **Figures 11** and **12** show the trip generation and attraction changes in zonal case after new land use modifications were carried out in Scenario-II.

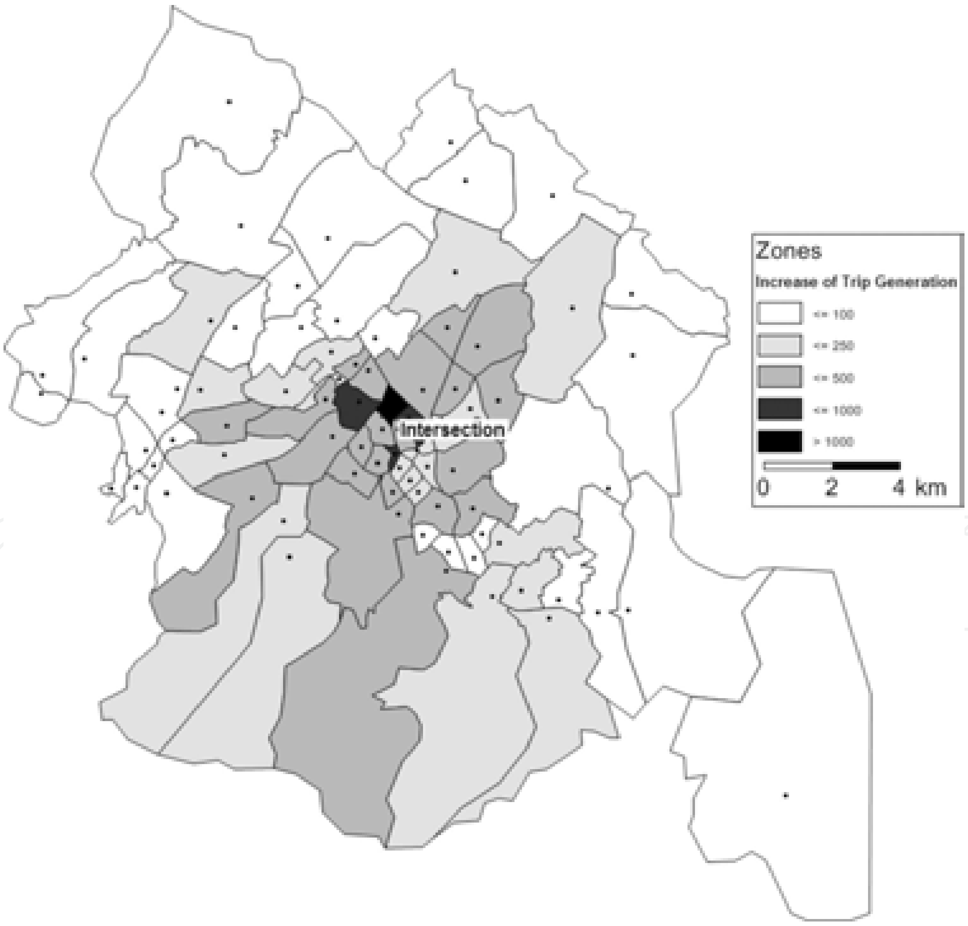

Figure 11. Rearranged trip generation increase for 2030.

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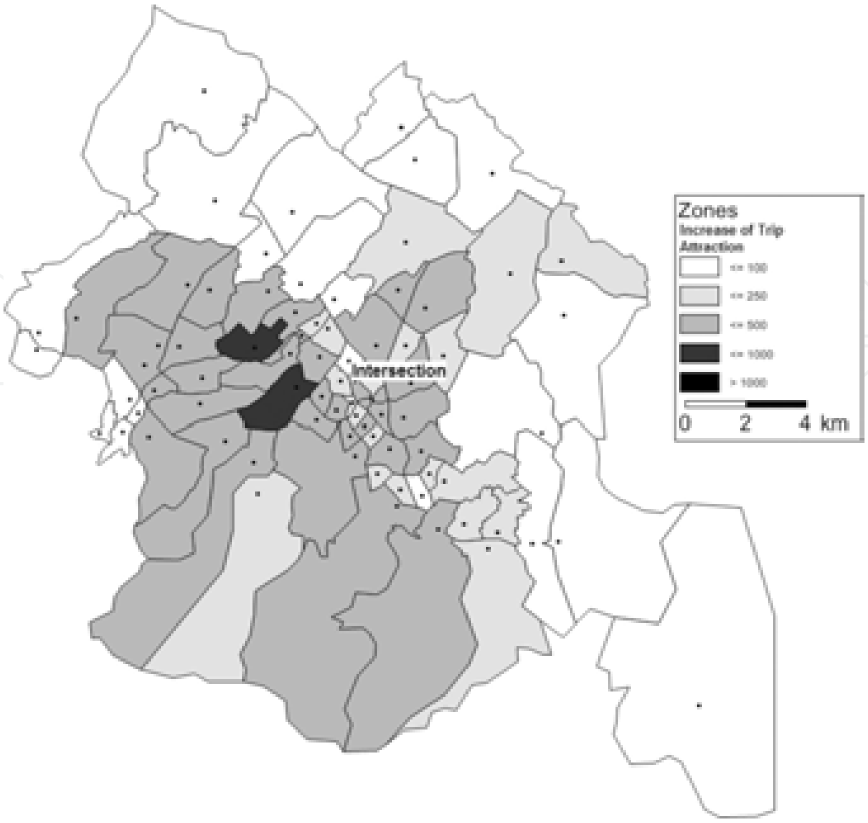

Figure 12. Rearranged trip attraction increase for 2030.

As can be seen in **Figures 11** and **12** that the land use densities are sprawled over the area more homogenously in comparison with Scenario-I as shown in **Figures 9** and **10**. For Scenario-II, a SUE assignment has been applied with the new O-D travel demand in order to calculate the link traffic volumes. The resulting volumes are given in **Table 3**.

Movements	Scenario-I (veh/h)	Scenario-II (veh/h)	Decrease (%)
R1	2410	1801	25.27
R2	1319	998	24.34
R3	574	540	5.92
R4	818	753	7.95
R5	3819	2502	34.49
R6	788	711	9.77

Table 3. SUE link flows for the scenarios.

As can be seen in **Table 3** that the traffic volumes along the approaches of the intersection may be decreased from 6% to 35% by applying Scenario-II. In order to evaluate the impacts of the SG strategies in terms of the performance indicators, VISSIM simulations have been made for Scenario-II and the resulting values of those indicators are provided in **Table 4**.

	Scenario-I	Scenario-II	Decrease (%)
Average delay time per vehicle (s)	166.21	158.96	4.36
Average number of stops per vehicle	3.08	2.82	8.44
Average speed (km/h)	11.24	11.71	−4.18
Average stopped delay per vehicle (s)	128.77	123.32	4.23
Total delay time (h)	285.29	269.75	5.45
Number of stops	19033	17198	9.64
Total stopped delay (h)	221.02	209.26	5.32
Total travel time (h)	334.97	319.12	4.73

Table 4. Performance indicators for scenarios.

Table 4 shows that the number of stops in the intersection may be decreased by about 10% while the total delay time decreases by about 5%. Meanwhile, the average travel speed in the study intersection increases by about 4% in comparison with Scenario-I. Therefore, it may be stated that the traffic congestion may be reduced, and performance of the road network could be improved by applying the SG land use planning strategies.

4. Conclusions

This study aimed to apply SG strategies to the land use planning process and evaluate the accuracy of land use planning decisions in the perspective of sustainable transportation. In order to reveal the effects of land use planning decisions on the available transportation infrastructure, a signal-controlled intersection serving heavy traffic volumes between three major/urban arterials was selected as the field of study, and two scenarios were investigated for 2030. In the first scenario, the conventional land use planning decisions were applied while the SG strategies were taken into account in the second one. Traffic volumes along the approaches of the study intersection were calculated in the SUE manner which considers the perception errors of drivers' route choice behaviors. Then, VISSIM traffic simulations were made for providing visual analyses and quantitative evaluations of the performance indicators. The results showed that the traffic volumes along the approaches of the study intersection may be reduced from 6% to 35% and the number of stops in the intersection may be decreased by about 10% while the total delay time decreased by about 5% with the application of SG land use planning strategies.

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