A MULTI-AGENT PLANNING SUPPORT SYSTEM FOR ASSESSING THE ROLE OF TRANSPORTATION AND ENVIRONMENTAL CONSTRAINTS IN URBAN PLANNING

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ABSTRACT

This paper reports the results of an analysis of twelve city plans based on environmental-sustainability indicators using a multi-agent model. The plans are based on three main-roads configuration and four types of city scenarios, each representing a a different planning concept. . The environmental indicators concern pollution from transportation, while the sustainability aspects relate to accessibility to facilities. The model supports planners to identify the best city form considering the selected performance criteria. In this case study, a compact form of a city in terms of main roads, coupled with a mixed land uses performed best.

Keywords: Urban Forms; Transportation, Land-Use, Pollution

INTRODUCTION

The strengths and nature of relationships between transportation, land use, and the environment have been well documented in the literature. These relationships are key factors for developing a sustainable built environment. However, the fundamental question of *how* can planners reach an equilibrium between these three aspects so that an attractive built environment is developed, traveling is minimized and environmental quality is reached, is still unsolved. It requires an application of the existing knowledge, represented in terms of a model, to compare alternative structure.

Hall (1996), considering the connection between the two first aspects, claimed that planners should consider land uses and transportation as one mesh, and handle the two in some fragile combination. O'Mera (1998), also dealing with the connection of the first two elements argued: "The physical structure of a city cannot change overnight, but decisions about transportation and land use will determine how it is shaped over time. By building roads, rail lines or bike paths, city planners decide not only how people will move around, but also where the accessible and desirable buildings will be…" (p 11). Newman and Kenworthy (1992) elaborated the connection between land use and environmental aspects: "The great challenge in our cities is to protect individual freedom in locating land uses and to provide access to them, while maintaining the public qualities of clean air, safe streets, and attractive public spaces" (p.360).

Although the question concerning optimized planning form still exists, (a question which has a long history in the planning research and literature), it is commonly agreed that city structure and planning can help to develop a sustainable built environment. That is, urban planning can play an essential role in the possibility of creating sustainable relationships between these three aspects: land use, transportation, and environment.

The aim of this study is to investigate the impact of city form and planning ideas/scenarios on transportation, land use, and environmental aspects towards the development of a sustainable built environment. Or, in other words, can urban planners suggest a planning form/scenario that will support reduction of travelling and consequently pollution, while at the same time creating a sustainable built environment, by suggesting optimal land-use and facility distributions?

To that effect, we have developed a multi-agent model, which can be used as a decision support tool to simulate the impact of different urban forms on activity-travel patterns and the evolution of land use. The results are then linked to pollution/emissions. The application of the model to fundamental principles of city form implies that this study differs from others that concentrate on the impact of different short and long term policies such as parking and congestion fees, ridesharing, car ownership or changing work place, in that it deals with planning form/scenarios as a tool for traveling reduction and hence city pollution. With that focus, we quote Newman and Kenworthy (1992 p 360): "The role of the planner is to help to choose the infrastructure around which the city and its marketplace can adjust. This choice needs to consider such issues as air quality and sprawl, questions of urban places and neighborhoods and community, and the vitality of centers and sub-centers. All of these have impact on economic performance but are much more than just marketplace choices. They are choice about the preferred city". The model/decision support tool (Arentze and Timmermans, 2000) incorporates these aspects and is thus potentially useful in the context described. The multi-agent model differs from widely applied cellular automata models in that cells are replaced by people as decision making units. It differs from integrated land use-transportation models in that an advanced activity-based model of activity travel patterns are used and in that location decision are based on a behavioural model of facility locators who interact with consumers rather than primarily on the concept of accessibility

The focus of this paper is however not on the model per se, but rather on its application to twelve city scenarios for 150,000 people, presented as a master-plan. The twelve versions are based on three city forms and four planning concepts. These different city scenarios are compared based on a set of performance indicators. Note that we are analyzing city forms from a more fundamental perspective and not an existing, real city.

In the course of this paper, we will discuss aspects of city pollution, and traveling in the city, followed by the description of the developed planning scenarios and city forms. Finally, the results of the simulations will be presented and discussed.

TRAVEL IN THE CITY AND POLLUTION

The last decades were characterized by a growing amount of travel in and around the city. Priemus (1999) claims that the living climate in cities is under great pressure through increasing nuisance, pollution and the lack of open green areas. According to the Dutch National Institute of Public Health and Environment Protection, traffic flows in and around the city cause environmental problems in the following categories: acidification (by car emissions) disturbance (noise, smell and accidents), fragmentation (of animals habitats), change in climate, estrangement and waste. A few of these environmental issues are coupled with health effects associated with exposure to gasses and particles emitted from vehicles. The environmental problems of cities are seen to be linked fundamentally to poor design of the urban fabric. This reached the level that Dutch people showed that satisfaction with housing and the living environment is lower in cities than elsewhere (Priemus, 1999). Evidence to this claim can be found in the fact that a positive relationship was found between living in a compact city and the degree of environmental friendliness of consumption behavior, which is partially explained as an outcome of restricted car based mobility (de Nijs, et al. 2004 and Geurs and van Wee, 2006). To add to the disturbance and dissatisfaction that people have in the city, the above research indicates that a major health problem originated from pollution, as mentioned earlier. O'Meara (2001) translated this health problem into death rate and claims that air-pollution from motor vehicles can kill more people than car accidents.

What increases the problem of the well-known existing trade-off between transportation development and environmental aspects, is the fact that pollution created in the city is not a local (inner city) problem, but a global one, as pollution extends beyond city borders. Hence the benefits of healthy cities are regional, national and global (O'Meara 1998). The growing amount of traveling, complexity in travel-patterns and the desire to understand the planning possibilities to change travel in the city led different scholars to investigate peoples' travel behavior. Moreover, travel distance within the city is regarded as a key parameter with respect to environmental aspects (for example Newman and Kenworthy, 1989, and Stone et al., 2007). Common to these studies is the understanding that parallel to the traveling "price", the increase in transportation/mobility options is the core of growth management (Waddell, 2002), and hence massive investments in transportation facilities are made to support greater progress in efficient movement of people and goods (Forkenbrock and Schweitzer 1999). These transport-behaviour studies include questions such as: How travel behavior is affected by new information and communication technologies? How does land use and growth management affect travel behavior? How much travel is induced as a result of new infrastructure? And how do travelers respond to auto restrain policies? Activity-based models as a tool for modelling behavioural response to such issues have been estimated and applied in different studies (e.g., Kitamura et al, 1996; Rossi and Shiftan, 1997; Gunn and Van der Hoorn, 1998; Shiftan, 1999; Algers and Beser., 2000; Salvini and Miller, 2005; Katoshevski-Cavari, 2007; Shiftan, 2008; and Katoshevski-Cavari et al., 2009). A common hypothesis is that different policies which include the encouragement of people to live in higher-density residential areas, mixed land-use, transit accessibility, and pedestrian friendliness, create an environment where people drive less (Cervero 1989). This reduction in travelling may result from fewer trips, shorter ones, or from shifting from single-occupancy vehicles to public transportation, walking, and/or cycling. Cervero and Kockelman (1997), Newman and Kenworthy (1989 & 1999), Holtzclaw (1990), Frank and Pivo (1994), Kitamura et al. (1997), Badoe and Miller (2000), and Roodra et al. (2009) are examples of studies that assume that living in higher density neighborhoods contributes to the reduction of motorized level. These assumptions have led some regions to try and implement such policies, for example, transit-oriented development, mixed land-use, and different concentration schemes. Bagley and Mokhtarian (2000) give an overview of early empirical studies of these policies and their effect on transportation

However, although there is a large body of research claiming to have found positive evidence of the effect of higher-density neighbourhoods on a reduction of motorized level, there is at least an equal number of studies showing no or little influence of the built environment on travel behavior (e.g., Handy 1996, Kitamura et al., 1997, Boarnet and Sarmineto, 1998, Crane and Crepeau, 1998). Doubt exist as to whether land use configuration itself affect travel patterns, or whether people with different travel behavior preferences select different types of neighborhoods, what is often referred to as "self-selective" (see for example Dunphy and Fisher (1996). Pontes Aquino and Timmermans (2010) take a critical stance on this debate. Thus, there is no consensus regarding the effect of urban form on travel behavior, but there is some consensus that our understanding of the effect of the various planning policies on travel behavior is still limited. The extension of this line of research to include pollution is less well developed. Marquez and Smith (1999) discussing the effect of four possible future city scenarios found that corridor-type of development (development along key transportation routes) and compact-type (increase densities in city central area) scenarios delivered a significant higher decrease in pollution than the "business as usual" scenario.

In parallel to this discussion concerning the possible influence of different planning policies, it is understood that good location choices for houses, work places and facilities are essential. Hence, an optimized city form is the essence for creating a sustainable built environment. In this research project, we therefore study the combined impact of city forms and planning ideas to better understand these relationships and be able to create a sustainable city in terms of activity-travel patterns, pollution and the distribution of land-uses and facilities.

THE SCENARIOS AND THE EVALUATION CRITERIA

As was clarified earlier, the study deals with an evaluation of twelve city-plans, which are based on four defined planning ideas/norms (planning scenarios) and three city forms (which differ in their road structure). These are detailed as follows:

The planning scenarios

Four planning scenarios are considered in this case study. Each one of these four scenarios deals with distinctive planning concepts/ideologies.

The "Recreation City": this involves a distribution of a number of city-level recreation cells in the city. According to this scenario the city will include a few city parks, instead of one main central city park. This scenario considers the possibility of spreading the limited number of recreation cells in the city in contrast to concentrating them all in a single big city park.

The "Nature City": this denotes a city with "green lungs". The idea of this scenario is to develop a city which includes a few areas of Nature cells. These green (Nature) areas should be big enough to offer the city population some significant open places in the city texture, places to be used for leisure activities. This scenario deals with the planning dilemma of how to create a “green environment”, and what the drawbacks of such a city are. Or, what is the transportation/accessibility "price" of such a city.

The "Mixed City": this scenario deals with mixed land uses. Based on that, the setting supports the land use mixture of Commercial cells, Housing and Industry-High-Tec. The idea in principle is that, in order to create a more compact development with an efficient facility distribution and less need for the reliance on transportation, these land uses should de developed in close vicinity. This scenario deals with the basic planning question of how to create a compact efficient built environment.

The "Separated City": a city based on two distinguished areas of dwellings, high density housing which include apartments in buildings and low density housing of mainly detached houses and row houses. The assumption is that in the high density areas in contrast to low ones, facilities should be more accessible and people to be less dependent on traveling for conducting activities. This scenario has a different planning focus, namely the question whether it is possible to plan a city which offers an area of a comparably low density but with appropriate facility dispersal? Such a city might be an appropriate alternative for those looking for detached or semi-detached housing in a suburban development.

The city forms-the road structure

As already mentioned we base our set of city forms scenarios, to be detailed below, on previous studies, such as the one described in Marquez and Smith (1999), and our previous study

(Katoshevski-Cavari, 2007) which presented the influence of urban form (road network) on spatial evolution.

The "Basic City": In this form, two main roads intersect at the centre of the planned area, forming an "x" shape, see Fig. 1. This layout is envisioned to produce a spread-out non-dense city with a main focal point at the centre, although local neighborhood centers may also be developed along the roads. Housing should develop outward from the center along the roads, creating “fingers” of development radiating from the centre but leaving undeveloped green areas between the roads. As this structure imposes only very limited development constraints, it is termed the "Basic" city in this study.

The "Corridor City": In this form two axial roads are added to the Basic City, also intersecting at the centre of the area, and together they divide the city into eight sections. This road layout should produce a drastic increase in overall city density, as development may be expected to spread outwards from the centre along the roads. In this "Corridor" configuration a strong focal point should emerge at the centre, but some neighborhood centers may also be developed along each road (Fig. 1).

The "Connected City": This form envisions the addition of several circular main roads to the “Basic City” layout, dividing the city into sections surrounded by roads (Fig 1). Such a layout is likely to result in a more constrained development and hence the emergence of a compact city.

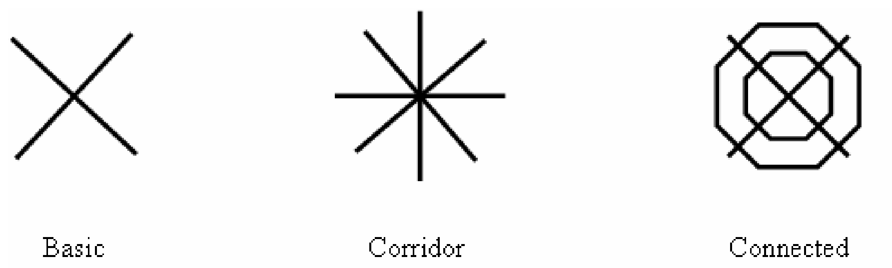


Figure 1. The three city forms.

The evaluation criteria

Using these planning ideas/norms and city forms twelve city versions were developed. The resulting spatial configuration of land use and facilities is compared by using two performance-indicators measuring aspects of sustainability. Analysis **of Mobility- transport demand** in the system is based on the trips resulting from a one day run of facilities used in the system by the city population For each activity type (at subclass level) the model determines the distance traveled (a straight line distance in meters) for each trip conducted for the activity type. **Accessibility** reflects the ease of access to facilities, that is, the convenience of moving from a home location to different facilities. It is commonly assumed that better accessibility is a positive indicator of sustainable development. For each facility type (at the subclass level) a number of accessibility measures for each housing cell are calculated. These include: the average distance to the nearest facility across home locations, the average distance to the second nearest facility across home locations and the average number of facilities (of that type) within a distance of 500, 750 and 1,250 m across home locations. In calculating these averages, the size of the population at the home location (origin cell) is used as a weight.

In order to address the environmental-sustainability issue, we have chosen to include the following specific aspects. The mobility aspects are represented by global city travel per day across all facilities by the population and the number of trips per one day. These two issues would be our two first measures. The first, the total travel distance simply implies that in a general view there is an emission rate per meter of travel which can be taken as an average across the various types of vehicles. The second measure, which is the number of trips, implies that a higher number of trips results in more pollution emission, due to more ignition actions of vehicles, and time during which the vehicle is not in motion while emitting pollution. The next sets of indicators reflect the accessibility, and are considered as fundamental for a sustainable planning. These are the number of facilities in different distance categories and distance to the 1st and 2nd nearest facilities.

THE MULTI-AGENT SYSTEM

The model which is used here, a multi agent planning support system, was employed for the development of the city plans. This model is described in detail in Arentze and Timmermans (2000), and Katoshevski-Cavari (2007), and hence we only summary the system, for the sake of convenience. The basis of this model is the assumption that urban dynamics are driven by decisions of at least three groups of actors: (1) The planning authority, (2) Supplier agents, and (3) Individuals and households. The behavior, decisions and interaction of these three actors are the drivers for the development of the built environment. This system is comprised of several stages and consists of co-evolving models for each of these actors. That is, the multi-agent system consists of three sub-models. 1) Land use model, 2) Facility location model and 3) Facility use model. These sub-models generate city-maps for land uses and the location of facilities. The model is based on people's preferences and observed activity-travel patterns. The input population data for the activity-based model is a synthetic population, derived from statistical data. The activity-based model, Albatross (Arentze and Timmermans, 2004), was adjusted to the available Israeli time-use survey (CBS, 1995), consisting of a sample of 3082 people in the age of 14 years and older spread across 86 localities living permanently in Israel. The sample includes the cities Jerusalem, Tel-Aviv and Haifa and another 83 different cities and settlements (Jewish and Non-Jewish).

THE TWELVE CITY FORMS

The settings

We now describe the development and outcomes of the twelve city-plans. First, the land use input and the main aspects (the suitability parameters) of each planning ideas/scenario will be described. Common to all planning scenarios are the population size and characteristics and a representation of the city area in terms of grid cells. The total number of cells for the whole study area, and the specific land use for each cell are provided. The planning scenarios are specified in terms of: (1) A set of suitability parameters which differ for different planning concepts/norms, and (2) The road-network structure of the city.

The land use and population settings

The following seven land use categories were distinguished: (i) Housing High density (labelled as Housing-H); (ii) Housing Low density (labelled Housing-L); (iii) Industry High Tech (Industry-H); (iv) Industry Low Tech (Industry-L); (v) Commercial; (vi) Recreation, and (vii) Nature. The plan area consists of a regular grid of 2500 cells of 125 x 125m in size divided as follows: 760 cells for Housing H, 400 cells for Housing-L, 96 cells for Industry H, 96 cells for Industry L, 96 cells for Commercial land use, 80 cells for Recreation and 972 cells for Nature. The CBD is located in the geographical center of the city. The total size of the area and proportional land use requirements are derived from an anticipated population size of 150,000 people and planning standards. The size of a cell was determined such that it is small enough to accurately represent facilities and not smaller to avoid excessive computation times.

In this application, the total number of households per cell equals 92 for high density housing cells and 39 for low density housing cells. These numbers follow from the assumption that, on average, a house occupies 210 m^2 and 500 m^2 in respectively high density and low density cells, and households on average have 1.24 adult members. The number of workers (in full time equivalence) follows the ratios 2 (high tech industry), 1 (low tech industry) and 3 (commercial). The simulation is based on a sample fraction of 10% of the population.

The land-use model settings- the suitability parameters

The initial land use distribution in the system is based on suitability parameters which are defined as an input. These suitability parameters for each of the four planning scenarios are summarized in Table 1. It is important to note that this stage, which deals with the development of the land use map, is completed prior to and independent of the actual multi-agent model. That is, this preliminary stage is on parameters, set by the planner (in our case based on the planner knowledge and a conjoint study, see Katoshevski and Timermans 2001, Katoshevsk-Cavari 2007). The result is an initial land use map which served as the starting spatial configuration of land use and the transportation for the multi-agent model.

Table 1: The four scenarios- the parameters settings for developing land uses

planning ideas	setting parameters			
	Cut-off points	Suitability scores	Weight	Adjacency scores
Recreation City	Housing to Nature: 200 m, 400, 600, 800	A monotonically decreasing function of distance regarding all land uses.	5	Housing to Nature: 5 Nature to Housing-*H*: 5 Nature-Nature: 10
Nature City	Housing to Recreation 200m, 400, 600, 800 Recreation to Housing: 100 m, 200, 300, 400	A monotonically decreasing function of distance	5	Housing (both kinds) to Recreation: 10. Recreation to Housing –*H*: a score of 10
Mixed-use City	Housing*H*+*L* to Commercial: 200 m ,400, 600,800 Commercial to Housing-*H*: 400 m, 600, 800, Commercial to Housing-*L 500m, 1000, 2000*: Industry-*H* to Industry-*H* most preferred distance between 100 to 500 m, Industry-*H* to Industry-*H* preferred 500-1000 m	Housing-*H* +*L* to Commercial: A monotonically decreasing function of distance, to Industry- *H* a decreasing function of distance Commercial to Housing –*H*: decreasing till 800m and zero thereafter, Industry- *H* to Housing a decreasing function of distance	Housing to Industry-*H* and Industry-*H* to Housing 4, Housing to Commercial 5and commercial to Housing –*H* 5 to Housing –*L* 2	Housing –*H* to Commercial and Commercial to Housing –*H*: score of 5
Separate City	Housing-to Housing (all kinds): 100m, 200, 300, 400, 500	A decreasing function of distance, and zero from 500m and on	Housing to its same kind: 5; to the other kind: 2	Housing –*H* to Housing- *H* and Housing-*L* to Housing –*L*: score of 10

Cut-off points –the distance range to a certain (other) land use, main road and city center divided by 6 intervals, Suitability scores - a score for each distance interval, Weight –the weight of each interval, Adjacency scores- bonus or penalty for land use to exist in one or more of the eight neighbourhood cells.

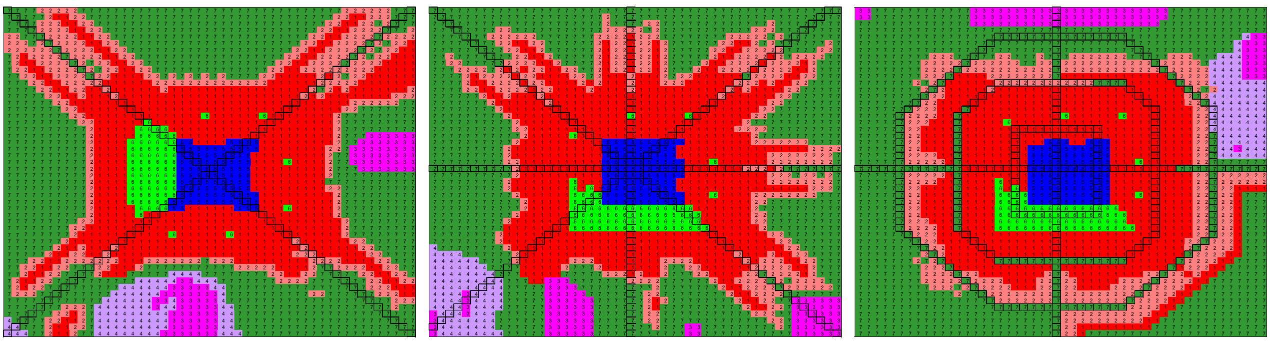
1. The Recreation City – As this scenario deals with the spreading of Recreation areas in the city, in addition to one big Recreation- cells cluster, the suitability parameters are showing preferences for short distances between the Housing and the Recreation cells. This is determined for all dimensions included: the cut-off points, suitability scores and weight score and adjacency scores.
2. The Nature City- In this scenario the parameters for the Housing and Nature cells were set such that they will support the desired distribution of Nature cells in the city. A clear preference was set Housing cells to be close to Nature cells, and for Nature cells to neighbor other Nature cells so that Nature polygon(s) will be created.
3. The Mixed-use City - The idea of this scenario is to mix Commercial, Housing (*H*+*L*) cells and Industry-*H* cells. For that, the parameters in this scenario were set such that a high score is given for Housing and Industry-*H* cells close to Commercial cells, and vice versa.
4. The Separate City - In order to create a clear separation between the Housing-*H* cells area, and the Housing-*L* cells area the suitability parameters were set such same time of Housing cell are close together, while a low weight was used to indicate that these cells should be separated from other Housing.

Based on the described suitability parameter settings of each planning scenario, the system allocates the required land uses to cells. This results in a land use pattern-an outline plan. This plan is used as a platform in the current study for locating facilities, as explained above.

THE CITY LAND USE CONFIGURATIONS

1. The Recreation city scenario (Figure 2)

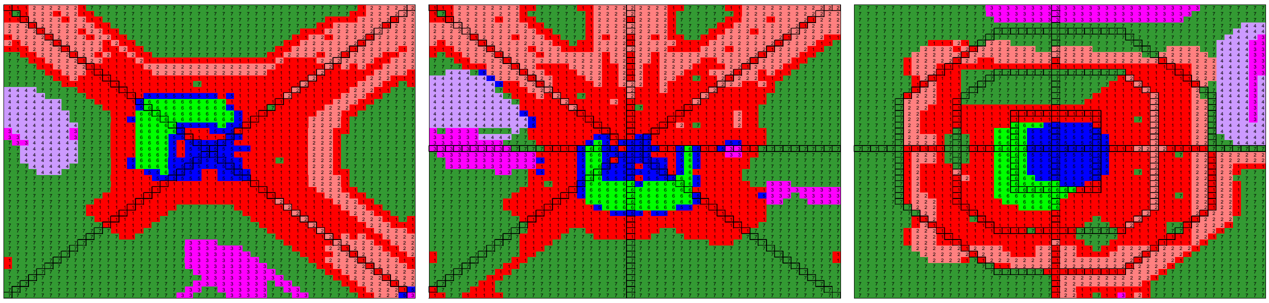
The Commercial area is located in the center of the city. The Recreation cells include one main area which is located in the center, attached to the commercial area and some Recreation cells that are spread across the city. In all three versions the isolated Recreation cells are distributed around the central part of the city at some distance from the center. The Connected version also includes some Nature cells that penetrate into the Housing areas. In the Connected scenario, the Housing-*L* wraps the Housing -*H* cells. In all three versions, Industry cells are in the outer area of the city and are divided into a number of clusters, some are a mixture of Industry*H* +*L* some include only one kind of Industry.



Basic City   Corridor City   Connected City

Housing –*H* –red, Housing-*L*-pink, Industry-*H*-dark purple, Industry-*L*- light purple, Commercial- blue, Recreation –light green, Nature- dark green.

Figure 2: The Recreation city scenarios



Basic City Corridor City Connected City

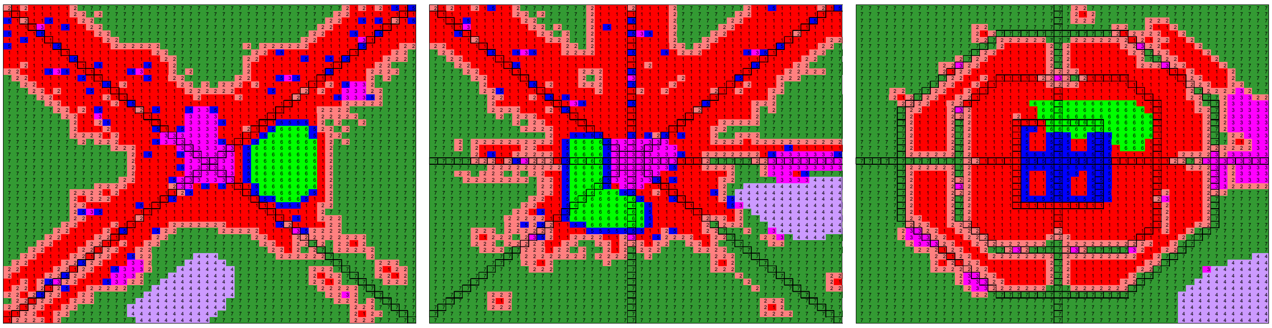
Figure 3: The Nature city scenarios

2. The Nature city scenario (Figure 3):

In the Basic and Corridor city-forms the Commercial area is spread-out from its basic central origin and includes some mixed uses by including Housing-*H* and Recreation cells. In addition, some Commercial cells are spread in these city-forms. On the other hand, in the Connected city, the Commercial cells are located in the central part of the city and are compact with no mixing with Housing-*H* cells. The Basic city version is characterized by Industry –*L* cells that are developed at a relatively large distance from the Housing cells. The Connected city is the only version that includes clusters of Nature cells in the city, in addition to some separate spread-out Nature cells. In both other options the city is developed into the Nature areas, however the penetration of Nature cells into the Housing areas is limited and includes only a few isolated cells.

3. The Mixed-use city scenario (denoted by Mixed-use) (Figures 4a and 4b)

The Connected city is characterized by a Commercial centre concentrated in one area in the city centre. In the Basic city and Corridor city the Commercial cells are spread all over the city in the form of a main cluster and many individual Commercial cells. The Connected city, different from the others, includes mixing of Commercial cells and Housing-*H* only in the central part of the city. Another characteristic of the Connected city is that Commercial cells only mix with Housing–*H* cells, while in the other two city forms also with Housing-*L* and Industry-*H.* In all three city forms, Industry-*H* is spread all over the city with distinguished focal areas. In the Basic and Corridor forms, there is a focal area in the center, while in the Connected city there is not. In each of the three versions there are Industry-*H* and Housing cells not located in the main body of the city. The difference between the forms in this regard is in the amount and the way they are spread. Note that all these differences emerge while the same settings are used for the land-use suitability function. As for Industry-*L*, in all versions Industry-*L* involves a focal area which is not mixed with Housing, but is located in a separate area. With respect to Nature distribution, only in the Connected city version there are some Nature cells that enclave in the Housing cells. In the other two city forms Nature is situated at the outskirts of the city. The fact that the Commercial cells in the Connected city version did not spread all over the city and the mixing of these cells occurred only in the central part of the city, is an interesting result in itself (Figure 4a). However, for comparison it is not useful as it would mean that the city forms are compared on an unequal basis in terms of mixing. Therefore, for the purpose of comparison, we artificially modified the land use map by "planting" cells of Commercial in different areas of the city (Fig 4b) .For the comparison between the scenarios we now replace the original Connected Mixed-use scenarios with the modified one displayed in Fig. 4b.



Basic City Corridor City Connected City

Figure 4a: The Mixed Use city scenarios

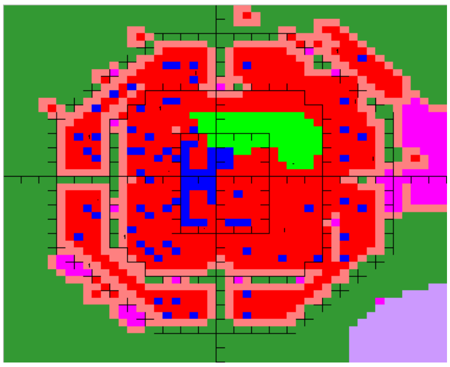
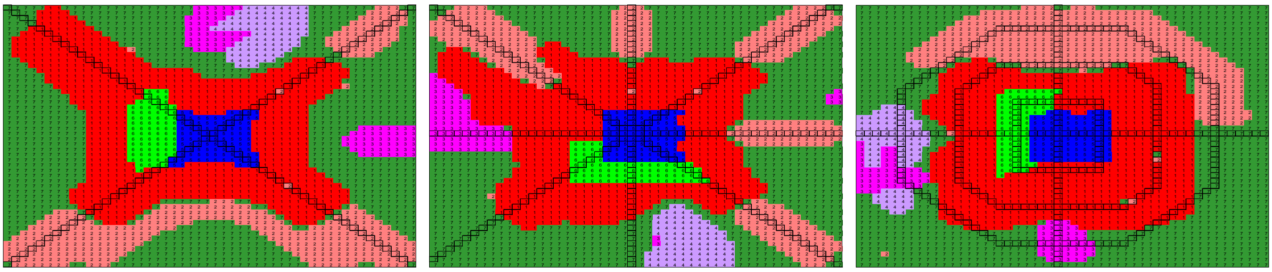


Figure 4b: The modified Connected Mixed-use scenario

4. The Separate city scenario (Figure 5)

For this scenario, in all three city forms, a central Commercial area is developed adjacent to a recreation area. In addition, Housing-*L* is a single cluster and not adjacent to Housing cells. However, Industry-*H* cells are located as two clusters in all forms, some are adjacent to Housing-*H* cells. The Connected city has two distinguished Housing areas: Housing-*H* and Housing-*L* while in the other two forms Housing-*H* is developed as one cluster, while Housing-*L* cells are developed in two or more clusters. In each case they are separated from the Housing-*H* cells.



Basic City Corridor City Connected City

Figure 5: The Separate city scenarios

These cities, different in terms of land use patterns, provide distinct settings for suppliers to locate their facilities, and for individuals/ households to conduct their daily activities. For each one of the city versions, the multi-agent model simulates how individuals and households organize their activities and travel in these spatial settings. Their behaviour generates spatial demand. Facility agents respond to this demand. The result of this interaction, co-evolutionary process after convergence is a city which a particular distribution of facilities. This process leads to a creation of nine facility maps for each city version. Each map indicates the distribution of a certain type of facility. (For further details, see Arentze and Timmermans, 2000, and Katoshevski-Cavari, 2007) As the focus of this study concerns global city implications which emerged from these distributions, we will confine the discussion in the remainder of this paper to these global aspects.

EVALUATION OF THE TWELVE CITY PLANS AND DISCUSSION

We now analyze the twelve city-plans/scenarios on the basis of mobility and accessibility measures: 1) Total travel distance per day, 2) Number of trips per day, 3) Number of facilities per distance category, and 4) Distance to the 1st and 2nd nearest facility. The comparison between the twelve scenarios is based on the outcomes of the numerical simulations.

Mobility: Total travel, and Number of trips

In terms of the estimated total travel distance, Fig. 6 clearly shows that the Connected city is significantly better than all other city forms, while the Basic form is the worse in that respect. The shortest distance was found for the Connected Recreation scenario, followed by the Connected Separate and the Connected Mixed-use form.

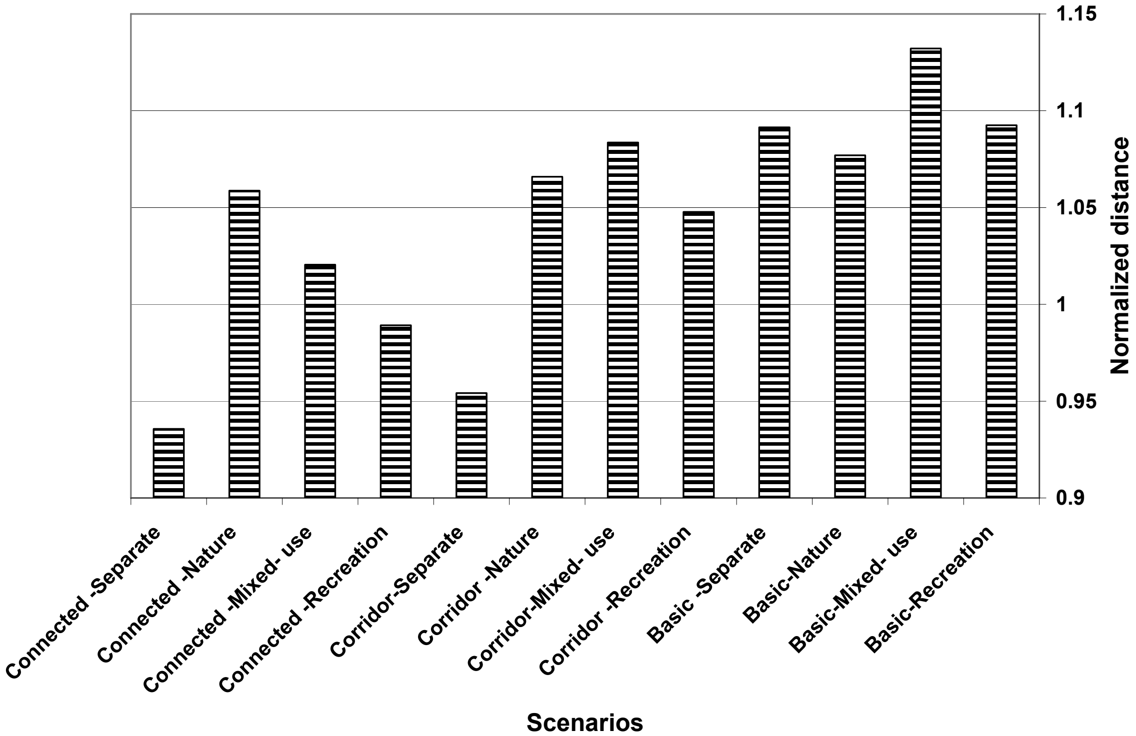


Figure 6: Normalized total travel distance per day. It is normalized by the value for the Recreation Connected scenario.

The effect of the Nature cells being spread in the city in all city forms, reflected in the Nature scenario is an increase of travel distance. That is because the urban area is spread-out more due to the inner Nature cells, which cause an increase in route length to the different facilities. On the other hand Nature areas may be considered as "green lungs" that intake some of the emitted CO_2. We currently do not address that aspect here, although we may assume that such Nature cells do not have a significant impact on any of the other emitted pollutants from traffic, such as SOx, NOx, and particulate matter (PM) which are considered to pose a health risk.

The second indicator that we account for, as already mentioned, is the number of trips made during one day. Figure 7 shows the comparison between the various scenarios on the basis of the predicted total number of trips in the city. As mentioned earlier, this indicator is associated with air pollution, because higher numbers of trips reflect higher pollution, while keeping total distance constant. Ignition (engine-start) of vehicles emits more pollution than that the amount emitted while travelling. The figure shows that the highest number of trips is generated for Corridor Separate, Connected Nature and Connected separate scenarios. Hence combined with findings of the total travel distance, the Connected Separate scenario seems best in these respects. The Basic-Recreation scenarios results in the lowest number of trips of all three Recreation scenarios, while the other Basic scenarios show the opposite behaviour; that is, they show the largest number of trips relative to all other scenarios.

It is interesting to note that the Recreation scenario in the Basic city form shows the lowest number of trips among the scenarios of the Basic city. This fact, combined with the findings in Fig. 6 suggests that the Recreation scenario is the preferred one *within the Basic city form* in terms of the two indicators for air pollution emission addressed here. In the Corridor city form there is a consistency between the above two indicators for the Separate scenario, which suggests the shortest travel distance in that city form, as well as the lowest number of trips. Hence for the Corridor city-form, this scenario would be the preferred one.

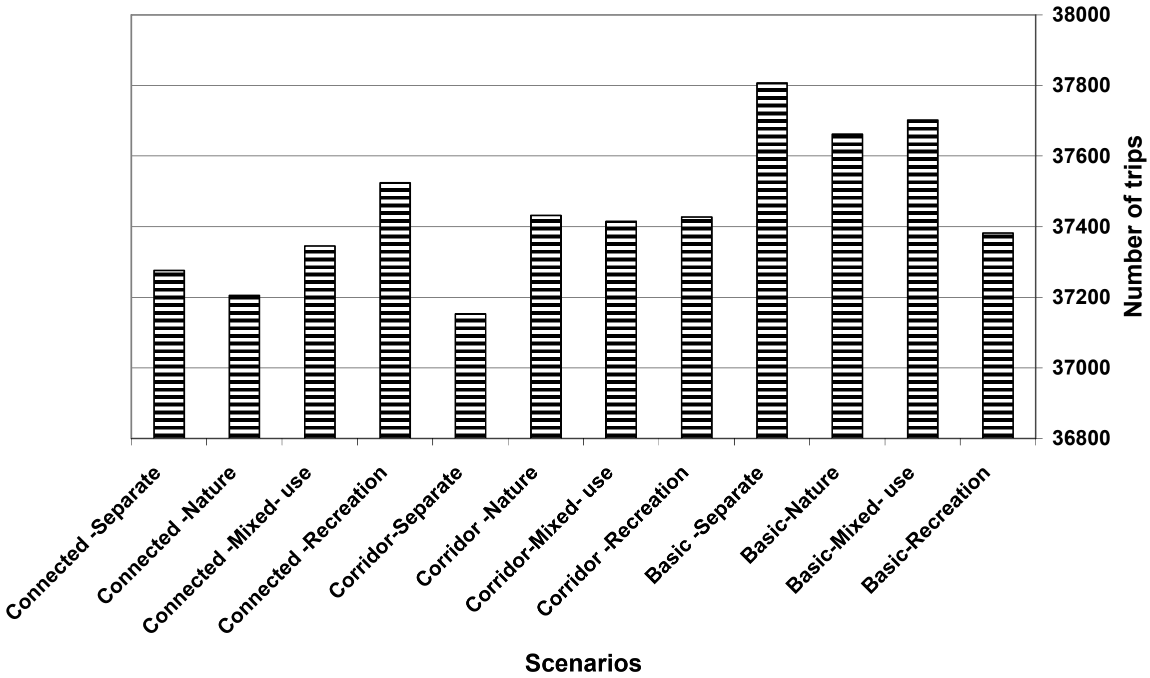


Figure 7: Number of trips per day

Accessibility: Number of facilities per distance category and Distance to the 1st and 2nd nearest facilities

The accessibility indicators number of facilities per distance-category and the distance to the nearest ones are assumed to influence the expected welfare of the population. Fig. 8 shows the number of facilities per distance-category. It demonstrates that the larger the distance, the more facilities are available, in all cities forms and scenarios. The total number for the two first distances of 500 and 750 meters is highest for the Corridor Recreation, and the Basic Separate scenarios, followed by Connected Recreation and Connected Separate scenarios respectively. Hence, the Connected Separate scenario, here as well, has some relative advantages which are in line with the former findings. The Nature scenarios in all city forms have the lowest number of facilities in the first two distance categories, which can be regarded as a disadvantage in terms of the variety of facilities offered by the city. The analysis shows that when comparing scenarios the proportions between the numbers of facilities of the three distances categories (where the total number of facilities for the three distances represent 100%) are very similar. The differences are in the order of 2 percent (we do not present that as a graph). Thus, the relative distribution of facilities in the city is similar for all scenarios. Hence, this indicator does not differentiate between the scenarios, while the absolute number gives a better indication, as described above.

The Recreation scenario in the Corridor city form which was ranked first in terms of the number of facilities in the closer distance categories also has the shortest distance to the 1st nearest facility, as is shown in Fig. 9. The same short distance to the 1st nearest facility is also found for the Recreation scenario in the Connected city (which was ranked 3rd before). In fact, all four scenarios for the Connected city perform well according to this indicator. The Recreation-Corridor scenario is 2nd in terms of distance to the 1st nearest facility, and 3rd is the Separate-Connected scenario.

As for distance to the 2nd nearest facility, displayed in Fig. 10, the Basic-Separate scenario has the shorter distance. All scenarios for the Connected city do not show any advantage here. It is interesting to note that Nature cells within the city have a profound influence in the Connected city form when comparing the distances to the 1st and 2nd nearest facility. On one hand the Nature scenario in the Connected city has the shortest distance to the 1st nearest facility among all Nature scenarios, while on the other hand it leads to the largest distance to the 2nd nearest facility in all three city forms. This effect can be attributed to the fact that the Nature cells are not distributed homogenously in the city and their concentration is larger in the outer areas of the city. The Basic separate scenario has the shortest total distance to the first and second nearest facility, followed by the Nature-corridor scenario, the Recreation connected and Connected Mixed-use scenarios respectively.

We thus conclude that the indicators of travel distance and number of trips help choosing a preferable scenario in terms of the extent of pollution emission. The number of facilities per distance category when normalized for each scenario was found to be a non differentiating performance indicator. The absolute number of facilities gave a better distinction between the scenarios and urban forms. The distance to the first and second nearest facility also gave a clear indication of the preferable city plan.

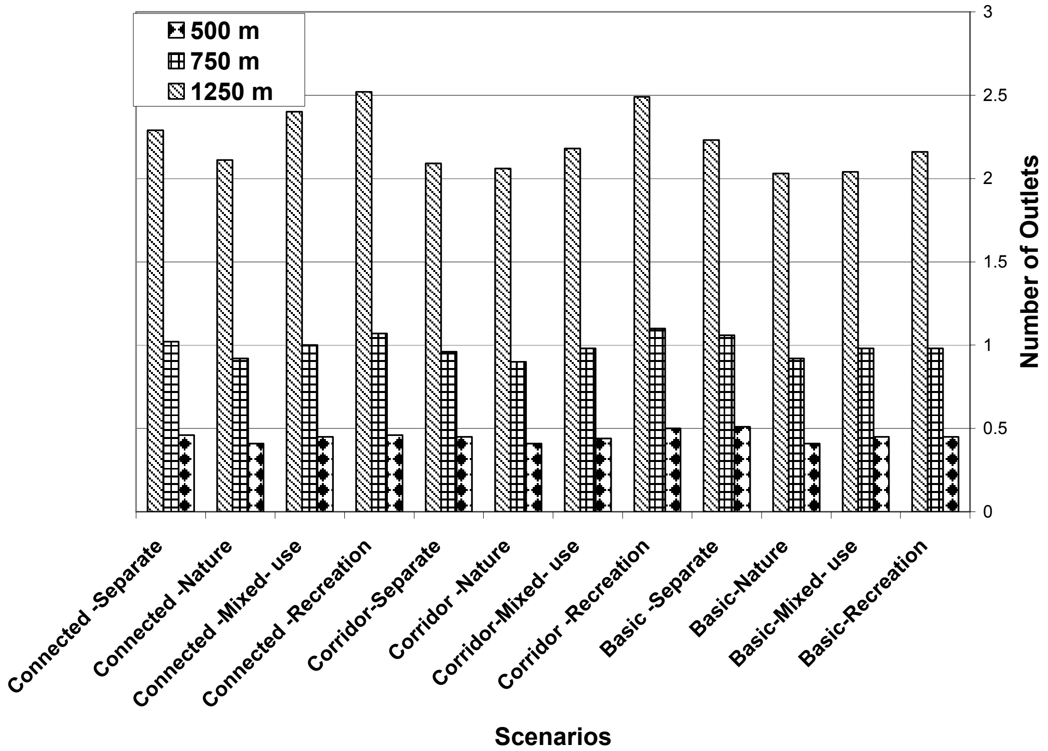


Fig. 8: The number of facilities per distance category

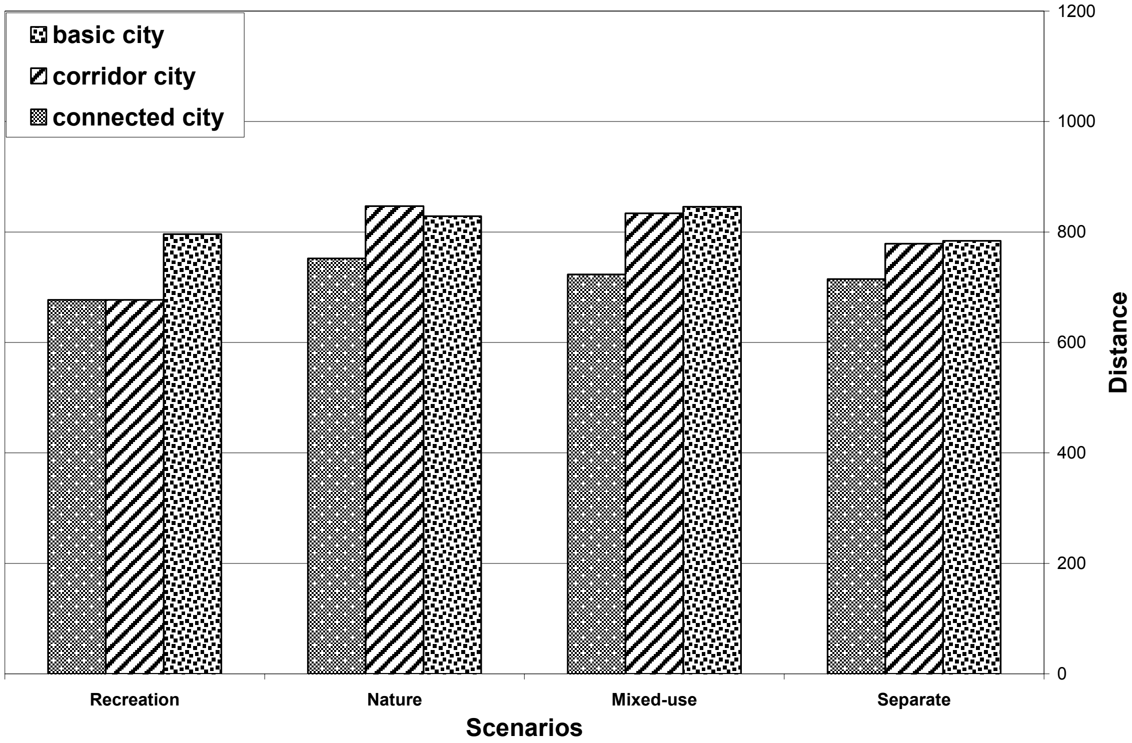


Figure 9: Distance to the 1st nearest facility, average in meters.

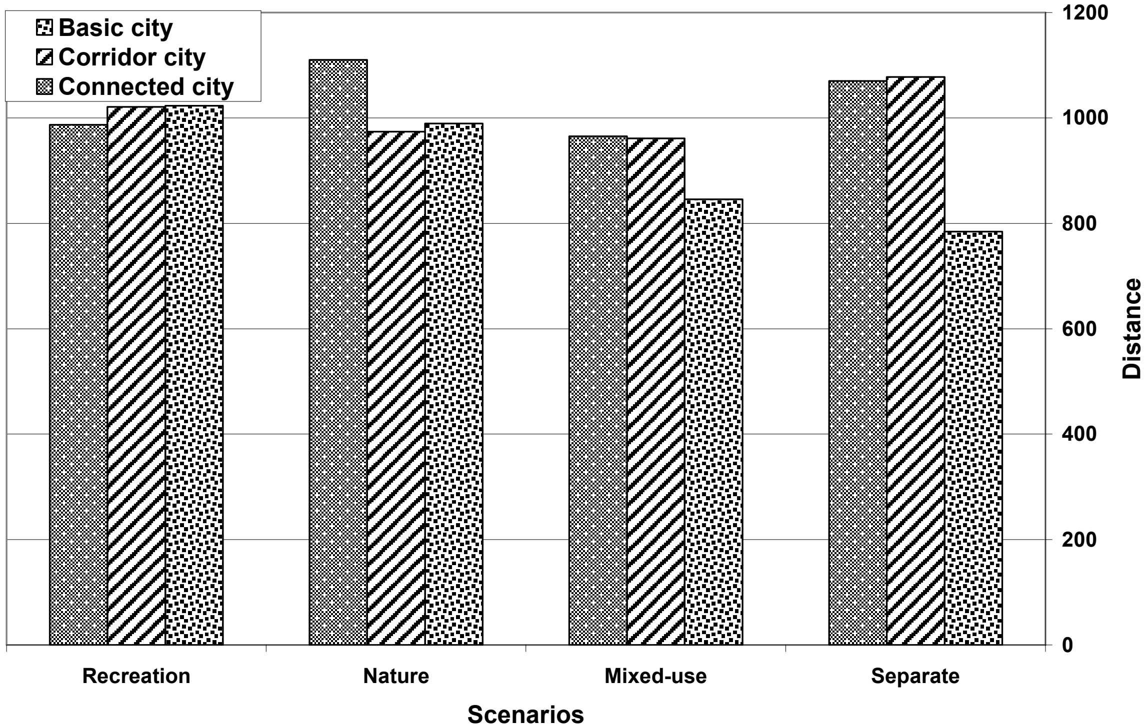


Figure 10: Distance to the 2nd nearest facility, average in meters.

CONCLUDING REMARKS

The current study has examined the likely effects of different planning concepts/scenarios on the development of a city as measured on a series of performance indicators related to mobility, environmental impact, and sustainability. The study is based on a decision support system that first generates basic land use configuration that are consistent with planning norms and expert knowledge and decisions, related to land use suitability, interdependencies of land uses and user preferences. Next, a multi-agent model is used to simulate how the decisions of interacting and co-evolving agents influence the dynamic development of the city, starting from basic urban forms and planning scenarios. The features of these emerging configurations of land use and associated activity-travel patterns are then captured in terms of the performance indicators, which allow planners to gain insight which urban forms and scenarios tend to generate more sustainable development.

The study, although theoretical in nature, is based on data about people housing preferences and an agent-based models daily activity patterns and location choice behaviour. The system has many parameters. In that sense, it will be clear that the generated outcomes are sensitive to the parameter settings. On the other hand, it should also be emphasized that the conjoint model of housing preferences and the activity-based models have been calibrated on empirical data. To the extent that these models capture underlying utilities and choice mechanisms, the results can be generalised in a global sense. Detailed statistics of course depend on the specific configurations of land use. Rather than using more or less abstract city forms, it will be evident that concrete city can be used as input. In that case, the agent-based models will simulate exogenous dynamics of the urban system.
Keeping these specifics in mind, the substantive results of this study suggest that of the different twelve scenarios, the "Compact"- Connected city scenarios perform best based on the considered performance indicators. Thus, if the goals of planning is to reduce emissions (generated by traffic), while maintaining relatively good accessibility to facilities, this urban form should be the target (of those considered). If the choice would be the Connected city, the Separate scenario seems to have some advantages. Because in this case several separated housing areas are surrounded by facilities, individuals' activity-travel patterns are characterized by relatively lower total travel distances and and shorter distances to facilities, a desired combination in terms of reducing emissions and higher social welfare.

Finally, we should emphasize that these conclusions relate to the urban forms and scenarios considered. For example, multi-nuclei forms may influence the ranking results. Future research should therefore examine yet other forms.

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