SUSTAINABLE SPATIAL DEVELOPMENT FOR KWANGJU, KOREA

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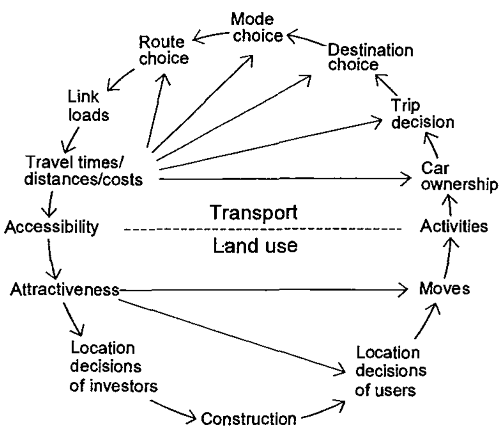
Abstract

The paper reports on a study to explore the feasibility of environmentally less harmful, more compact patterns of spatial urban structure for a city in South Korea, Kwangju. For this task a transport simulation model is combined with a multi-criteria environmental assessment model. The transport simulation model calculates link loads in the road network based on the spatial distribution of residences, work places, schools and shops in 142 traffic zones of the metropolitan area. The environmental assessment model calculates environmental impacts resulting from link loads and actual driving speeds with respect to the spatial distribution and intensity of land uses in the zones using a geographic information system. In the paper the model design, in particular the environment submodels developed, and the results of scenario simulations will be presented.

INTRODUCTION

Environmental problems have become a serious issue in the fast growing metropolitan areas of Far East Asia. The most critical problems are the rapid expansion of built-up areas and the explosive growth in mobility. The ecosystems of these cities have become seriously damaged from the vast losses of open space and biotopes. The incessant growth in traffic demands a heavy toll in terms of noise, air pollution, energy consumption, traffic accidents and time lost in road congestion. Against them many sectoral policies such as expansion of the transport network, improvement of public transport, construction of bicycle roads, improvement of traffic and parking systems, and manufacture of less energy consuming vehicles have been proposed and adopted. However these policies alone have not been enough to reduce the problems, because the expansion of built-up areas and the growth in mobility reinforce each other and aggravate the environmental problems. It can be rather expected that the environmental problems of these cities may become worse in the near future in spite of these policies. The environmental problems in the cities, therefore, should be considered in a comprehensive way with respect to spatial urban development resulting from the relationship of land-use and transport (see Figure 1).



Source: Wegener, 1997

Figure 1 - The 'land-use transport feedback cycle'

The paper reports on a study to explore the feasibility of environmentally less harmful, more compact patterns of spatial development for a city in South Korea with a population of 1.5 million, Kwangju. The central area of Kwangju contains the most important urban and regional functions. There are still many residences in the central city. However recently many residents have moved to outer suburbs because of high land prices and the scarcity of land in this area. The rate of car ownership has increased dramatically in the recent past. Traffic volumes have grown rapidly and are increasingly causing serious problems of traffic congestion, hazardous transport conditions and degradation of the environment. Against this detrimental urban development of Kwangju a sustainable spatial structure should be suggested; urban form and planning can play a role in achieving sustainability (Breheny, 1992).

In the study different combinations of land-use and transport policies to reduce environmental problems of Kwangju are investigated. For this task a transport simulation model is combined with a multi-criteria environmental assessment model. The transport simulation model calculates link loads in the road network based on the spatial distribution of residences, work places, schools and shops in 142 traffic zones of the metropolitan area. This model also predicts the actual driving speeds of automobiles on each link as a function of its capacity. The environmental assessment model calculates environmental impacts resulting from link loads and actual driving speeds with respect to the spatial distribution and intensity of land uses in the zones. In contrast to some recent research on urban form and sustainability with a few environmental indicators such as Rickaby's (1991) modelling of energy consumption and urban form, this model deals with a large number of important indicators for both local resource consumption and pollutants. The model determines noise, air pollution, energy consumption, the amount of sealed-off land (land take) as well as effects on biotopes and the urban climate (heat islands) using a geographic information system.

The model is used primarily to analyse the prevailing environmental problems of Kwangju resulting from its present spatial urban structure. It is used further to construct three scenarios with different combinations of land-use and transport policies in order to identify a sustainable spatial development for Kwangju: a trend scenario (toward further decentralisation) and two alternative scenarios (toward a more compact city and toward decentralised concentration). In this study the extent of spatial interaction and dispersion of location of the scenarios is represented using a format proposed by Brotchie (1984). The model is also employed to experiment with the scenarios and to compare the results with those of the scenarios in order to identify policy packages leading to a more sustainable spatial urban structure of Kwangju.

This study is an PhD project which was ended in November 1998. The paper presents results of the project. It starts by presenting the model design, in particular the environmental submodels developed. The structure of the model, the functions of each submodel and the operation of the model are mentioned. Subsequently the paper describes the study area Kwangju. The location and the spatial urban structure of Kwangju will be briefly illustrated. The paper closes by presenting and comparing the three scenarios and the results of the scenario simulations.

MODEL

The model used for the study is designed to experiment with different combinations of land-use and transport policies (scenarios), to calculate environmental impacts of the scenarios resulting from built-up areas and vehicle mobility, and to compare the results in order to identify a more sustainable scenario. For this purpose the model consists of four components: a scenario technique, a simulation model, an environmental assessment model and a geographic information system (GIS). Figure 2 shows the components of the model and the exchange of data between them.

Each component of the model has a different type of database with a different spatial resolution. As an example the environmental assessment model requires micro spatial database for small-area simulation of environmental indicators. On the other hand the zone-based transport simulation model used for the study calculates link loads based on zonal aggregate data. The model of the project takes a hybrid approach using a GIS to combine these different scales. The GIS (Raster GIS) disaggregates zonal data as well as link loads to about 200,000 raster cells (size of a raster cell is 150 x 150 m) of the study area - one of the four functions of GIS (see below). With this spatially disaggregate database the environmental submodel calculates the impacts on environmental indicators. For this purpose many intermediate programs should be developed. Each submodel subdivided into land-use and transport modul respectively has the following functions (see Figure 3):

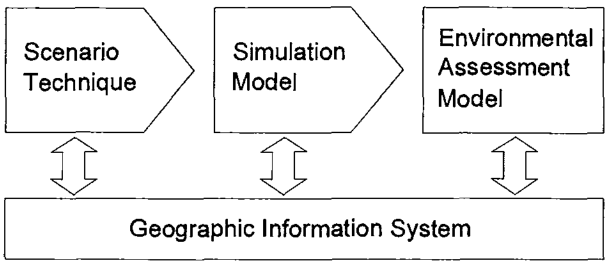


Figure 2 - Model structure

Geographic information system (GIS). The GIS supports other submodels in four fields: *storage of spatial data, generation of new data, disaggregation of data* and *visualisation.* The spatial data of the study area such as zoning system, land uses and transport networks are stored in GIS. This data can be used immediately by other submodels or processed to generate new data using analytical tools of GIS such as overlay or buffering. The raster GIS generates a probabilistic disaggregate spatial data base (Wegener and Spiekermann, 1996b) for the environmental submodels. All other submodels display their input data and intermediate and final results using the visualising function of GIS.

Scenario technique. This submodel prepares different combination scenarios consisting of land-use and transport policies with two separate modules (land-use and transport modules). Three combination scenarios are created taking account of existing planning documents for the future of the study area, opinions of urban planning experts in Kwangju, and theoretical arguments on sustainable urban development: a trend scenario and two alternative scenarios. Each module of the submodel converts the assumptions of the scenarios into zonal and spatial database using a GIS (generation of new data).

Simulation model. The transport simulation model used in this study is a zone-based model adopted from an existing urban simulation model, the IRPUD model (Wegener and Spiekermann, 1996a). This transport simulation model calculates link loads in the road network based on the spatial distribution of residences, work places, schools and shops in 142 traffic zones for each scenario. The transport model also predicts the actual driving speeds of automobiles on each link as a function of its capacity. There is no submodel simulating the distribution and intensity of land uses. The land-use module uses external data which an authorized planning institution has already prepared for the future of the study area. These data are then modified for two alternative scenarios. Simulation outputs are zonal aggregate data. Therefore these data need to be disaggregated to raster cells for the environmental assessment model using a GIS (see above).

Environmental assessment model. This submodel was developed for the study. It calculates environmental impacts of the scenarios based on disaggregated simulation results. Its land-use module determines the amount of sealed-off land (land take), effects on biotopes (loss of biotopes) and the urban climate (heat islands) resulting from the spatial distribution and intensity of land uses with respect to the existing ecological potentials of the area such as open space and biotopes. On the other hand the transport module predicts noise, air pollution (NO_2) and energy consumption resulting from link loads and actual driving speeds. When calculating noise and air pollution, the spatial distribution and intensity of land uses are considered to estimate the percentage of affected population by the immissions after propagation of the indicators (Altenhoff and Lee, 1993). For the calculation of noise and air pollution German guidelines were used (*RLS-90* for noise and *MLuS-92* and *TA-Luft* for air pollution). The calculated environmental indicators are displayed in tabular and graphic form using a GIS (visualisation).

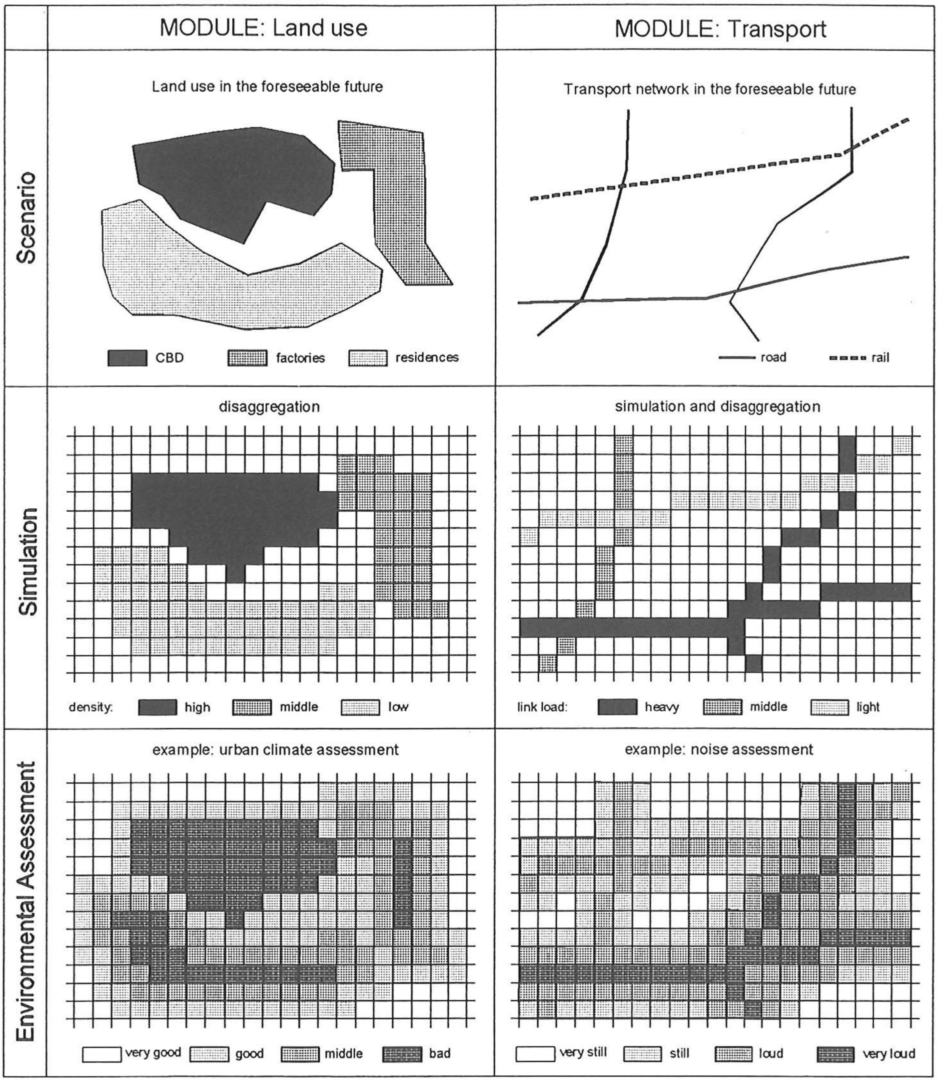


Figure 3 - Functions of submodels

The model with the above functions is used to create different scenarios, to simulate their spatial distribution and intensity of land uses and link loads of road networks, and finally to evaluate them with respect to environmental indicators. In this study the model is used to analyse the prevailing environmental problems of the study area resulting from its present urban structure and to experiment with three scenarios (a trend scenario and two alternative scenarios) to compare their environmental impacts in order to identify a more sustainable urban structure for the study area.

STUDY AREA: KWANGJU

The study area is the urban region of Kwangju, South Korea, located in the south-western province of Chollanam-Do. The urban region consists of the city of Kwangju and its five neighbouring rural districts (see Figure 4). The suburban area which is economically and culturally influenced by the city of Kwangju lies within a distance of 30 km from the centre of the city. The urban region is very compact in the core; the city of Kwangju had in 1990 a population of 1.1 million and the suburban area a population of 0.4 million. The whole study area is subdivided into 142 traffic zones for the transport simulation according to administrative districts.

Kwangju is the fifth biggest city in South Korea. In comparison with other big cities in the country Kwangju has a relatively concentrated spatial urban form. The central area of Kwangju contains the most important urban and regional functions such as work places, schools, hospitals, services as well as shopping centres. Many residences are located also in the central area. However, after the role of a growth pole in the province of Chollanam-Do has been assigned to Kwangju in the 'Second National Physical Plan for 1982-1991', Kwangju has grown fast not only in population but also in urban and regional functions. For this reason many residents have had to move to outer suburbs because of scarcity of land and high land prices in the central area. This suburbanisation process has been strongly reinforced by the introduction of a very compact residential form, 'appartment houses'. In addition, the service sector in the central area has been much more concentrated, while factories are more and more moving to sites in the outer urban districts of the city or in the suburban semirural districts. The rate of car ownership has increased dramatically in the recent past parallel to the increase in income of the population of Kwangju. This decentralising spatial development together with the increasing car ownership generates much more traffic in the central area and inner and outer suburbs of Kwangju. Besides, Kwangju has currently a 'star network', i.e. all roads and railways run to the centre of the city Kwangju (see Figure 5). This type of network aggravates the traffic congestion and transport conditions of the central area of Kwangju because of through traffic between suburbs. The transport simulation model is applied to examine all the traffic problems generated by the present urban spatial form and traffic network of Kwangju. According to the simulation results the main roads which connect the city centre of Kwangju with the centres of suburbs are heavily loaded.

As the last step of the simulation of the present situation of Kwangju the environmental assessment model calculates the environmental problems resulting from the spatial distribution and intensity of land uses and link loads. The number of population severely affected by a noise level of more than 59 dB(A) at daytime is about 5 percent (78, 034 residents) of the population in the study area. The number of population affected by NO_2 concentrations of more than 0.16 mg/m^3 for half a peak hour is about 12 percent (185,659 residents) of the population in the area. It can be seen from the graphic output of the results that the residents mostly in the city centre are severely affected by the noise and NO_2. The gasoline consumption by cars for a day in the area amounts to about 49,800 litres (corresponding to 1.2 tons of CO_2). The amount of land coverage is 5.7 percent (16,523 ha). The ecologically valuable biotopes which are not disturbed by human activities amount to about 66 percent (191,277 ha) of the area. Heat islands are areas which are scarcely ventilated and have high temperature; they amount to 0.4 percent (1,087 ha) of the area.

SCENARIOS

According to 'The Master Plan of Kwangju for 2011' and also the opinions of the urban planning experts of Kwangju the urban region Kwangju will be changed in 2011, so that the population in this area will be increased up to 2.5 million and large amount of new transport infrastructures will be constructed. It can be expected that the spatial structure of the future Kwangju will be much more expanded toward its suburbs.

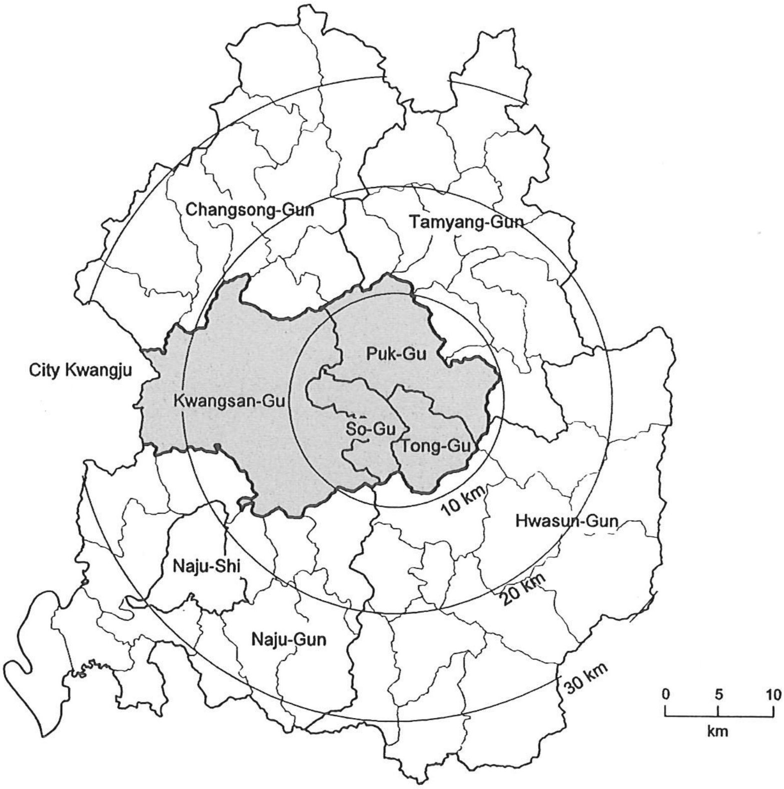


Figure 4 - Study area: Kwangju

With respect to this a Trend Scenario of the most likely land-use and transport policies of Kwangju for 2011 was developed. In contrast to this scenario with further decentralisation, two scenarios discussed in the current literature were selected for investigation: a compact urban settlement structure (Scenario A) based on the reduction of energy consumption by a dense city form (Newman and Kenworthy, 1989) and an urban structure of decentralised concentration (Scenario B) representing an attempt to direct suburbanisation to medium-size suburban centres (Breheny, 1992).

Figure 5 presents the principal roads of the transport networks of the three scenarios. In the Trend Scenario the accessibility within the city of Kwangju and between the city centre and the centres in the inner and outer suburbs will significantly improve. However, the accessibility of the outer suburbs will change only little. Corresponding to this, the residential areas will expand towards the boundary, where the accessibility is improved. In comparison with the present situation of Kwangju the residences will expand very much into the outer suburbs near the city, while new work places will remain within the city Kwangju except factories.

In Scenario A the accessibility within the city of Kwangju and between the city centre and the centres in the inner suburbs will be remarkably enhanced. However, the accessibility of the outer suburbs and between the city centre and the centres of outer suburbs will not improve much compared with the present. Only within the city the residential areas will expand especially in the inner suburbs. Therefore the number of residences and work places within the city will significantly increase, while those of the outer suburbs will grow only little. This is the *compact city* scenario.

In Scenario B the accessibility between the city centre and the centres of inner and outer suburbs will improve remarkably. Also the accessibility within the city will be enhanced but only in a limited area. The accessibility of the outer suburbs will change only little except for the centres. Corresponding to this the residential areas within the city centre and the centres of inner and outer suburbs will expand significantly. Therefore new residences and work places will expand mostly in these areas. This is the *decentralised concentration* scenario.

The transport simulation results in different numbers of trips and link loads in each scenario. The numbers of trips is also different for each transport mode. In the Trend Scenario the road links between the city centre and centres of outer suburbs are most congested. The road links within the city, especially between the city centre and the centres of inner suburbs, are also heavily loaded. In comparison with 1990, the number of trips is more than doubled. Car trips increase almost three times. In Scenario A the road links in the entire urban region are less heavily loaded except those between the city centre and the centres of inner and outer suburbs. Therefore the number of trips in this scenario is much less than in the Trend Scenario. In comparison with the Trend Scenario walking and cycling trips increase significantly, whereas car trips increase much less. In Scenario B the road links between the city centre and the centres of outer suburbs are congested as in the Trend Scenario. However the numbers of total trips is less than in the Trend Scenario and greater than in Scenario A. Car trips increase as in the Trend scenario. However, the numbers of km travelled by cars is much less than in the Trend Scenario. This means that most of the car trips in Scenario B are generated within the city.

Figures 6 and 7 represent the spatial structure of the study region using a method proposed by Brotchie (1984). Figure 6 represents possible constellations of spatial interaction and spatial structure in a diagram (Brotchie Triangle). In the Brotchie triangle spatial structure is represented on the horizontal axis as spatial dispersal (for instance, mean travel distance of employment from the centre of the region), spatial interaction on the vertical axis as some measure of total travel such as mean travel distance to work. Point A represents a situation in which all jobs are in the centre, i.e. dispersal of employment is zero. Points B and C represent regions in which all jobs are dispersed as the population. Point C represents a situation in which all workers walk to work, point B a situation in which they do not take travel time into account. Point D represents the real situation of a city (Wegener, 1997).

Figure 7 represents the spatial structure for the present situation of Kwangju and the three scenarios as well. According to this the present situation of Kwangju (point D_{1990}) lies almost in the middle of the triangle. Point D_T of the Trend Scenario moves towards point B_T (more dispersed location and longer travel distances). The size of the triangle of the Trend Scenario is almost twice as large as in 1990. Point D_A of Scenario A moves also towards point B_T but lies on the left and below point D_T (less dispersed location and shorter travel distances than in the Trend Scenario). The size of the triangle of Scenario A is much smaller than that of the Trend Scenario. Point D_B of Scenario B lies on the right and below point D_T (more dispersed location and shorter travel distances than in the Trend Scenario). The size of the triangle of Scenario B is a little larger than that of the Trend Scenario.

Finally all scenarios were investigated by the environmental assessment model with respect to its environmental impacts on residents and local resources. As expected, the environmental problems of Kwangju in the future will be severely aggravated by the enormous expansion of built-up areas and the corresponding explosive growth in mobility.

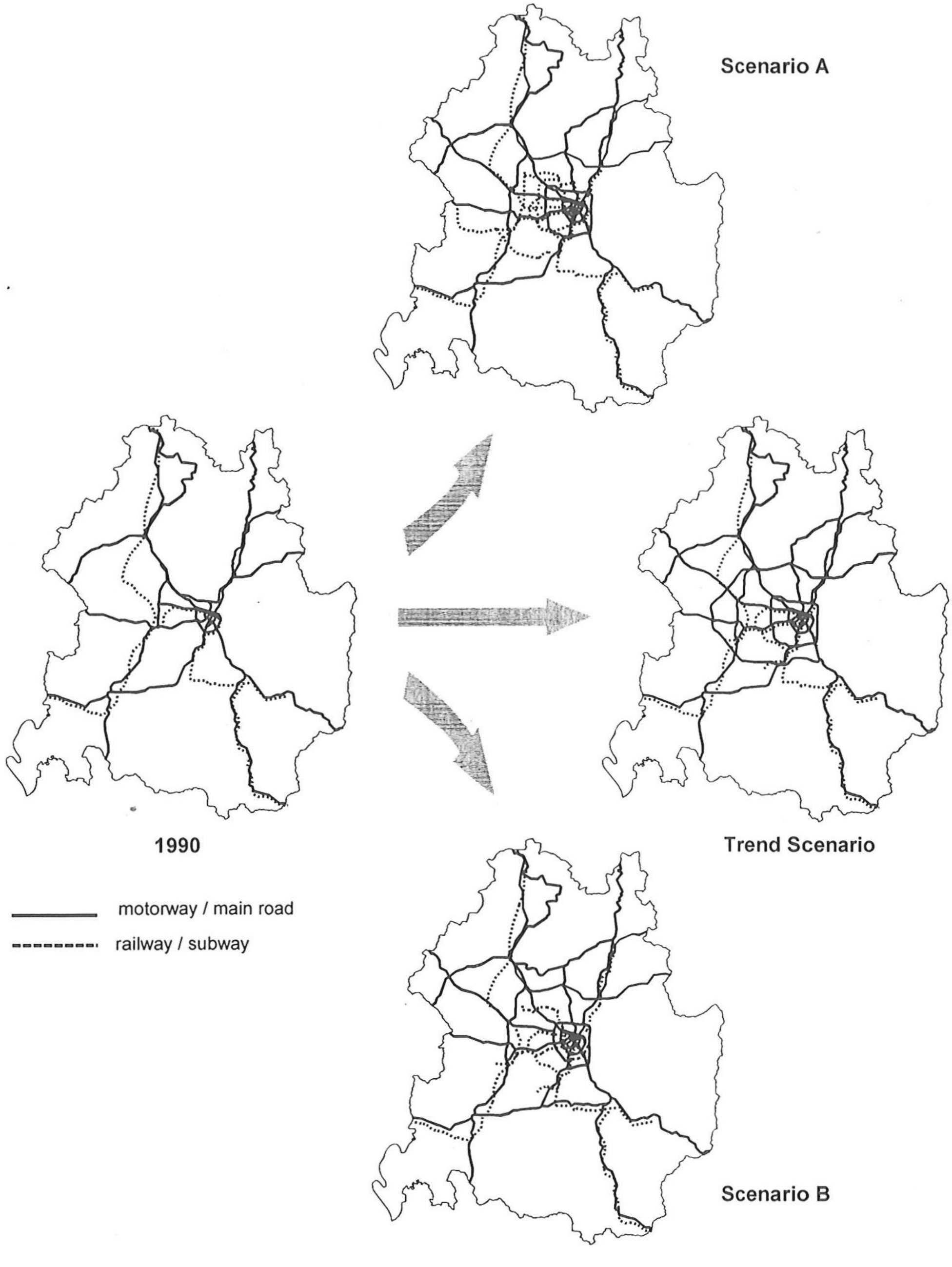


Figure 5 - Comparison of transport networks (principal roads)

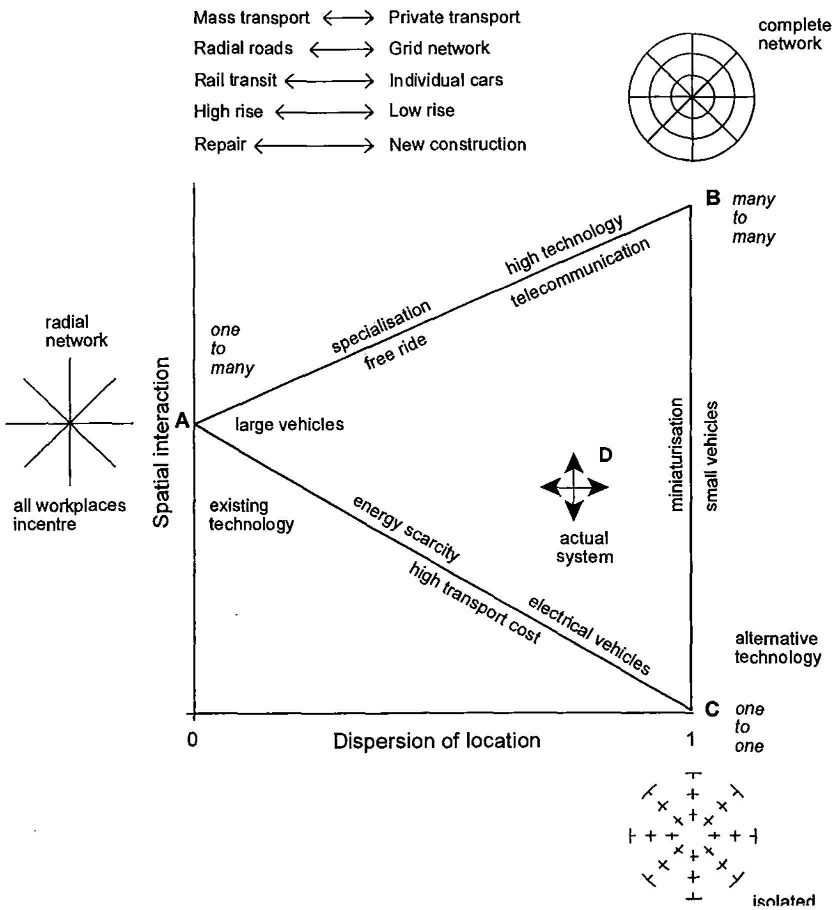


Figure 6 - Brotchie Triangle

According to the environmental calculations, the number of population severely affected by a noise level of more than 59 dB(A) at daytime will be 5.33 percent (137,214 residents) of the population in the area for the Trend Scenario, 5.04 percent (129,626 residents) for Scenario A and 5.12 percent (131,825 residents) for Scenario B. The number of population affected by NO_2 concentrations of more than 0.16 mg/m^3 for half a peak hour will be 12.13 percent (312,103 residents) for the Trend Scenario, 7.84 percent (201,794 residents) for Scenario A and 8.95 percent (230,245 residents) for Scenario B. The petrol consumption by cars in the area will amount to 122,575 litres per day (corresponding to 2.9 tons of CO_2) for the Trend Scenario, 76,498 litres (corresponding to 1.8 tons of CO_2) for Scenario A and 105,287 litres (corresponding to 2.5 tons of CO_2) for Scenario B. The amount of land take will be 9.0 percent (26,089 ha) of the total area for the Trend Scenario, 8.1 percent (23,309 ha) for Scenario A and 8.6 percent (24,781 ha) for Scenario B. Ecologically valuable biotopes will amount to 60.8 percent (175,595 ha) of the area for the Trend Scenario, 62.1 percent (179,451 ha) for Scenario A and 58.3 percent (168,500 ha) for Scenario B. Heat islands will amount to 0.5 percent (1,553 ha) of the total area for the Trend Scenario, 1.0 percent (2,851 ha) for Scenario A and 0.5 percent (1,508 ha) for Scenario B. As an example, noise immissions are presented in Figure 9 comparing 1990 (left) with the three scenarios in 2011 (right).

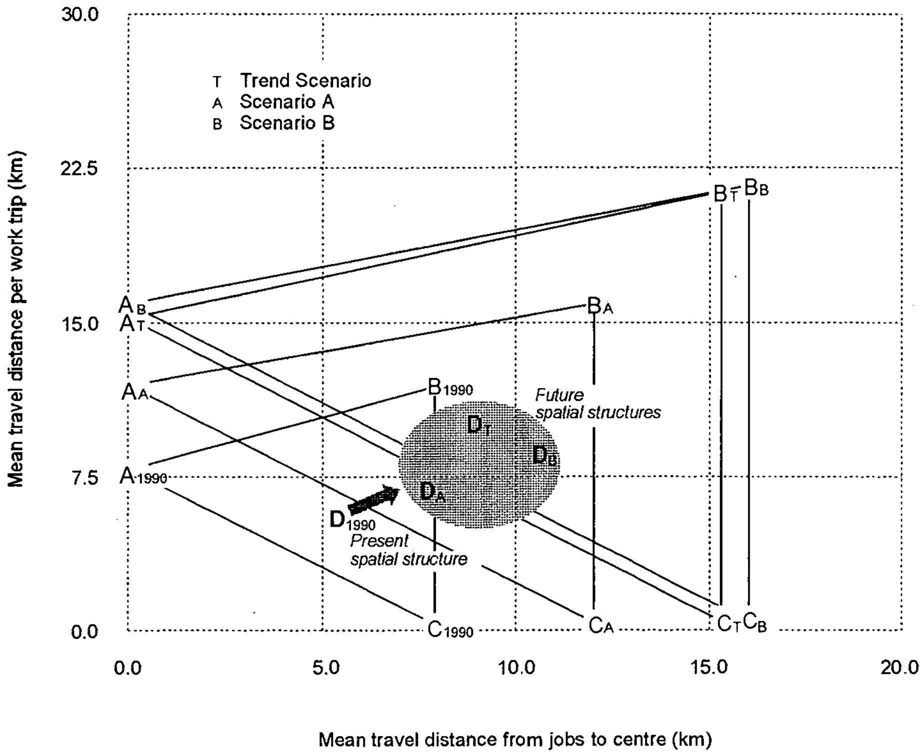


Figure 7 - Comparison of spatial structures

The differences between environmental impacts of the three scenarios are summarised in Figure 8 by comparing them with the present situation. All environmental indicators will have increased by the year 2011. However, the extent of change is very different for each indicator. For example heat islands increase very much in Scenario A because a large part of development takes places in compact high-density form, whereas they change only little in the Trend Scenario and Scenario B, which have a dispersed spatial structure. The reason for these extreme differences lies in the small amount of heat islands in 1990. Therefore heat islands should not be given too much weight in the evaluation of sustainable urban structure of Kwangju. Noise and biotopes have a narrow spectrum of change. From the logarithmic function of noise emission noise immissions do not change with a small difference of traffic loads, whereas NO_2 concentrations change very much even with a difference. Loss of biotopes does not play an important role in this study area because the expansion of residential areas take places mostly on arable land which is not an ecologically valuable biotope because of its chemical pollution.

The scenarios can be now compared with respect to the changes of the impacts on environmental indicators to find a more sustainable spatial urban structure of Kwangju. For this the curves of the environmental indicators of the three scenarios are compared in Figure 8. The figure shows the rank of the scenarios for the sustainable spatial development for Kwangju; Scenario A takes the first rank, Scenario B the second and the Trend Scenario the last rank: Scenario A is the most sustainable spatial development for Kwangju.

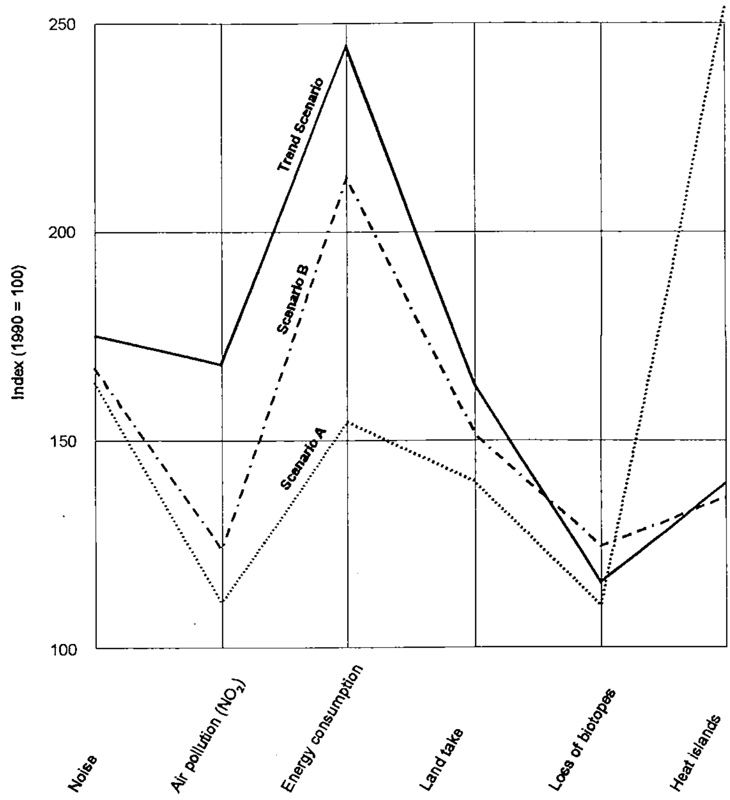
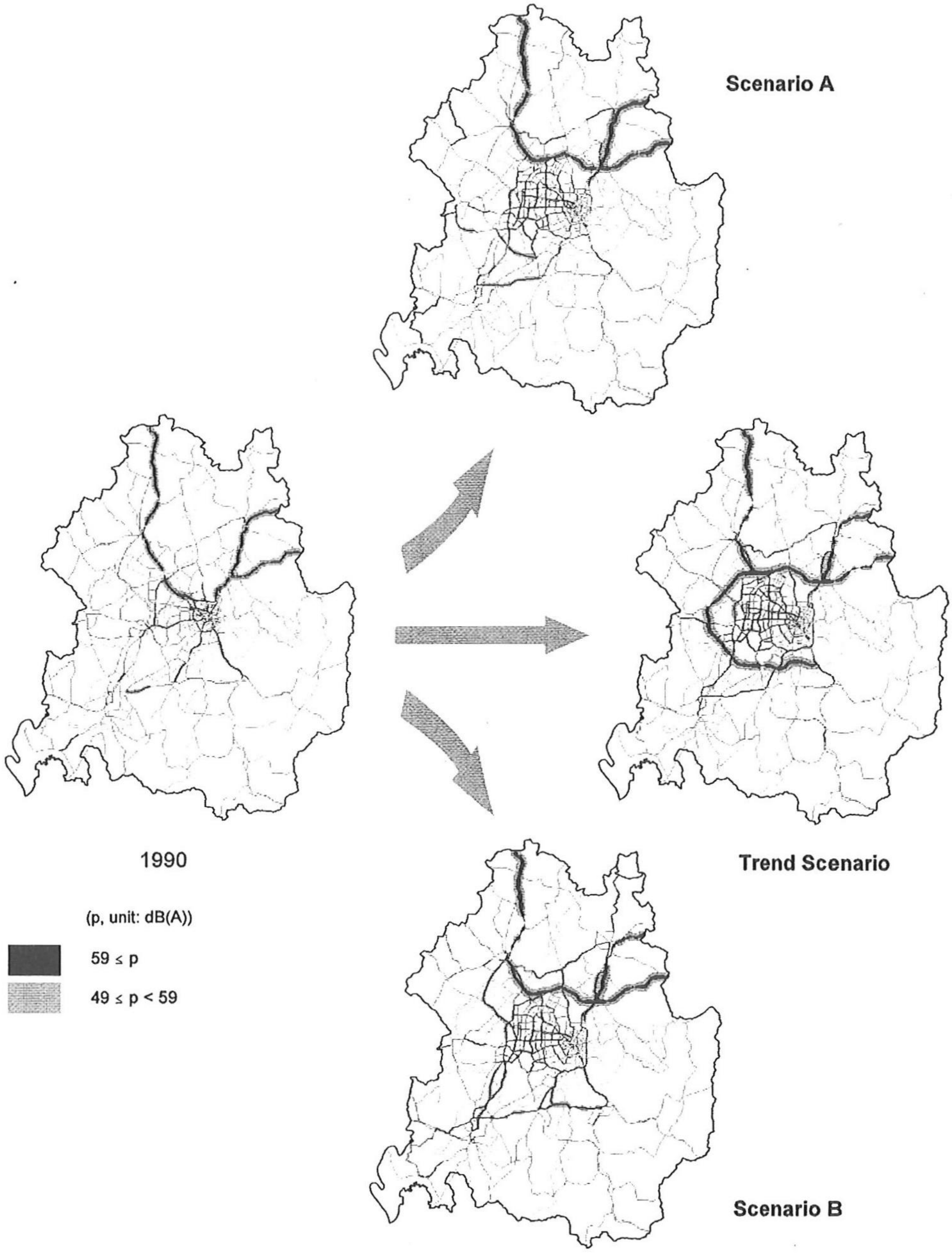


Figure 8 - Comparison of environmental indicators

However, sustainability is not restricted to ecological sustainability (World Commission on Environment and Development, 1987). A sustainable spatial urban structure should be efficient, equitable and ecological. This study concentrated mostly on environmental impacts of spatial urban structure. Quality of life (for example more green spaces) and social aspects (for example differences in being affected by traffic noise) were not considered. If these other aspects were considered, the rank of the scenarios might change. For example, if heat islands, which are related to a comfortable living environment, would be given more weight in the evaluation, Scenario B might be the most sustainable urban development for Kwangju. This further investigation of sustainable urban development will remain for a future study.

CONCLUSIONS

The model described in this paper is used to analyse the prevailing environmental problems of Kwangju and to evaluate its environmental problems that will be caused by the increase in population and the changes in urban spatial structure in the future. It was possible to analyse the environmental problems resulting from different combinations of land use and transport policies. The environmental assessment model calculates the impacts on six environmental indicators which could be affected by policies. Therefore it was possible to compare the results of the scenarios in order to identify the one leading to a more sustainable spatial development for Kwangju. The model can be also applied for other cities.



Scenario A
1990
Trend Scenario
(p, unit: dB(A))
59 ≤ p
49 ≤ p < 59
Scenario B

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