**Overview**

SPARTACUS (System for Planning and Research in Towns and Cities for Urban Sustainability) is a European project undertaken to analyze the implications of urban land use and transportation policies. The SPARTACUS research project included model development and policy testing in three European cities: Helsinki, Naples, and Bilbao. The project has successfully demonstrated a number of analytical approaches that can be used to model metropolitan-level policies not only in Europe, but in the United States as well.

The SPARTACUS system is based on an integrated transportation-land use model, MEPLAN. A Geographic Information Systems (GIS) Raster module is used to process many of the outputs of MEPLAN and to calculate and display micro-scale indicators. Additional analysis tools are used to process other model outputs, calculate impacts, and aggregate the results into economic, environmental, and social indices.

**Some of the primary benefits of the SPARTACUS approach include modeling of the feedback between transportation and land use, and the disaggregation of air quality, noise, and land use data to allow the detailed assessment of socioeconomic impacts.**

**Figure 1. Traffic Noise Levels, Helsinki**

**Helsinki Metropolitan Region**

Note: Large parts of the Helsinki Metropolitan Area are affected by high traffic noise levels. Noise impact areas are large in outlying areas around main roads and highways. However, only a few people live along the noisy links in these areas. In the baseline scenario, about 29 percent of the metropolitan population would feel disturbed by traffic noise in the peak hour.

**Context**

The SPARTACUS project was initiated in 1996 by a consortium of regional planning agencies and consultants in Europe. Its purpose is to assess the sustainability implications of urban land use and transport policies. The approach taken by the SPARTACUS project team was to develop a modeling system for forecasting various indicators of sustainability, and to apply this modeling system to three typical European
cities. Their objectives were twofold: first, to compare the effects of similar policies in different cities; and second, to demonstrate technical methods that can be applied locally to test policies in other cities.

Funded in part by the European Commission under its Environment and Climate Programme and in part by local agencies, the SPARTACUS projects reflect a growing interest in Europe in developing indicators of sustainability and measuring progress on those indicators. Consistent with the 1992 Rio Declaration on Environment and Development, all European Union member states have committed themselves to preparing national strategies for sustainable development and to submit progress reports to the United Nations Commission on Sustainable Development.

The SPARTACUS project team measured "sustainability" through a variety of environmental, social, and economic indicators. The team recognized that they could not measure the sustainability of an urban area in an absolute sense. Nonetheless, they could measure progress on a variety of indicators. From this perspective, progress toward sustainability can be viewed as maximizing social and economic benefits while at the same time minimizing negative environmental impacts and meeting desired social objectives.

The range of indicators (or impacts) tested by the project is relatively comprehensive and includes:

- Travel times and accessibility;
- Emissions of pollutants and greenhouse gases;
- Exposure to pollutants and noise by socioeconomic group;
- Traffic deaths and injuries;
- Land coverage and land use by area;
- Resource consumption; and
- Economic impacts.

The range of policies tested in the SPARTACUS project includes:

- Different types of transportation network and other investments;
- Demand management;
- Various automobile and transit pricing strategies; and
- Land use strategies such as restrictions on outlying land development and redistribution of commercial activities.

Three test cities were selected: Helsinki, Finland; Naples, Italy; and Bilbao, Spain. These areas were selected because of the interest of local partners, the availability of data and modeling tools, and because they represent a diversity of environmental and policy settings. The test city, or regional or national authorities, participated in the project by financing a portion of the work or by participating as a Client-Partner. Client-Partners contributed to developing the system, formulating the indicators, selecting policies for testing, and participating in the definition of weights and value functions for the indicators.

The consortium that conducted the project includes LT Consultants Ltd, Finland; Marcial Echenique & Partners Ltd, UK; Marcial Echenique y Compania SA, Spain; TRT Trasporti e Territorio srl, Italy; and the Institut fur Raumplanung, Universitat Dortmund, Germany. Further work is now underway to expand the SPARTACUS methodology to additional European cities.

Methodology

Analytical Framework

The SPARTACUS analytical framework is illustrated in Figure 2. The system includes four main components:

1. The "engine" incorporates the modeling tools, MEPLAN and the Raster module. MEPLAN is a computer software package based on a land-use transport interaction modeling framework. The Raster module is a GIS-based method to calculate indicator values at a spatially disaggregate level, based on a grid of 100m x 100m cells. These tools carry out the policy simulation and much of the basic mathematical computation.

2. A set of input files that provide data to the models and translate policy packages into a form suitable for model simulation.

3. An integrated GIS module, MEPLUS, that provides tools for policy analysis and reporting of results. MEPLUS includes facilities for storing, manipulating, and screen-browsing of selected model outputs, as well as calculation of indicators and background variables based on the output of MEPLAN and the Raster module.

4. The USE-IT (Urban Sustainability Evaluation and Interpretation Tool) module, a decision support tool that allows the user to define indicators; give weights and value functions to create overall indices of economic, environmental, and social sustainability; and view results in tables or graphical forms.

Figure 2. Analytical Framework
The principles of the MEPLAN model and Raster module, as well as their use in calculating various impacts, are discussed in more detail below. MEPLUS and USE-IT are not discussed here, but more information on these tools can be found on the SPARTACUS web site.

**Land Use - Transportation Model**

**Structure**

MEPLAN was used as the land use-transportation model in the SPARTACUS study. (Each of the three metropolitan areas in the SPARTACUS study had an existing, operational MEPLAN model.) The model has three interrelated modules:

1. The land use module produces a spatial allocation of activities (such as employment and population) and produces trade flows between zones;
2. The transport module assigns flow matrices to different transportation modes and routes and calculates the resultant transportation disutilities; and
3. The interface module converts land use trade matrices into transportation flow matrices and, conversely, converts transportation disutilities into trade disutilities.

MEPLAN is based on the principles of economic input-output models as well as random utility models from the transportation sector. Three key theories drive the model:

1. Interactions between activities are determined by input-output analysis (for example, coefficients state how much of an input factor is required by households in different socioeconomic groups);
2. Locational choices, mode choices, and route assignment are determined by random utility models; and
3. Capacity restrictions in the land and transportation markets alter prices and thus affect disutilities.

The three MEPLAN modules are applied dynamically, with land use affecting transportation and vice-versa; feedback typically occurs in five-year increments. The interface module is used in such a way that land use changes produce immediate changes in the demand for transport, whereas transport changes have only gradual effects upon the pattern of land uses and trades.
Data Requirements and Calibration

The MEPLAN model is custom-built for each area for which it is applied, based on the availability of information and on relationships which best reflect the area and the users' interests. Typical inputs for the land use submodel include population, employed persons, land and floorspace area, incomes, land prices, and goods vehicle travel by area. Employment must be separated into an exogenous (basic) and an endogenous (non-basic) element to drive the input-output mechanism.

The transportation submodel inputs, which describe the transportation network and trip patterns, are similar to those for typical four-step transportation modeling systems. The land use and transportation models may be built on different zonal structures; for example, economic data may be available at the jurisdictional level for the land use module, while transportation data may be provided at the traffic analysis zone (TAZ) level for the transportation module. The interface module translates between these different zone structures.

Additional information on the MEPLAN model is provided in the Sacramento case study.

Outputs

A large volume of information is generated by running the model. Typically, this includes:

- Land use characteristics by zone, including households by socioeconomic group, employment by type, and land/floorspace by type;
- Zonal cost information, including cost of living, income, and rental incomes;
- Characteristics of transportation by mode, traveler type, and zone pair;
- Screenline traffic counts and loaded networks;
- Summary statistics such as vehicle-miles of travel, vehicle-hours of travel, energy consumption, and emissions; and
- Total trips, average distance, average user cost, and average travel time for each travel type/user mode combination.

The model also offers an economic evaluation module that can be used to compare alternative policies or scenarios. This module is based on flows of money (e.g., transit fares) as well as other benefits such as time savings. Using principles of consumer surplus, the model provides a measure of the distribution of benefits among firms, households, the government, transport operators, and landowners/developers. In the SPARTACUS study, net economic benefits are divided by the population of the region to achieve an overall economic indicator value.

Comparison with Other Land Use/Transportation Models

MEPLAN is one of a number of packages available for modeling the interactions between land use and transportation. The overall level of effort as well as the sophistication of these packages varies considerably. Among models that have been applied in the U.S., DRAM/EMPAL and HLFM II+ require somewhat fewer data inputs and a lower level of modeling effort. MEPLAN, TRANUS, and UrbanSim are examples of models that require more data and effort to develop, but at the same time can model a broader range of relationships with greater sophistication.

Models such as MEPLAN, TRANUS, and UrbanSim have a strong economic foundation, and business and residential location decisions are modeled based on a range of factors. Land markets are key to the modeling framework, with prices driving development. This is in contrast to models such as DRAM-EMPAL that re-allocate land use only on the basis of transportation accessibility. UrbanSim advances the state of the practice by using the logit model structure, typically used to predict transportation mode choice, to model a broad range of decisions such as business and residential location.

At the same time, some of the economic data required to calibrate MEPLAN or other large-scale urban models may not be readily available. For example, in many urban areas, a single database on factors such as land prices. Data on goods movement - such as truck trip generation, truck flows, or goods flows - are also typically poor. Commonly available data sources may not provide a breakdown of exogenous versus endogenous employment at less than the county level. As a result, any region considering implementing a land use/transportation model should carefully consider the availability of data as it relates to modeling requirements, in addition to other factors such as staff resources.

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Policy Scenarios

To test alternative policies and policy combinations, the following approach was taken:

1. A "Reference Scenario" was constructed, based on the existing network and committed projects as well as baseline land use forecasts.
2. A list of policy ideas was drafted. These fell under the categories of land use, pricing, regulation, and transportation investments.
3. The mechanism for modeling the policy in the SPARTACUS system was identified. In some cases, measures had to be tested indirectly. For example, land use controls were modeled as a redistribution in employment and population, consistent with the objectives of the controls.
4. Individual policy elements (e.g., changes in transit fares) were tested and screened using the MEPLAN run results only. This helped demonstrate the effects of individual measures as well as check that the model system produces reasonable results.
5. Based on the MEPLAN results, the most promising policy elements were selected for further testing using the entire SPARTACUS system to generate indicators.
6. Combinations of policies were selected for analysis. In some cases, effective policies were combined to evaluate joint impacts. Policies were also combined when one policy could offset the negative side-effects of another policy. For example, lower transit fares and teleworking could offset some of the negative effects of higher car pricing. As policy combinations were analyzed, additional policy elements were added incrementally, while policies that had a negative or inconsequential impact were dropped.
7. For each policy combination, the absolute or percent change for the indicators were calculated with respect to the Reference Scenario. Also, pairwise comparisons of scenarios were performed to evaluate the effects of adding or dropping individual policy elements.
8. Alternative scenarios were also tested, based on exogenous variables, such as higher-than-projected growth in population.
9. The results were compared for all three test cities.

Findings

Figure 7 illustrates the results of some of the policy combinations on the overall indicator values. "B" represents the baseline (Reference Scenario) indicator level. Green bars indicate a positive (desirable) change in the indicator value, while red bars indicate a negative (undesirable) change.

Figure 8 illustrates the results of a pricing scenario on the distribution of employment, while Figure 9 illustrates the results of the same scenario on the distribution of population. Note that the scenario causes employment to shift to middle-ring zones, while population shifts toward the center of the metropolitan area, compared to baseline forecasts.

Figure 7. Policy Result Graphs
Figure 8. Impacts of Pricing on Distribution of Employment, Helsinki


**Figure 9. Impacts of Pricing on Distribution of Population, Helsinki**
The comparisons showed that some policies had consistent effects in all three cities, while others had different effects depending upon local conditions. Some overall findings include:

- The most effective policies to improve the sustainability indicators were pricing policies. Increases in car operating costs of 50 to 100 percent decreased car mileage by roughly 15 to 25 percent. Pricing policies led to some negative side effects, but these could be offset by other policies. For example, reductions in accessibility to the city center could largely be offset by land use policies and public transportation investments. Car pricing increases greater than 100 to 150 percent had negative marginal economic and social benefits.

- Land use policies alone did not have significant effects, and some land use policies (such as moving either population or employment to balance jobs/housing ratios in zones) did not improve the indicators. The authors concluded that land uses had already adapted to the transportation system. However, redistribution of both population and employment resulted in some positive impacts, particularly in combination with other policies.

- Some measures to decrease travel demand, such as carpooling, teleworking, and some public transport scenarios, led to long-term increases in car mileage. This is because these policies initially resulted in less congestion, which allowed households to move to more peripheral areas where car use increased.

- Investment programs alone had limited potential to improve environmental and social indicators. In some cases, the effects of individual projects in an overall investment package worked in opposite directions so there was little net effect on the indicators.

- Reducing car speeds had positive environmental and social effects, but these were outweighed by the negative impacts on mobility.

- Some results, such as the equity of exposure to noise and pollution, were not consistent among the three cities. This suggests that local conditions are important in determining these measures.

These results, of course, may not directly apply to U.S. cities, which have different urban forms and transportation systems than their European counterparts. Also, the study did not include some important measures such as the equity of mobility/accessibility impacts. Nevertheless, the results demonstrate the power of an integrated transportation and land use modeling system to provide insights into a range of alternative policies, both individually and in combination.

**Conclusions**
Strengths

The SPARTACUS project was admittedly a large-scale modeling project with substantial data and resource requirements. It is not necessary to apply all elements of the approach at once, however. For example, the GIS analysis of emissions and noise exposure can be applied independently of the land use model. Also, a smaller set of policy scenarios or impact measures can be defined.

Overall, the case study illustrates a number of features that are relevant to metropolitan-level transportation and land use scenario testing in the United States. Specifically:

- An urban land use-transportation model can be used as a platform to develop environmental, social, and economic indicators for assessing policy options. This allows the inclusion of intermediate effects, such as household and employment relocation in response to policies, that are not typically accounted for in a transportation model.
- Maintenance of land use and network data in a raster-based (grid cell) GIS environment allows environmental impacts, including air quality and noise, to be identified in a spatially disaggregate format. This allows both the total affected population and the distribution of impacts by socioeconomic group to be estimated. It also permits the effective graphical display of impacts.
- While exposure to air pollution and noise are traditionally measured only at a project level, simple pollutant dispersion and noise models can be used to assess these impacts at a regional level as well.
- The inclusion of truck traffic and an economically based land use model can more fully assess economic, transportation, and land use impacts that relate to industry as well as to households.
- Large amounts of information can be aggregated down to a small number of indicator values (e.g., environmental, social, and economic) based on a set of user-defined weights.
- Reduction, management, and display of large amounts of model-generated information can be facilitated with appropriate tools for post-processing model output.
- Screening of individual policies based only on land use-transportation model output reduces the time and effort involved, since post-processors do not have to be applied to every policy or combination. In addition, the thoughtful combination of promising policies, compared through an incremental process, can result in the reduction of a potentially large number of combinations to a manageable set of scenarios.

Equity and social justice implications of alternative scenarios can be quantified in a number of different ways. The SPARTACUS system allows the user to select any of four options for valuing equity impacts. While the selected option can impact the relative ranking of the scenarios, in the SPARTACUS study, those that performed well under one option tended to perform well under all four.

Limitations

- The SPARTACUS project was admittedly a large-scale modeling project with substantial data and resource requirements. Application of the MEPLAN model, in particular, may require some data not readily available in all U.S. urban areas (data requirements for MEPLAN are also discussed in the Sacramento case study.) It is not necessary to apply all elements of the SPARTACUS approach at once. For example, the GIS analysis of emissions and noise exposure can be applied independently of the land use model. If this were done, however, the results would overlook potentially important feedback relationships between transportation and land use. Also, a smaller set of policy scenarios or impact measures can be defined.
- The SPARTACUS study was a research study rather than a component of a planning process. Therefore, the usefulness of the study results for local planning and decision-making has not been demonstrated. Nevertheless, the study was conducted with input from local agencies and should provide useful information to local decision-makers.
- The use of a single model (MEPLAN) for both land use and transportation simplifies the modeling process by eliminating the need to link two different models. However, while the transportation component of MEPLAN is reasonably sophisticated, it may not contain all of the features of a state-of-the-practice regional travel model. Therefore, areas with a more advanced travel model may lose some precision if they use an integrated transportation land use model rather than interfacing a land use model with their own travel model.
References

Published References


SPARTACUS web site: [http://www.ltcon.fi/spartacus/](http://www.ltcon.fi/spartacus/)

Contacts

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