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Nijkamp, P.; Baggen, J.; van der Knaap, G.A.

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SPATIAL SUSTAINABILITY AND THE TYRANNY OF TRANSPORT: A CAUSAL PATH SCENARIO ANALYSIS

Peter Nijkamp

*Department of Economics
Free University
Amsterdam
Netherlands*

John Baggen

*School of Systems Engineering
Policy Analysis and Management
Delft University of Technology
Delft
Netherlands*

Bert van der Knaap

*Economic Geography Institute
Erasmus University
Rotterdam
Netherlands*

ABSTRACT This paper aims at positioning spatial development at the crossroads of the conflicting needs for spatial mobility and spatial sustainability. Such tensions have explicitly been recognized in recent local, national and international policy documents. A reconciliation of such antagonistic driving forces in our modern network economy requires a solid theoretical framework in which the relevant force fields are depicted and in which the uncertainties inherent in any attempt at steering human behavior in space are explicitly recognized. This requires an analytical framework in which relevant scenarios are systematically projected on a model structure describing the above mentioned force field. This paper will try to offer an operational methodology for coping with the above mentioned conflicting issues in planning for sustainable spatial development. Particular attention will be given to the spatial scale of analyzing sustainable development. The methodology will be illustrated by presenting empirical results from a case study undertaken in the western part of the Netherlands, the so called Randstad.

1. SUSTAINABILITY IN SPACE

The modern western world is rapidly moving towards a *complex network economy* in which *spatial interactions*—both physical and non-physical—are an essential and dominant feature. The increasingly important role of *infrastructures* (road, rail, air, waterways, telecommunication) witnesses the network megatrends of our society. Transport and communications play a critical role nowadays, as they add significantly to the synergy of the multi-layer, multi-modal and multi-actor connectivity structure of modern economies, in which *globalization* trends appear to take place simultaneously with a rising sense

of *local identity and regional self-reliance*. This multi-faceted configuration is not only affecting the position of central regions, but has also far reaching implications for peripheral regions (for example, the internal border regions in Europe; see for instance Cuadrado-Roura et al. 1994 and Nijkamp 1994).

The strategic position of transport and communications in a mobile and interactive society has, however, also its shadow sides which is mirrored in environmental and other *externalities* at all levels, such as air pollution, noise annoyance, visual intrusion, destruction of landscapes and of historic city centers, congestion, accidents and the like (see Barde and Button 1990; Button 1994). This means that *spatial externalities*, in which environmental externalities are linked to land use patterns and site-specific developments, are an intriguing and policy-relevant issue. Spatial dispersion creates interactions, and the resulting mobility patterns generate—spatially discriminating—external costs which impact in turn on residential and industrial location patterns. Clearly, the above observations suggest at the same time the need for closely connected and coordinated physical planning and infrastructure planning principles.

An important widely accepted principle nowadays is *environmentally sustainable economic development*, advocated in particular in the Brundtland Report (see WCED 1987). The rather abstract and global concept of sustainable development is currently 'translated' in a variety of ways towards more concrete and meso-oriented focal points of policy interest and competence, such as sustainable industry, sustainable agriculture, sustainable tourism, sustainable city and sustainable transport (see Van den Bergh and Verhoef 1994). All such concepts try to find a balanced—or co-evolutionary—pathway for socio-economic interests, distributional (or equity) considerations and environmental constraints. In the spirit of these concepts various measurable indicators have also been suggested recently, such as critical loads, permissible threshold values, maximum sustainable yield, carrying capacity, environmental utilization space or maximum environmental capacity use (see Nijkamp and Vleugel 1994).

The description and operationalisation of sustainability at a meso level is still fraught with many ambiguities, although the direction of policy is normally rather clear. For example, in the new Community strategy of the European Union (EU) several attempts have been made to offer guidelines for sustainable mobility and sustainable transport, inter alia by setting out strict environmental standards for various modes of transport and by promoting guidelines for infrastructure and the development of urban transport. Such guidelines would "discourage unnecessary transport demand and encourage where appropriate the development of alternatives to road transport, such as railways, inland waterways and combined transport" (EC, 1992, p. 127). At the same time, also the socio-economic significance of mobility is recognized, as this should "contain the impact of transport on the environment, while allowing transport to continue to fulfil its economic and social functions, particularly in the context of the Single Market, and thus ensure the long term development of transport in the community. It should also contribute to social and economic cohesion in the Community and to the creation of new opportunities for the peripheral regions" (EC, 1992: p. 128).

In the Dutch context sometimes the notion of 'spatial quality' is used, in order to express the need to care for the daily quality of life in a densely populated country which is suffering from heavy traffic, at least in the western part of the country. It is noteworthy that maintenance of 'spatial quality' is at the same time also propagated as a policy strategy to be internationally competitive and to attract more foreign investments. Consequently, a significant increase in major transport infrastructure projects is foreseen (even though regional and local transport needs also improvement and mass transit public transport investments in metropolitan and urban areas are still lagging behind). Therefore, there is a need for a thorough scientific analysis of spatial conflicts in terms of land use, transportation infrastructure and environmental quality. This requires the use of a systemic model encapsulating the various driving forces at hand, in order to generate more environmental-benign pathways to spatial sustainable development.

The above described methodology forms the essential contribution of the present paper, which is organized as follows. Section 2 will be devoted to a further exploration of spatial sustainability issues in the context of spatial scenario design. Then in the next section a concise description will be given of recent problems in spatial development and transport policy in the Netherlands, with a particular view on the Randstad. Section 4 will then describe the structure of a causal path model and present empirical estimates. Next, Section 5 will focus on future developments in a scenario context, while Section 6 will present spatial sustainability results from various scenario experiments. The paper will be concluded with a retrospective evaluation.

2. DESIGN OF SCENARIOS FOR SPATIAL SUSTAINABILITY

Despite the abundance of literature on the issue of sustainable development, it appears that an operationalization of this concept at the concrete level of regions or transport systems is not an easy task (see Van den Bergh 1991; Giaoutzi and Nijkamp 1993). *Sustainability in space* refers in general to an ecologically compatible spatial and socio-economic development in a spatial system, taking into account mutually conflicting but also mutually supporting developments in all areas of that system. This means that a certain development in space does not jeopardize the interest of other land users, now and in the future. Clearly, the spatial scale of analysis is of critical importance here. A rather promising approach which ensures a balance between theoretical-conceptual justification and operational validity is to construct a spatial system's model which would depict the structural relationships of the system under consideration (both nodes and corridors) - focusing in particular on those variables which are (directly or indirectly) linked to sustainability notions - and to assess and evaluate the outcomes of such a system's model on the basis of alternative policy-relevant scenarios for spatial, economic or infrastructural development (see also Meadows et al. 1982; Nijkamp and Blaas 1994).

Sustainability (in space) is closely connected with spatial externalities. Such externalities emerge as a result of the geographical separation of economic activities and related transport flows, and are hence site-specific. The existence of externalities in a network may have—given the synergy and interdepen-

dence—system-wide impacts in relation to both supply and demand of transport; in any case a distinction has to be made between mobile sources (e.g., vehicles) and fixed facilities (e.g., infrastructure).

In the context of sustainable development strategies it has in the recent literature become common to make a distinction between *weak and strong sustainability* (see e.g. Van Pelt 1993). A strong sustainable development implies an improvement of all constituents of a welfare function, without allowing for a decline in any component. A *weak* sustainable development would still imply a rise in the overall welfare function, but would allow for some trade-offs in terms of positive and negative changes in some components. This distinction has of course a clear interpretation in a spatial system, as substitution and compensation can easily be envisaged in different areas of such a system. Consequently, spatial sustainability will normally be weak in nature.

Another distinction concerns *internal and external* sustainability, where internal refers to sustainable development (be it weak or strong) inside a given area, and where external refers to resulting sustainable developments (be it again weak or strong) in adjacent areas. Thus the latter distinction refers to the *open* nature of spatial system (see also Nijkamp and Opschoor 1994).

The achievement of *ecologically sustainable spatial and socio-economic development* means that spatial mobility in a network economy should not be harmful to quality of life and should at the same time ensure a sufficient level of access to all necessary services in a network society (cf. Owens 1992). In consequence, we may position mobility in the framework of spatial sustainability in the following force field (Figure 1).

In light of the interactions in the force field depicted in Figure 1, it is now important to look at ways in which a mobile network society can be organized and influenced so as to fulfil conditions for spatial sustainability. This requires the design of a concise conceptual model in which causal links.

FIGURE 1. The force field of spatial mobility

between behavioral variables, external conditions and policy handles are included. In a later stage this general model can then be extended, operationalized, and empirically filled. Figure 2 gives an illustrative presentation of the main structure and components of such a model. Clearly, the degree of complexity of such a model in an empirical setting is relatively high, so that in practice one has to resort to a more simple and less comprehensive structure.

It is evident that the design and implementation of effective policies focused on spatial sustainability presupposes a complex assessment and evaluation, characterized by a high degree of uncertainty regarding facts and behavioral responses, now and in the future. Therefore, it is plausible to use scenario experiments—in the form of 'flight simulators'—to test and evaluate alternative options and policies. Consequently, it is then necessary to construct scenarios in a systematic way in order to deal adequately with the complex issue of spatial sustainability. Clearly, a myriad of *angles* for designing scenarios may be imagined. We will present here six possible angles (reference criteria) which may be relevant for alternative spatial development options and from which future scenarios addressing sustainability issues may be derived (see also Masser et al. 1992).

1. External circumstances (EC). Examples are:

- demographic developments, migration, changes in labor force participation, life style changes etc.
- macro- and international-economic developments, changes in employment levels etc.
- major changes in international power blocks, alliances etc.

2. Spatial lay-out (SL). Examples are:

- changes in spatial concentration or deconcentration (including compact city strategies)
- shifts in locational patterns, e.g. from urban to suburban or peripheral areas etc.

3. Mobility patterns (MP). Examples are:

- changes in commuting or recreational behavior, frequency of trips etc.
- qualitative changes in commodity distribution (e.g., high value, low volume) etc.

4. Technological changes (TC). Examples are:

- new developments in vehicle technology (e.g., electric cars or zero-emission cars)
- improvements in infrastructure networks etc.
- introduction of telematics for fleet management etc.

5. Scale of transport system (ST). Examples are:

- metropolitan or local roads etc.
- trans-European networks etc.

FIGURE 2. A conceptual model for spatial sustainability

- international hub-and-spokes systems or gateway developments

6. *Types of transport policy intervention (TP). Examples are:*

- price and fiscal regulations (e.g., road pricing) etc.
- organizational and institutional rules for transport systems (e.g., cabotage rules) etc.

Each of these six categories can now be used to typify transport systems and hence a blend of these angles may form the basis for scenarios. This is illustrated in Figure 3.

This approach leads clearly to a broad spectrum of possible scenarios which can next be evaluated on the basis of suitable judgement criteria, such as economic performance (*efficiency*), distributional fairness (*equity*) and environmental quality (*sustainability*). The methodology for evaluating such scenarios will be described later on this paper, after an exposition on actual environmental problems in the Netherlands and after the empirical estimation of a causal path model for the Randstad area in the Netherlands. Having discussed now some important building blocks of spatial sustainability analysis and related scenario aspects, we will give in the next section a concise outline of some current spatial and environmental issues in the Netherlands.

FIGURE 3. A typology of transport system's characteristics as a basis for spatial sustainability scenarios

3. SPATIAL AND ENVIRONMENTAL ISSUES IN THE NETHERLANDS

The Netherlands is one of the most densely populated countries in the world, with an extreme high residential and industrial concentration in the western part (the so-called Randstad or Rimcity). Also the density of roads and—to a lesser extent—of railways in this part of the country belongs to the highest ones in Europe. In addition, the Randstad houses two major main ports, viz. the port of Rotterdam and the airport of Amsterdam. It goes without saying that consequently the environmental stress in the Randstad is a source of permanent public and policy concern (cf. Priemus 1994). Land use planning and environmental management has consequently become a major policy issue in the country. As a result, the development of land use for various purposes and its related environmental impact has in the past decades been governed by strict physical planning regulations, supported by strategic policy documents on land use planning, environmental management, and traffic and transport policy (see Van der Knaap and Van Delft 1989; Van der Knaap and Baggen 1991). In this respect, spatial policy in the Netherlands is unique in that for several decades already many efforts are being made to achieve a coordinated policy between various conflicting objectives on the one hand and between institutional actors (state government, province and local authorities) on the other. One of the successes of this policy has, for instance, been the protection of the so-called Green Heart of the Randstad, the spacious low density central area of the Randstad which otherwise would have been lost (see for various scientific contributions on this area a recent publication by Dieleman and Musterd 1992).

We will first offer now a sketch of some megatrends governing the development of the Randstad, followed by a picture of various recent policy initiatives. Such megatrends are based on past and current observations and form the starting points for spatial scenario analysis. The following *megatrends* can be mentioned:

(i) international

an increasingly important position of the Randstad in the European 'Blue Banana,' even though in the past decade the economic force field has shifted towards Southern Germany (see also Nijkamp 1993).

an increasing political importance of Mediterranean countries in European developments, including transport and infrastructure.

a new orientation in eastward direction (after the opening up of Central and East-European countries) and in north-eastward direction (after the increasing connectivity with Scandinavian Countries).

the construction of new international infrastructures such as high speed train links and the Channel Tunnel. The increasing importance of Brussels as the administrative centre of Europe.

(ii) national

a continued suburbanisation process at small distances (in the form of satellites such as Zoetermeer or Capelle aan den IJssel) or long distances (in the form of growth centers such as Almere or Purmerend) from major cities.

a continued interest in compact city movements as a principle for urban planning and design.

an increasing commuting distance in which housing and labor markets move more towards polycentric spatial structures.

a decline in regional disparities in the Netherlands, so that the traditional role of regional policy is gradually vanishing.

(iii) Randstad

despite many spatial claims, a continued support for the Green Heart principle of the Randstad.

a growth of the Randstad towards a complex urban zone with multiple centers and a differentiated housing and labor market (urban field).

an increasingly important role for metropolitan areas as a new administrative institution in public policy.

(iv) local

a trend toward large scale core projects in larger cities (Utrecht, Rotterdam, Amsterdam).

a shift from traditional urban policy to more business-oriented city management and marketing.

an increasing interest in modern light rail connections for (sub)urban mass transit.

In order to cope with all these developments and to ensure spatial sustainability in the Randstad, strategic policy concepts and measures have been developed and implemented in the past years. Here we will focus our attention mainly on physical planning, transport policy and environmental management.

(i) physical planning

Various future spatial scenarios for the Randstad have been designed in the past years ranging from nation-wide pictures (e.g., Act Local - Think Global, A World of Regions, or Randstad Worldcity) to Randstad-specific pictures (e.g., Randstad Ring, Randstad Network of Cities, or Randstad Regions). A common element is that the Green Heart concept is still dominant, but that the action radius and the sphere of influence of the Randstad is increasingly reconsidered, including for instance also parts of the

southern and eastern regions of the Netherlands. This means that internationalization of the Randstad economy is increasingly stressed, a view which is also expressed in the decisions to favor simultaneously two international main ports, viz. Amsterdam and Rotterdam, and to invest also heavily in international infrastructure networks (e.g., transport corridors).

(ii) *transport policy*

Transport infrastructure has become a focal point of policy interest, as it clearly reflects the tension between international accessibility (and competitiveness) and environmental sustainability. Significant investments are foreseen in railway infrastructure and in general in public transport in the Randstad (see also Nijkamp and Oosterman 1994). In addition, the infrastructure debate is increasingly positioned in an international context (Rietveld 1994), witness also the discussions on high speed links with Belgium/France and Germany. In principle, the transport system will be subdivided into a Eurocity/Intercity, an Interregional and a Regional/Agglomeration network. In all cases the notion of sustainable development in the transport sector was explicitly present (although it is noteworthy that the notion of road pricing has temporarily been rejected in the Netherlands).

(iii) *environmental management*

The recognition of environmental decay has induced in the Netherlands a wide variety of policy initiatives ranging from clean air, water and soil Acts to strict environmental impact assessment procedures. Furthermore, at a European level an increasing number of environmental management plans is being developed (for instance, the EC Green Paper on the Impact of Transport on the Environment, 1992), in which a plea for 'sustainable mobility' can be found. In general, the Brundtland Report has had a far reaching impact on Dutch environmental policy, a development which was strongly supported by the large number of thorough environmental studies of the National Institute for Health and Environment Protection (RIVM).

In the context of the general debate on environmental protection, much attention has been given to land use planning in the Randstad, e.g. via the creation of buffer zones and a 'Randstad Green Structure'.

It is clear from the above observations that spatial sustainability in a dynamic network economy with a high degree of mobility is an ambitious goal, especially if the transport system has to be based on an increasingly important role of public transport in combination with a complementary role of private transport (Frieling 1994). This means that at the level of both the Randstad as a whole and its constituent urban areas a balanced land use and infrastructural development has to take place. This situation is, in light of the diversity of the spatial structure of the Randstad, not easy to reach and requires a supply-based *service system* which should increase the efficiency of the transport system without impacting nega-

tively on the ecological quality conditions. In the context of the physical planning tradition in the Netherlands it seems thus an interesting new departure to investigate how the supply of the service and facility structure for transport (e.g., infrastructure, complementary services) can ensure a sufficient level of accessibility in the complex structure of the Randstad with its myriad of criss-cross relationships in a polycentric ring, where at the same time spatial sustainability in relation to environmental quality is guaranteed. This requires a thorough investigation of the service level of the Randstad transport system and its consequences for ecological compatibility. Such a system would have to fulfil economic conditions (e.g., accessibility), high quality conditions (e.g., service levels) and ecologically sustainable spatial development (e.g., quality of life).

For analytical purposes, it seems meaningful to describe the Dutch transport facility and service system on the basis of quantitative indicators for the following characteristics:

- functionality (e.g., service level, system features)
- modality (e.g., public transport, private transport)
- transport system typology (e.g., infrastructure, vehicles etc.).

Clearly, all such characteristics have a service structure with a certain service level. They form also the distinct ingredients for the modeling experiment of this paper. In the next session, we will give a more analytical representation of the service level and structure of the transport system in the Randstad, using a causal system's model which depicts all multifaceted relationships of mobility and infrastructural services in this area.

4. A CAUSAL PATH MODEL FOR SPATIAL MOBILITY AND SUSTAINABILITY

The conceptual approach offered in the previous sections will now be operationalized by specifying a model structure on the basis of measurable indicators (or variables). This model gives an explanatory (causal) pattern of transport and sustainability phenomena in the Randstad on the basis of a multidimensional stimulus-response supply-oriented approach, so that the model—once calibrated or estimated—can also be used to trace consequences of various future scenarios. The model will be limited to passenger transport in this area.

The model used here aims to be a blend between *comprehensiveness* and *simplicity*, by focusing on key forces and constraints in a spatial system with different areas from the viewpoint of spatial sustainability. The design of the combined modeling scenario experiment is based on the principle that the greater the number of models connected in a complex chain, the lower the quality of prediction (see Karplus, 1992). This leads to an analysis framework in which *qualitative/quantitative scenarios* are linked to a *causal path model*.

Methodologically, the *causal path model* adopted here gives a multi-dimensional explanatory picture of a set of *latent* variables (denoted as LV) which are connected on the basis of stimulus-response linkages and which are mea-

sured by means of sets of *observable or manifest* indicators (denoted as MV). In statistical terms, this latent variable model will be estimated by means of PLS algorithms (partial least squares; see also Lohmöller 1989, and Wold 1982). The basic structure of this model is as follows: This causal path model needs next a formal operationalisation of its constituent variables. First, the scores of the manifest variables have to be *standardized*, using so-called z-scores, which means a zero mean and a unit standard deviation, so that quantitative results can easily be interpreted. Next, all manifest variables in a spatial system have to have the same *reference framework* in that they have to be scaled for an appropriate spatial unit in order to avoid heteroscedasticity. In annex A a formal definition of all LV's and MV's is given. The latent variables X, Y and Z refer in general to the quality level of private transport systems, the quality level of public transport systems and the level of environmental decay, respectively.

FIGURE 4. Results for the estimated causal path model

After the definition and operationalisation stage of the various indicators in our causal path model, the coefficients of the model can be estimated on the basis of empirical values of the successive manifest variables. Essentially two steps have to be undertaken here, viz (i) the *identification of significant manifest indicators* impacting on the latent variables and (ii) the *execution of an effect analysis* on the basis of a reduced model. The final outcomes of a PLS-model can essentially be evaluated from three angles, viz. (i) links between latent variables, (ii) (spatial) variance between latent variables, and (iii) links between a latent variable and its constituent manifest variables.

The results of the statistical estimation of our PLS-model are contained in Figure 4. These results can be interpreted as follows.

The *internal relations* (i.e., the connectivity between latent variables) are represented by the estimated values of the three path coefficients in Figure 5. We observe that LV Z is almost equally 'explained' by LV X and LV Y. Apparently, both private and public transport services and facilities have a negative impact on local quality of life, but the previous result does not imply that each km of infrastructure in both categories (private and public) has the same impact, since this depends on the value and sign of the coefficients linking latent to manifest variables, as will be discussed hereafter (the so-called *external relations*). It should also be noted here that X and Y refer to supply characteristics of network infrastructure and do not necessarily reflect use intensity.

It is also important to examine the *variance* in the explanatory model. It turns out that the variance in the endogenous latent variable LV Z (i.e., negative quality of life impacts of passenger transport services and facilities) is for 86% explained by the underlying latent variables LV X (i.e., private transport facilities) and LV Y (i.e., public transport facilities). The variance in LV Y (i.e., public transport facilities) is only explained for 74% by LV X (i.e., private transport facilities).

Finally, we will take a look at the *external relations*. All estimated parameters (i.e., weights) in Figure 5 have a positive influence. The positive scores on LV X are largely determined by MV X1, MV X4 and MV X5. Thus, the quality aspect of motorways has a high weight; most manifest variables appear to refer to system's facilities.

The high scores on LV Y are mainly caused by MV Y1, MV Y2 and MV Y3, so that again system's facilities appear to be of decisive influence. Finally, the weights regarding LV Z appear to be fairly high.

Clearly, in order to determine the real influence of any of the explanatory manifest variables on the endogenous latent variable LV Z, the corresponding weight has to be multiplied with the related path coefficient. In this framework, it can be estimated that the quality of life consequences of one km of the private transport system is far higher than that of public transport infrastructure. It should also be emphasized once more, that the relationships between the successive variables in our model are exclusively related to supply-based determinants, so that a fair judgement would of course also have to consider the actual use of these transport supply categories.

Statistically, it should be noticed that the t-test for our PLS-model suggests that the explanatory values of MV X2, MV X3, MV X6, and MV Y4 are not clearly significant, so that it makes sense to eliminate these variables from

our model¹. This leads then to a reduced model, as shown in Figure 6. The results of this model are only marginally different from those in Figure 5. We will use the latter model for further experimental purposes, as it also fulfils all plausible standard t-tests.

After the final estimation of the reduced model, it is now possible to determine the latent variable LV Z from the values of LV X and LV Y, while the latter two variables can be calculated via the weights from their corresponding constituent manifest variables. On the basis of this approach one may next assess the Randstad outcomes for the latent variables LV X, LV Y and LV Z for each regional unit distinguished (see Figure 6).

These maps can in a concise way be interpreted as follows. The facilities level of the *private* transport system in the Randstad is relatively high in the (medium) large cities, with the exception of a few cities like Dordrecht or Hilversum. Also the urban agglomerations of Amsterdam and Rotterdam score relatively good.

The facilities level of the *public* transport system in the Randstad is largely similar to that of private transport, although it is noteworthy that—in contrast to private transport infrastructure—the public transport system has a high quality in the southern wing of the Randstad (in particular the area enclosed by Leiden—The Hague—Rotterdam—Gouda). In general, the public transport system is better here than in the northern wing of the Randstad.

FIGURE 5. Results for the reduced causal path model

FIGURE 6. Spatial depiction of values of reduced form values of all manifest variables in the sustainability model for the Randstad

Finally, the (negative) *spatial sustainability* indicators show somewhat more variation. The general picture is that regions with a satisfactory or high level of private and public transport system's facilities are here scoring significantly lower in terms of quality of life. The best performance in terms of spatial sustainability is found in the Green Heart and various medium size cities following some sort of concentric pattern. In general, the impact of the private transport system on spatial sustainability in the Randstad appears to be more severe than that of the public transport system. Clearly, it has to be recognized that this conclusion is only based on *supply-oriented* information and not on the *density of spatial demand* in the Randstad.

5. DESIGN OF SPATIAL DEVELOPMENT SCENARIOS FOR THE RANDSTAD (2015)

It is clear that the Randstad is a complex web of spatial interactions, where a myriad of driving forces (both internal and external) is at work. In principle, it would be possible to develop a combinatorial scenario analysis for all possible long-term developments instigated by exogenous events, internal transport and physical planning strategies, and spatial behavioral responses, as indicated in Section 2. In view of the great many uncertainties and combinations, in this study a choice has been made between two types of reference criteria, one external and one internal criteria, viz. *demographic development* (related to EC in Figure 3) and *spatial concentration* (related to SL in Figure 3). The reason why the combinatorial choice of scenarios has been limited to these two major orientations is that in many recent policy studies in the Netherlands these two factors have been identified as key forces, while other developments may mainly be regarded as variations around this central theme (like TC or ST in Figure 3) or as consequences/policy responses to these compound scenarios (like MP and TP in Figure 3). For each of these two reference criteria two variants (or contrasts) have been distinguished, viz. a high and low variant.

The *demographic* reference criterion includes both natural growth and (in)migration and is based on statistical information from the Central Bureau of Statistics in the Netherlands. This information source contains detailed statistical data on regional migration movements and national population growth. This information - in combination with expectations on future housing construction in each of these areas - has been used to compose both a high and a low growth demographic scenario.

Next, we will use the spatial concentration reference criterion for the identification of *spatial (de)concentration* options. It is clear that various types of spatial lay-out in the Randstad (e.g., compact city design, population dispersion and ongoing suburbanisation) will have different implications for transport flows and the related spatial sustainability in each area in the Randstad. Based on various studies which in the past decade have been undertaken for the Randstad, two main variants of dispersion have been studied in more detail and used as key scenarios, viz. concentration and deconcentration. This presupposes of course also due insight into housing construction programs in all municipalities in the Randstad in the next two decades.

TABLE 1. Compound spatial scenarios for the Randstad

		spatial lay-out	
		concentration	dispersion
demographic	high	<i>scenario i</i>	<i>scenario ii</i>
growth	low	<i>scenario iii</i>	<i>scenario iv</i>

In consequence, the following combination of reference criteria has been used for the design of compound scenarios in view of in our exploration of the future spatial sustainability in the Randstad (see Table 1).

Each of these scenarios has implications for the size and direction of development in the Randstad. Such implications may largely be described in a compact form as follows (see Table 2).

The above mentioned spatial—demographic scenarios for the Randstad have to be consistent with quantified housing and workplace developments in all areas in the Randstad. Consequently, a spatial distribution of households, jobs, offices and industrial areas has to be made, taking into consideration prevailing physical planning procedures in the Netherlands. Complementary information on the conditions imposed by the Green Heart and its buffer zones is also necessary. The same applies to all necessary adjustments in the private and public transport infrastructure and its related service and facility aspects. All this information has been quantified at a detailed level for all areas in the Randstad (see for details Baggen 1994), and will next be used to assess the expected impacts of scenarios for the Randstad in the year 2015.

6. TRANSPORT AND SPATIAL SUSTAINABILITY IN THE RANDSTAD: SCENARIO FORECASTS

In this section we will portray the long-term consequences of the four scenarios presented above with a view on a sustainability test of these scenarios. The causal path model described in Section 4 will be used here as an analytical tool for making conditional forecasts. This means that - by means of Figure 5 - the - spatially disaggregate and detailed - characteristics of each of the scenarios outlined in Section 5 will be used as inputs for the reduced form equations, on the basis of the chain of linkages between (MV X, MV Y) and (LV X, LV Y) on the one hand, and between (LV X, LV Y) and LV

TABLE 2. Spatial characteristics of compound scenarios

	development Randstad ring	centrifugal development	centripetal development
<i>scenario i</i>	•	•	
<i>scenario ii</i>	•		•
<i>scenario iii</i>	•		
<i>scenario iv</i>		•	•

Z on the other hand. At the end the (negative) spatial sustainability consequences—incorporated in MV Z—can then be assessed.

In our four spatial distribution scenarios, the variables MV X5, MV Y1 and MV Y3 may be regarded as *policy* variables, whereas MV X1, MV X4 and MV Y2 may be regarded as *structure* variables whose values are more robust vis-à-vis the various scenarios. The values of the policy variables (e.g., infrastructure investments in terms of length and site) stem from the specific scenario features and are introduced as inputs into our model. This is in line with the various different angles which have been used to compose scenarios (see Section 2).

This leads then to four scenario-specific sets of input variables, in which also all policy relevant variables are area-specific in the Randstad. The same applies to structure variables where, for instance, demographic conditions and housing construction plans lead to site-specific consequences, which can be estimated by means of regression analysis (see Baggen 1994).

Next, the expected area-specific transport supply and sustainability implications—denoted respectively by the LV X, LV Y and LV Z variables—will be gauged for the year 2015, using the causal path model described above. These quantitative results are next depicted in Figure 7. The scores in these maps represent the relative position of each area with respect to the average value in the Randstad. Thus the images of all these maps cannot be compared in absolute, but only in relative terms within the scenario for 2015 itself.

The images from Figure 7 indicate clearly relatively higher values of all variables in and around urban areas in the Randstad. For the variable representing private transport services and facilities (LV X), it turns out that the implications of the various scenarios are fairly well and plausibly depicted (e.g., the position of Hilversum). The public transport services and facilities (LV Y) show, for instance, clearly the expected implications of new urban transport investments in the areas of The Hague and Rotterdam. Finally, the negative impacts on the quality of life development (LV Z) represent clearly the implications of the four physical planning scenarios for the Randstad, e.g. regarding concentration, ring development etc. The same applies to the consequences of population growth. The LV Z images of Figure 7 show convincingly that especially urban areas will face the threats of an unfavorable spatial sustainability in case of higher mobility levels in the Randstad. The maps are clearly able to identify all areas in the Randstad with a vulnerable sustainability pattern. Examples of such vulnerable areas are Haarlemmermeer near Amsterdam, the area between Rotterdam and The Hague, Zoetermeer and Valkenburg near The Hague, Nieuwegein near Utrecht, and Gouda and its environments in the Green Heart. In view of the environmental-benign role of public transport, a compact city system and concentrated physical planning seems to offer promising favorable sustainability consequences.

Although physical planning may be a suitable instrument to ensure a co-evolutionary development of mobility, accessibility and amenities, it should be recognized that population developments may pose severe restrictions. Clearly, especially the (medium) large cities in the Randstad score often very high with regard to negative amenity effects, so that due attention for these problem situations is needed. The results seem to call in general for a con-

FIGURE 7. Implications of four development scenarios for the Randstadvariables in the sustainability model for the Randstad

FIGURE 7. Implications of four development scenarios for the Randstadvariables in the sustainability model for the Randstad (continued)

tinued active role of physical planning in the Randstad. If physical planning is unable to solve the various bottlenecks identified for the Randstad, a spill-over to areas adjacent to the Randstad will likely take place, thus aggravating the current problem situations. In conclusion, spatial concentration seems to offer the best sustainability consequences for the Randstad.

7. RETROSPECT AND PROSPECT

This paper has made an attempt to identify sustainable futures of a space-economy. It is indeed a major challenge to rationally explore future options for spatial development, taking into consideration that modern transport and communication systems in a network economy have to strike a balance between opportunities and impediments. *Strategic and pro-active research* will be necessary to satisfy the needs of individuals, groups and society at large; this is also a sine qua non for overcoming the—often frustrating—social dilemma in an individualized society. Cohesive spatial modeling and strategic scientific reflection are necessary in order to alleviate severe bottlenecks for sustainable spatial development and to create a sense of voluntarism in shaping the physical and geographic structures of a country. Scenario experiments - supported by solid empirical modeling work - seem to offer a window of creative opportunities, provided they are governed by strict methodological guidelines focusing on a consistent analysis of the force field of social, economic, political and institutional interests.

Clearly, much research still remains to be done. The notion of sustainability in space is not unambiguous, neither in terms of substance nor in terms of policy strategies in an open spatial system. In the transport sector there is much need for a thorough analysis of *intervention and regulatory principles* ensuring a balanced co-evolution of various regions, while at the same time there is a need to investigate the potential and significance of *self-organizing strategies* (notably in case of market and intervention failures). Another issue which would deserve much attention is the question why people in a voluntary society *do not exactly behave* (in terms of responses to measures or loyalty questions) *as they should behave* in our scientific perception of the space-economy. Consequently, the achievement of spatial sustainability may - despite good intentions - yet become problematic. This poses a final question of a fundamental nature: is the speed of our ability to encapsulate our current spatial network society keeping pace with the speed of its increasing complexity caused by multi-layer, multi-modal and multi-actor ramifications and mechanisms?

NOTES

1. It should be noted that the t-test in a PLS-model does not allow definite conclusions (in contrast to a LISREL-model) as no assumptions on the distribution of variables and error terms are made.

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APPENDIX

Definition of Manifest Variables in Causal Path Model

In this Annex the various manifest variables in our causal path model will concisely be described; more details can be found in Baggen (1994). In all cases the explanatory variables have to be interpreted in the sense of 'the higher the better'. For example, a high score of various MV's on LV X means a high quality of the service structure of private transport. The endogenous variables incorporated in LV Z refer to sustainability (or quality of life) variables and have to be interpreted in a 'negative' sense ('the lower, the better'), as all indicators concerned refer here to negative aspects of quality of life (such as noise etc.).

(1) *Supply structure private transport*MV X1: *Fuel stations*

This variable is defined as the number of fuel stations per square km.

MV X2: *Complementary facilities*

This variable refers to the quality level of fuel stations by calculating the average complementary sales area per fuel station.

MV X3: *Car shops and service stations*

Also here the relevant manifest indicator is calculated as the number of car shops per square km.

MV X4: *Road network*

The road network indicator represents the network density of roads, calculated as the total length of all relevant roads per square km.

MV X5: *Main roads*

This variable refers to the total length of main roads (corrected for numbers of lanes) per square km.

MV X6: *Complementary road service areas*

This variable comprises inter alia parking space, carpool points and many other service areas; they are measured as the average number of such service areas per square km.

(2) *Supply structure public transport*MV Y1: *Terminals and stops of railways*

The quality of access of the railway system is measured by means of the number of terminals and stations per square km.

MV Y2: *Terminals and stops of bus and tram*

The complementary service provided by buses and trams is measured by the total number of stops per square km in a given area.

MV Y3: *Car infrastructure network*

This variable measures the length of railway connections (corrected for number of tracks) per square km in a given area.

MV Y4: *Complementary services at railway stations*

The quality level of complementary railway services is measured as the density of such services (e.g., Park & Ride places, train taxi's, bicycle rent facilities etc.) in a given area.

(3) *Environmental decay*MV Z1: *Car wrecks*

This variable represents the density of car wrecks in a certain area.

MV Z2: *Anti-noise screens*

This variable is measured as the total length of anti-noise screens in some area, corrected for the presence of open asphalt on the road.

MV Z3: *Fuel consumption*

Energy consumption is used here as a proxy for the level of all kinds of air pollution in an area and is measured as the total sales of fuel per square km in some area.

MV Z4: *Space consumption infrastructure*

The land use by main road and railway infrastructure is measured as the surface occupied by a given length and width of an infrastructure segment per square km in a given area.

MV Z5: *Spatial fragmentation caused by infrastructure*

The spatial fragmentation caused by infrastructure connections is approximated here as the length of various connections per square km in some area.

MV Z6: *Traffic unsafety*

The safety indicator - seen from the supply side - refers to lighting, signalling and quality of asphalt and is calculated as an unweighted average of all these services per square km in a given area.

It should be noted here that high values of MV Z2 and MV Z6 do not mean a high quality of life; on the contrary, the prevailing low quality of life necessitated to invest in abatement investments. Thus, for all MV Z scores a lower value is to be preferred to a higher one.

All above mentioned MV's have been calculated at the level of so-called Economic-Geographical Areas in the Randstad. For each of the three classes of latent variables (i.e. LV X, LV Y and LV Z) the corresponding constituent manifest variables have been assessed and represented in classes of 'very high', 'high', 'average', 'low' and 'very low' on maps for the Randstad (see Figure 6). Clearly, high scores on the MV Z variables (figure 6, the lower (Z)) mean a low quality of life performance. Such maps are also interesting, as they may be used in a later stage for scenario experiments, as described in Sections 5 and 6. For all maps the following interpretation based on standardized z-scores holds:

- very high: $z\text{-score} \geq 1.00$
- high: $0.25 \leq z\text{-score} < 1.00$
- average: $-0.25 \leq z\text{-score} < 0.25$
- low: $-1.00 \leq z\text{-score} < -0.25$
- very low: $z\text{-score} < -1.00$