Measuring Sustainable Accessibility

Jianquan Cheng *
Department of Environmental & Geographical Sciences
Manchester Metropolitan University
John Dalton Building, Chester Street
Manchester, M1 5GD, UK
Telephone: (0044) 0161 247 1576
Fax: (0044) 161 247 6344
Email: J.cheng@mmu.ac.uk

Luca Bertolini
AMIDST
Department of Geography and Planning
University of Amsterdam
Nieuwe Prinsengracht 130
1018 VZ, Amsterdam
The Netherlands
Telephone: (0031) 020 525 4007
Fax: (0031) 020 525 4051
Email: l.bertolini@uva.nl

Frank le Clercq **
AMIDST
Department of Geography and Planning
University of Amsterdam
Nieuwe Prinsengracht 130
1018 VZ, Amsterdam
The Netherlands

Submission date: August 1, 2006
Revised: November 15, 2006
Final version: March 20, 2007

Word Count: 6,040 + 6 figures (1500) =7,540

* Corresponding Author
** Prof. le Clercq, a major force behind this work, has since, and sadly, deceased
ABSTRACT

Transport is one of the most significant sources of un-sustainability in urban regional areas. This challenge is stimulating urban planners and decision-makers to incorporate the concept of sustainability into their policy design at various levels. Despite its successful implementation in several sectors and wide recognition in the academic and professional debate, sustainability is still not as evident in day-to-day regional planning practice. Interpretable measures integrating accessibility and sustainability and linking with policymaking practice are relatively scarce. This paper aims to make some steps towards measuring sustainable accessibility, which in turn is intended to help regional planners define the potential problems and design possible alternatives at strategic planning level for a sustainable regional transport and land use system. The proposed methodology for such measurement consists of the concept of conflicts in the planning process, job opportunity modeling, sustainability and spatial conflict analysis. The Amsterdam urban region in the Netherlands is taken as a case study and sustainable accessibility is measured in an integrated GIS environment, followed by corresponding policy implications for strategy design. The experimental study demonstrates that the indicator of sustainable accessibility can be incorporated into the process of strategic policy design.
INTRODUCTION

The major trend characterizing urban transportation in the 20th century is the increasing preference for, and use of, private cars instead of public transport, walking and cycling [1]. Cars have provided people with unprecedented levels of mobility. However, the negative impact of transportation activities on the environment and people has also increased dramatically. The transportation sector has been the fastest growing energy-consuming sector during the last two decades and is responsible for a major contribution to global warming and climate change. Transport is one of the most significant sources of un-sustainability in urban areas [2]. These challenges are stimulating urban planners and decision-makers to incorporate the concept of sustainability into their policy design at various levels.

Sustainability has become an important topic both in society and in politics. However, despite its successful implementation in several sectors and wide recognition in the academic and professional debate, sustainability is still not as evident in day-to-day regional planning practice. At this regional level – precisely the level at which strategic decisions are increasingly made and the greatest impacts are to be expected – the gap between the worlds of land use and transportation planning seems to be the largest. Persisting institutional barriers cause much of this gap. Land use and transport decision-making typically are the responsibility of different agencies, encompass different spatial scales, follow different procedures, and involve different sets of stakeholders. However, even when these institutional conditions are more favourable, differences in the disciplinary background and language of land use and transportation policymakers are an obstacle to policy integration. Thus, next to the development of more integrated planning institutions, methods and instruments that combine land use and transportation planning views need to be designed. For example, [3] used the concept of sustainable accessibility as a framework for the interactive design of integrated transport and land use plans in two areas of the Netherlands. The objective of their exercises was to identify solutions where economic, social, and environmental goals could be combined, defined as the achievement of ‘sustainable accessibility’. However, as they stated, a major challenge is to find a workable balance between an accessibility measure that is theoretically and empirically sound and one that is sufficiently plain to be usefully employed in interactive, creative plan-making processes. For example, they recognised a lack of tools which could be used to support the design of policies, as opposed to the relative abundance of tools for analysing the problems at hand and evaluating alternative solutions.

Extensive academic literature on accessibility measures suggests that there are a lot of ways in which to define, represent and quantify accessibility and these have widely enriched the theoretical understanding of accessibility by taking more and more social, economic, spatial and temporal, and behavioural components into account. Different measures have shown many potentials for the accessibility concept. First, accessibility is able to link physical space and functional activities. For example, a locational accessibility perspective assesses the attractiveness of places within the urban system relative to one another. In contrast, an individual accessibility perspective focuses on the geographic scope of activities available to a given person [4]. Second, accessibility can be linked with various transport and land use policies on different scales: neighbourhood e.g. [5], intra-urban e.g. [6] and regional levels e.g. [7]. However, any interpretable measure integrating accessibility and sustainability and in particular linking with policy making practice is relatively scarce.

This paper aims to make some steps towards measuring sustainable accessibility, which in turn is intended to help regional planners define the potential problems and design possible alternatives at strategic planning level for a sustainable regional transport and land use system. The next section focuses on a methodology for such measurement, which consists of the concept of conflicts in the planning process, modelling job opportunity and sustainability, and spatial
conflict analysis. In section 3, the Amsterdam urban region of The Netherlands is taken as a case study and sustainable accessibility is measured in an integrated GIS environment, followed by corresponding policy implication for strategy design. This paper ends with some general conclusions and future works.

METHODOLOGY

Conflicts in the Planning Process

The path to sustainable development involves tough, often controversial choices. Actions for sustainability should aim to establish a firm foundation for sound, balanced decision-making that takes the whole process of plan development into account. Particularly the complexity of planning at the regional level – where multiple and often divergent interests and goals are at stake – calls for an integrated approach. In this way the result is likely to be a broadly supported strategy to guide the operational phase of the regional planning process more adequately.

Similarly to [8], we see design as ‘making sense together through practical conversations’ and aim to develop analytical tools which ‘structure’ such a process. A land use and transport strategy consists of a combination of various instruments. More importantly, it involves the selection of an integrated package of policy instruments (synergy) that reinforce one another in meeting the objectives and in overcoming barriers. A key element of an integrated strategy is thus the determination of the way in which different policy instruments are integrated and the balance between them determined. Such instruments might include conventional transport measures such as new infrastructure, traffic management and pricing policies, but increasingly they also involve attitudinal changes and the use of information technology. Equally importantly, land use changes can contribute significantly to the reduction of transport problems. A clearly specified list of problems is the most suitable basis for identifying potential solutions. It thus provides a direct input to the process of developing alternative strategies. This problem-oriented approach to strategy formulation is an alternative to starting with objectives, but does still need to be checked against the full list of objectives. To perform such an objective analysis of problems, we need indicators for all objectives and target values or thresholds for the indicators. Indicators should provide sufficient (rather than exhaustive) information to pass judgement on the sustainability of alternative urban land use and transport strategies. When a condition is measured, or if the prediction is that it will differ from a threshold, then a problem is said to exist. A range of thresholds can be set, so that problems may be graded by severity.

Conflicts are the result of incompatible activities, represented as contradicting objectives. Conflict analysis reveals the reason for conflicts by identifying the influence of individual factors. This evidence can be used to support conflict management and negotiation, for instance by supporting the search for solutions which may diminish disagreement. There are five basic strategies for managing conflicts: avoidance, forcing, compromising, accommodating and problem solving. The latter is the one adopted in this project. The specific aim is identifying conflicts and synergies between policy instruments aimed at enhancing the accessibility of the urban region and policy instruments aimed at enhancing the sustainability of the transport system. Finding ways of achieving both, or ‘sustainable accessibility’ can be seen as a, if not the central goal of many current regional land use and transport planning efforts. As a first step, in the following sections both objectives are defined in a way which makes them suitable for further analysis.

Measuring Accessibility

Accessibility reflects the ability to reach frequently-visited places efficiently and conveniently. It can be enhanced either by increasing travel speeds or by bringing urban activities closer together,
or some combination of the two. Accessibility is determined by the spatial distribution of potential destinations, the ease of reaching each destination, and the magnitude, quality and character of the activities found there [9]. Improving accessibility can be seen as the core objective of transport development. For the sake of simplicity, in this study we only take job accessibility by car as an example to illustrate the methodology. As it will be shown, this limited focus already allows identification of some basic interdependencies, conflicts and potential solutions between the objectives of enhancing accessibility and enhancing sustainability in an urban region. However, it should also be stressed that a thorough exploration should also entail accessibility by other means of transport (e.g. public transport, biking and walking) and other travel motives (e.g. leisure travel).

In his seminal paper, Hansen [10] proposed a simple gravity model to quantify job accessibility:

\[ A_i = \sum_{j=1}^{n} E_j \times t_{ij}^{-\beta} \]  

[1]

Where \( A_i \) is the job accessibility at location \( i \), \( E_j \) is the number of jobs at location \( j \), \( t_{ij} \) measures the spatial barrier between \( i \) and \( j \), \( \beta \) is the travel friction coefficient and \( n \) is the number of job locations. The major contribution of this measure is the introduction of distance decay, or the idea that – all else being equal – the value of a destination is inversely related to its distance. However, job accessibility is not only influenced by the interactions between land-use structure and transportation (e.g. availability of vehicles, existing road network, congestion in high-density areas), but also by the functional aspects of jobs and workers (e.g. employment type, gender, age, education, their household roles and income). For example, on average, workers change job less frequently with increasing age and experience. Accordingly, a definition as in equation 1, based on natural science (physics), was later criticized as being too simple because it did not consider or quantify a number of social, behavioral, spatial and temporal components. Over the past four decades, therefore, a substantial amount of literature on the modification of job accessibility measures has been produced, such as [9], [11], [12], [13], [14], [15].

Many examples have shown the impacts of competition (for jobs and for workers) and distance decay on job accessibility. However, the previous methods (see equation 1), take a relative measure for comparing the difference of accessibility between the sites in a study area, and as such are not so understandable to many of those involved in the planning process. Alternatively, access to spatially dispersed opportunities or ‘opportunity’ is a simplified, easier to grasp representation of accessibility, which has proven to be more understandable. It is often expressed in terms of an absolute value such as the number of jobs, number of people, etc. Opportunity has many potential uses including the comparison of accessibility changes for different population groups, the identification of the catchment for a destination and the comparison of accessibility for car available and non-car available trips. The understanding of opportunity is the pre-requisite for a lot of relevant decisions related to accessibility, such as residential and employment location and allocation. The job opportunity concept can then be represented as the total number of jobs accessible to any residential location as follows:

\[ O_i = \sum_{j} E_j \quad \text{When } t_{ij} < T \]  

[2]

Where \( O_i \) is the aggregated job opportunity accessible to the workers at residential location \( i \), \( E_j \) is the number of jobs at employment location \( j \), which can be reachable to \( i \) within a certain travel time, \( t_{ij} \) is the travel time or cost from location \( i \) to \( j \), \( T \) is the user-defined travel time threshold for a work trip. Based on this starting point, more and more components can be incorporated into the job accessibility measure, so that the theoretical and empirical shortcomings of previously defined measures can be overcome without too much loss in clarity. This relative
‘plainness’ is a fundamental prerequisite for a measure that aims at being employed in an interactive strategy design process typically involving a variety of stakeholders, and many without a disciplinary background in transport planning \[3\]. In this project, we propose a new measure to model accessibility, and in particular job accessibility, by incorporating the different components of job accessibility (opportunity, competition, distance decay and diversity) (the details can be seen from \[16\]). The final format of the measure is represented as equations 3-6:

$$O_i = \sum_j E_{ji} \neq W_i$$ \[3\]

$$E_{ji} = \frac{E_i \times P^s_{ji} \times W_j \times f(t_{ij})}{\sum_k P^s_{jk} \times W_k \times f(t_{kj})}$$ \[4\]

$$P^s_{jk} = \frac{E_j \times f(t_{jk})}{\sum_s E_{js} \times f(t_{js})}$$ \[5\]

$$f(t_{ij}) = \frac{1}{e^{\beta t_{ij}}}$$ \[6\]

Where \(i, k\) denote residential location and \(j\) employment location, \(O_i\) is the total job opportunity which residential location \(i\) can access, \(E_{ji}\) is the job opportunity assigned to residential location \(i\) from employment location \(j\) and \(j(i)\) means all employment locations \(j\) which residential location \(i\) can access within the travel time threshold \(T\) (e.g. 30 minutes). \(W_i\) is the number of workers at location \(i\), \(t_{ij}\) is the travel time from location \(i\) to \(j\), \(E_j\) is the number of jobs at location \(j\). \(P^s_{ji}\) implies the job-desire probability at any location \(i\) to seek for jobs (at location \(j\)), or rather, the relative attraction of employment \(j\) to residential location \(i\), \(f()\) is the traditional distance decay function - negative exponential function, \(\beta\) is the travel friction coefficient to be calibrated. \(S(k)\) means all employment locations \(s\) which residential location \(k\) can access within the travel time threshold \(T\) and \(D_j\) is the job diversity at location \(j\).

This measure can reasonably estimate the job opportunity accessible to any residential location by systematically considering competitions, distance decay and job diversity. Its main advantage lies in the fact that the job accessibility can be transparently linked with relevant transport and land use policy, as its value will be impacted by densification (workers and jobs), job diversification, and transport improvement.

**Measuring Sustainability**

Sustainability is an ambiguous concept. Sustainability can be understood and defined from various perspectives, e.g. social, economic, and environmental. For the sake of simplicity, we will focus here on environmental aspects of sustainability. There is an extensive literature and lively debate on how to measure sustainability of the transportation and land use system. The limited focus adopted in this paper sharply contrasts with the much more elaborate, multi-dimensional indicators being proposed in the literature (e.g. 17-18). We agree that a thorough assessment of sustainability would have to address the many facets of the concept. However, we believe that the limited focus adopted in this paper already succeeds in helping identify essential interdependencies, conflicts, and potential solutions between the objectives of enhancing accessibility and enhancing sustainability. As the core part of this paper, sustainable accessibility
should aim to make a balance between the accessibility and the environmental losses it may bring. The environmental losses such as energy use, noise, CO2 emissions, air pollution, traffic noise and resource consumption are primarily caused by automobile trips (at least in the current technological context). Rises in energy consumption and the emissions from the automobile are regarded as the main contributors to the problem. Per-capita distance travelled by car (kilometers) is a frequently used indicator to represent the environmental impacts of transportation. Accordingly, average trip length will be used in our exercise as an indicator of un-sustainability.

Supposing that \(d_{ij}\) denotes the travel distance (not the travel time \(t_{ij}\)) from residential location \(i\) to employment location \(j\), then the average trip length \(L_i\) at location \(i\) can be calculated as follows (equation 7). The greater \(L_i\), the less sustainable the transport and land use system.

\[
L_i = \frac{\sum_{j} d_{ij} \times E_{ji}}{\sum_{j} E_{ji}} \quad [7]
\]

Spatial Conflict Analysis

The objective of this project is to identify ways of achieving a balance between accessibility and sustainability. We model the concepts using two indicators (accessibility and un-sustainability) based on GIS spatial analysis. GIS is functionally powerful in the processing and representation of spatial features and their relationships. A map can facilitate mutual understanding and common agreement about basic facts, and can be used to develop consensus across a diverse set of participants[19]. Although such indicators are not representative of the whole range of relevant issues, they poignantly illustrate the challenge. These two indicators are not only interdependent but also contradictory with regard to the policy objectives. Their conflict in spatial terms results in the detection of the potential problems when achieving the objectives. This helps us to understand the impacts of possible policy instruments or spatial interventions, at the various levels, or problems based on spatial modelling. Such an understanding would help policymakers create their own plan opinions in order to form some strategies. This process is ill-structured and needs to be supported by interactive workshops, in which policymakers discuss and reach consistent consensus. This analysis could be employed in such strategy design workshops.

The objective of policy design is to achieve sustainable accessibility by solving the conflicts between sustainability and accessibility. \(A\) is the assumed residential area targeted for analysis and policy design; supposing that \(L_A\) denotes the value of un-sustainability (average trip length) in area \(A\) and \(O_A\) denotes the value of accessibility in area \(A\), the first step as regards policy design is to identify the problems. The conflicts between sustainability and accessibility can be classified into four classes as Figure 1 (\(O\) is the acceptable standard of accessibility, \(L\) is the acceptable standard of sustainability; for example, they can be either mean or median values in the region). This classification can be used to hypothesize and analyze the likely policy-making interventions, as will be investigated later on using a real case study.

Case (++) is the most desirable since it represents better accessibility and sustainability (shorter trip length) in a strategy term. It means that a large number of jobs are accessible to \(A\) and that the travel distance is short. In other words, there is a good functional mixture near \(A\) in terms of amount and distance. In this case, more new workers can be encouraged to locate in area \(A\) as the job opportunities exceed job demand while still satisfying sustainability conditions.

Case (+-) is desirable only as regards accessibility but not with respect to sustainability. This result indicates that many of the jobs accessible to \(A\) are far away from \(A\) because the trip length is longer. Hence, a solution could be to try and support the location of jobs away from \(A\) and closer to other residential locations.
Case (+) is desirable as regards sustainability but not as regards accessibility. This result may imply that the accessible jobs are nearer to \( A \) because the travel distance is not excessive. However, the number and diversity of jobs are limited. Hence, accessibility can be improved from two sides: workers or jobs. In the case of the former, we may think at ways of discouraging the location of workers in \( A \) (or encouraging their location to more suited areas). In the case of the latter, more and more diverse jobs can be attracted to locations near \( A \) in order to provide more opportunities. Another alternative would be to improve travel speed from \( A \) to surrounding areas.

Case (-) is the least desirable since it has poor accessibility and sustainability. This shows that the jobs are limited in number and diversity, and also that they are far away from \( A \), as shown by the lengthy trip lengths. To solve the problem, more jobs would have to be attracted to area \( A \), or its vicinity.

These descriptions show that a complex network existing in areas \( A \) and surroundings affects job opportunity and sustainability. The complexity of the network is dependent on the social interaction (amount and structure of workers and jobs) and spatial interactions (location, spatial relationships, and trips). The analyses described above provide a framework for defining possible spatial interventions, which can be implemented to remove the spatial conflicts in reaching sustainable accessibility. These spatial interventions can be summarized as: land use intensification (increase or decrease the number of workers or jobs), land use mixture (residential with jobs, or workers themselves), job diversification, and transport infrastructure improvement (speed).

Spatial conflict analysis conceptually defines the potential spatial interventions by identifying the problems (i.e. four classes in this project) in achieving the objectives of the development plan or spatial strategic planning, in this case the balance between accessibility and sustainability.

Spatial interventions identify policy instruments or a solution space for policymakers to design their strategy. The question of how to organize these interventions effectively is becoming the core of policy design. Spatial strategy is a combination of acceptable spatial interventions, and a global organization of them. This kind of spatial organization is dependent on the perspective that the urban (regional) development plan adopts to achieve its social, economic and environmental objectives that are integrated into, and represented as, spatial concepts like compact urban form and urban network. Policy design is the creative process during which policymakers organize acceptable spatial interventions based on desirable spatial concepts. Hence, different spatial concepts will produce different spatial strategies even with the same set of spatial interventions. The generation, understanding and selection of spatial concepts come from the group discussions in one or more workshops, during which consensus can be built among all participants. However, to understand these spatial concepts, the impacts of corresponding spatial strategy need to be quantified for the purpose of evaluation and comparison. Unlike the indicators mentioned above, this quantification would have to be a global measure for the entire study area. We take the concept of an urban network as an example and define a global indicator to evaluate spatial strategy.

The concept of an urban network focuses on the functional integration of social and spatial interactions. To achieve sustainable accessibility, the integration should maximize the job accessibility and minimize un-sustainability, at the same time satisfying the access-to-jobs demand of workers in the study area. Supposing that there is a total of \( n \) locations for workers, then the sustainable accessibility denoted as \( S \) can be represented as the ratio of accessibility and sustainability (in this case-average trip length) weighted by the number of workers (eq.8). The greater \( S \) is, the more sustainable the accessibility.
\[ S = \frac{\sum_{i} O_i \times W_i}{\sum_{i} L_i} \] \[ \text{[8]} \]

**CASE STUDY**

In the following sections, the proposed methodology, aimed at the policy design of sustainable job accessibility, will be implemented in a GIS environment and tested in the Amsterdam urban region. The Amsterdam region consists of the core city of Amsterdam and other smaller towns around it that have become specialized regional centres. At the urban regional level, the central transport planning challenges of the last 150 years have focused on developing adequate heavy rail linkages between secondary centres and Amsterdam, and later on connecting the regional links into the national motorway grid. Today, with increasing specialization and the expansion of activities, the challenge is rather to develop a regional sustainable transport and land use system which can improve the integral accessibility of jobs, services etc. [20]. Providing for job accessibility is an important step towards this goal.

**GIS Data Analysis**

The information requirement here is related to the transport network and activities (working and housing) on an urban regional scale. Car network is classified into 11 classes based on the attributes of speed, direction and exits. Employee and employment (with job structure) are registered on a 6-digit postcode level, represented as point data. They can both be approximately aggregated/dis-aggregated into a user-defined spatial unit.

In this project, a desktop GIS package MapInfo 7.5, together with MapBasic 7.0 and DriveTime 6.2 module are selected as a platform to implement the spatial analyses described before. DriveTime is a professional module for computing isochrone, travel distance and travel time between any two locational sites. MapBasic, as a script language, is utilized for data processing, interface design, visualization and, in particular, for the required spatial analysis. It is also used to link modelling closely to spatial data in the context of communication with policymakers.

Although the study area is concentrated on the Amsterdam region, the spatial extent for modelling has to be greatly enlarged when considering competition for jobs and workers (figure 2). We start with the spatial boundary of the workers (Inside worker) located in the Amsterdam region and then produce isochrones to define the areas which can be accessed from all inside worker at residential locations within a given travel time threshold \( T \) by car (e.g. 30 minutes). The resulting boundary - Inside Job - defines the target jobs which workers in the study area (inside worker) are able to compete for. Outside worker defines the areas in which inside jobs can be accessed within travel time \( T \). Outside worker accommodates all the workers competing for inside job with inside worker. However, if the competition for demand (worker) is considered, outside job, – which compete for workers with inside job - has also to be created using isochrone. As a result, the study area is the Amsterdam region, but the final spatial extent for modelling (outside job) is much larger.

We selected a 500*500 m\(^2\) grid as a basic analysis unit, to which both employment and inhabitant data can be aggregated and disaggregated. Secondly, in order to reduce the computational time for travel time matrix, the analysis was limited to the 90% most spatially concentrated residents and jobs within the defined spatial boundaries. In this project, a total of
about 6,900 residential locations (outside worker) and 7,700 employment locations (outside job) are thus extracted for accessibility measure purposes.

For the sake of simplicity, we took the car as the only mode by which to make the home-based work trip. The first step was to define the time threshold $T$. The commuting tolerance of most workers is limited. For example, a commuting time of 45 minutes is the maximum for most employees [21,22]. In practice, [22] found that, in the USA, almost two thirds of all employees spend less than 35 minutes commuting to work. In the Netherlands nearly 90% of commuters use private modes of transport (car, bike, walk) and 80% of the working population travels less than 30 minutes per single journey to work [23]. We therefore defined 30 minutes as the travel time threshold for the trip to work by car for the first step of our modelling exercise, i.e. $T=30$ for all equations defined above. Second, from the Dutch national traffic survey, the average travel time for a work-oriented trip by car is 25.3 minutes, based on which the global calibration of the distance decay parameter $\beta$ was estimated to be 0.15 by using a spatial doubly constrained model.

**Strategy Design for Sustainable Job Accessibility**

In the Amsterdam region, employment is classified into the nine major types of job of offices, education, health, industry, transport, retail1 (daily goods), retail2 (non-daily goods), restaurants and agriculture. We assumed (following the national figure) that on average 40% of inhabitants are workers. The job opportunity and average trip length are calculated as Figures 3 and 4. The total number of jobs that are accessible to the workers (790,400) in Amsterdam region is 840,800. The spatial correlation between job opportunity $O_i$ and average trip length $L_i$ is -0.43, which implies a contradiction between the two objectives. The global index of sustainable accessibility is 203.7 based on equation 8, which will be utilized for the comparison with any new strategy later.

Then we used a mean value (589 jobs for job accessibility and 5.94 km for average trip length) as the watershed to detect the spatial conflicts between accessibility and sustainability as shown in Figure 5, which indicates the problems that exist in the study area when the objectives of sustainable accessibility are established.

In Figure 5, the most ideal or sustainable locations (++) are concentrated in the centres of both Amsterdam city and other smaller cities. The most unsustainable locations (--) are scattered in various corners and directions, mostly in suburban areas. This may imply that the plan made at Amsterdam city level is more successful than that made at regional level. Or rather, the past plan paid more attention to compact urban form than regional urban network. The class (+-) has the least number and is also distributed more on the fringe.

As a summary of these analyses, we can conclude by listing the following potential policy instruments which can be implemented in the neighbourhood of the residential locations for each class of spatial conflict:

++: Encourage the relocation of jobs to a location further away (decrease the density of jobs);
+-: Try and enhance job diversity and attract workers (diversify jobs and increase the density of workers);
-+: Favour the location of workers to a location further away or stimulate the development of jobs in the location (decrease the density of workers and increase the density of jobs);
--: Support the development of jobs nearer to the location (increase the density of jobs and reduce the distance).

It is clear to see that this result is consistent with that of the qualitative reasoning in spatial conflict analysis. These instruments can be used as input for workshops focusing on the discussion of spatial strategy, together with the maps in Figures 3-5. The impacts of policy design
from workshops can be evaluated based on spatial concepts such as urban network and sustainable accessibility (e.g. equation 8). Let us show this by means of the example of Almere, on the East side of the region.

Almere is dominated by the (+) class in Figure 5. A major reason contributes to this: the relatively high density of workers. Following the analysis mentioned above, increasing job density would be an effective instrument for Almere. Meanwhile, Amsterdam city centre falls completely in class (++), and is thus amenable (within this framework of analysis) to a decrease in the density of jobs. It is thus interesting to assess the impact of a hypothetical relocation of jobs away from Amsterdam and towards Almere. Figure 6 illustrates what the impact would be of such a relocation of jobs from Amsterdam city centre to Almere. A total of 24,800 jobs are relocated in this example. The corresponding change of spatial conflicts is displayed in Figure 6-b (where the same definitions of $O'$ and $L'$ are adopted as in Figure 1). The global index of sustainable accessibility is improved from 203.7 to 240, indicating an increase in sustainability. This change results from the complex social and spatial interactions between various land-uses linked by a transport network. Similar examples could be generated for the impacts of other land use and transport policies.

CONCLUSIONS

Sustainable regional transport and land use planning involves a number of specific topics (e.g. land use allocation, job-housing balance and sustainable mobility) and perspectives, including sustainable accessibility. In this study, sustainable accessibility is limited to two indicators, namely job opportunity as a way of representing accessibility and average trip length as a way of representing un-sustainability. In particular, it took account of the home-based work trip by car. The indicator of job opportunity is a means of linking transport and the land use system, particularly when incorporating components such as distance decay, competition and job diversity. The indicator of average trip length reflects the environmental impacts of job accessibility. The spatial conflict analysis found that the two indicators are able to define potential problems and solutions or issues for planning thinking.

In terms of modeling, spatially explicit indicator-based analysis is not new in GIS application. For example, landscape metrics have recently been applied on a wide scale in order to understand urban growth dynamics [24]. However, the incorporation of indicators into various processes of policy making is a new attempt to link with planning practice. These indicators are defined very simply but are understandable to users. Thereafter, their interactions or integration can reveal a lot of spatial complexity inherent in the process of strategy design.

Returning to the issue of planning, it is important to emphasize that sustainability is a very complicated concept to address in the planning process, with multiple conflicting indicators in terms of the interests of actors and their objectives. A conceptual model of multi-mode travel and land use pattern is illustrated in the literature [20] as a way of addressing such complexity. This provides a framework that can be used for further consideration of the integration of transport and land use interactions at various scales (e.g. neighborhood, city, or region) into sustainable accessibility. To support such a process of policy making, the models in this paper need to be expanded to include more activity-based indicators and different transportation means and features, which can be linked with other transport and land use policies.

This exercise has clearly shown the crucial roles of GIS in the whole process of policy design. A GIS environment helps participants to understand the concepts and impacts of any strategy. The major focus as regards GIS is not on the advanced spatial analyses but on ways of improving communication with participants. Integrated tools to support planning process at various spatial scales [25], namely PSS (Planning Support Systems), have been developed over the past few decades since the concept first emerged in the 1980s. Most of them are mainly applied for structured alternative evaluation. However, planning is not only evaluation, the stages
of problem definition and alternative design are at least as important, as including creative
components and being fully ill-structured. These stages should be the core parts of any PSS as
well, but have not received enough attention, especially at the regional level.

The spatial analytical process proposed in this paper is a first attempt at filling this gap. It
can be structured as several steps that provide a unified checklist to practitioners:

*Step 1:* Process and generate spatial data sets of grid-based employment (with job
structure) and residents, and road network (with car speed) within a GIS
environment;

*Step 2:* Set up parameters (travel time threshold $T$, travel friction co-efficient $\beta$) from
previous empirical studies.

*Step 3:* Define spatial extent (or boundary) for accessibility measure and calculate the
travel time $t_{ij}$ from the cell of workers to cell of employment within the defined
spatial extent.

*Step 4:* Compute and map job accessibility $O_i$ and then average trip length $L_i$.

*Step 5:* Set up acceptable standards of accessibility $O'$ and sustainability $L'$.

*Step 6:* Map and interpret spatial conflicts.

*Step 7:* Visually detect the potential for interventions and explore their local and global
impacts with policy makers.

ACKNOWLEDGEMENTS

This work was largely conducted at the Department of Geography and Planning in the Faculty of
Social and Behavioural Sciences at the University of Amsterdam, at a time when all three authors
were active there. Several anonymous reviewers provided useful comments on an earlier draft of
this paper.

REFERENCES


Framework to Integrate Transport and Land Use Plan-making: Two Test-applications in
the Netherlands and a Reflection on the Way Forward. *Transport Policy*, vol.12, 2005,
pp. 207–220.


Environment: Synthesis and a Case Study in the Chicago Region. *Environment and

1989.

[9] Handy, S. L. and D. A. Niemeier, Measuring Accessibility: an Exploration of Issues and


LIST OF FIGURES AND TABLES

FIGURE 1 Conflict analysis between accessibility and sustainability

FIGURE 2 Spatial boundary of inside worker (a), inside job (b), outside worker (c) and outside job (d)

FIGURE 3 Pattern of job accessibility represented by opportunity

FIGURE 4 Pattern of un-sustainability represented by average trip length

FIGURE 5 Spatial conflict between job accessibility and sustainability

FIGURE 6 An example of spatial intervention and its evaluation. a). relocating jobs; b) new spatial conflicts (comparing with Figure 5)
<table>
<thead>
<tr>
<th>Sustainability L</th>
<th>Accessibility O</th>
</tr>
</thead>
<tbody>
<tr>
<td>((-))</td>
<td>((-))</td>
</tr>
<tr>
<td>(O_A &lt; O')</td>
<td>(O_A &gt; O')</td>
</tr>
<tr>
<td>(L_A &gt; L')</td>
<td>(L_A &gt; L')</td>
</tr>
<tr>
<td>(\langle+\rangle)</td>
<td>(\langle+\rangle)</td>
</tr>
<tr>
<td>(O_A &lt; O')</td>
<td>(O_A &gt; O')</td>
</tr>
<tr>
<td>(L_A &lt; L')</td>
<td>(L_A &lt; L')</td>
</tr>
</tbody>
</table>

**FIGURE 1** Conflict analysis between accessibility and sustainability
FIGURE 2 Spatial boundary of inside worker (a), inside job (b), outside worker (c) and outside job (d)
FIGURE 3  Pattern of job accessibility represented by opportunity
FIGURE 4 Pattern of un-sustainability represented by average trip length
FIGURE 5 Spatial conflict between job accessibility and sustainability
FIGURE 6 An example of spatial intervention and its evaluation. a). relocation of jobs; b) new spatial conflicts (comparing with Figure 6)