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RIJKSINSTITUUT VOOR VOLKSGEZONDHEID EN MILIEU
NATIONAL INSTITUTE OF PUBLIC HEALTH AND THE ENVIRONMENT

RIVM report 408505 006

Accessibility measures: review and applications

Evaluation of accessibility impacts of land-use transport scenarios, and related social and economic impacts

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June 2001

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This investigation has been performed by order and for the account of Directorate-General for Environmental Protection of the Ministry of Housing, Spatial Planning and the Environment within the framework of project S/40850501/FF, Evaluation Methodology for Transport Scenarios.

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Abstract

This report describes an extensive literature study and three case studies aimed at reviewing accessibility measures for their ability to evaluate the accessibility impacts of national land-use and transport scenarios, and related social and economic impacts. Several activity- and utility-based accessibility measures were computed to analyse job accessibility by car and public transport in the Netherlands for: (1) the (base) year 1995, (2) a Trend, or business-as-usual, scenario, representing the continuation of (restrictive) Dutch land-use policies and historical land-use trends for 1995-2020, (2) a Tolerant scenario, representing a land-use scenario, in which consumers' housing preferences determine land-use developments for 1995-2020. The scenarios are based on calculations using national land-use models and a national transport model. The main conclusion arising from this study is that the current Dutch practice of evaluating the (infrastructure-based) accessibility impacts of (land-use) transport projects, plans or scenarios can be improved by estimating activity-based accessibility measures, using existing land-use and transport data, and/or models. Activity-based accessibility measures are very well able to analyse accessibility impacts, satisfactorily incorporate the different components of accessibility (i.e. the transport, land-use, temporal and individual components) and serve as a useful tool for analysing social impacts. Utility-based accessibility measures may provide a useful basis for economic evaluations of land-use transport scenarios, but further research is necessary to analyse the added value to existing evaluation methods.

Preface

This report has been written as part of the first authors' PhD research programme 'Ecological, Social and Economic Evaluation of Transport Scenarios: An Integral Approach'.

The authors thank the AVV Transport Research Centre of the Ministry of Transport, Public Works and Water Management to permit us using (the output of) the National Model System and the 1995 Dutch National Travel Survey.

Furthermore, Lucas Harms is thanked for carrying out the statistical analysis using the National Travel Survey.

Finally, the authors thank the people who took the effort to read and comment on earlier drafts of this report. Firstly, Professor Bert van Wee (RIVM, Utrecht University) is thanked for comments on the several draft reports. Secondly, Professor Piet Rietveld (Free University Amsterdam), Professor Toon van der Hoorn (AVV, University of Amsterdam), Jan van der Waard (AVV), Freddie Rosenberg (AVV), Johan Visser (Delft University), Martin Dijst (Utrecht University) and Leon Crommentuijn (RIVM) are thanked for their comments on (parts of) earlier drafts of this report.

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Samenvatting en conclusies

Bereikbaarheid is een sleutelwoord in het verkeers- en vervoerbeleid in vele landen. Bereikbaarheid is echter geen eenduidig begrip: het kan op vele verschillende manieren worden gedefinieerd en geoperationaliseerd, zoals ‘de moeite om van A naar B te komen’ en ‘het aantal activiteiten dat kan worden bereikt vanuit een herkomstlocatie’. In dit rapport worden drie perspectieven of benaderingen van bereikbaarheid geïdentificeerd:

1. Een op *infrastructuur gerichte benadering*, gericht op kenmerken van infrastructuur en het gebruik ervan. Voorbeelden zijn: ‘mate van congestie’ en ‘gemiddelde snelheid op het hoofdwegennet’. Deze benadering wordt met name gebruikt in verkeers- en vervoerplanning en –beleid;
2. Een op *activiteiten gerichte benadering*, waarbij het veelal gaat om de vraag hoeveel activiteiten met hoeveel moeite (bijvoorbeeld reistijd en/of afstand) bereikbaar zijn. Deze benadering wordt veelal in de geografie en planologie gebruikt. Deze benadering is verder uit te splitsen naar (a) ‘geografische’ bereikbaarheidsmaten, die de nadruk leggen op de potentiële bereikbaarheid van activiteiten vanuit een locatie, en (b) ‘tijd-ruimte’ bereikbaarheidsmaten, die de nadruk leggen op de tijden waarop individuen (kunnen) participeren in specifieke activiteiten;
3. Een op *nut gerichte benadering*, gericht op het nut, of de baten, die mensen toekennen aan het kunnen bereiken van activiteiten. Deze benadering wordt vooral in economische studies gebruikt.

De verschillende benaderingen incorporeren in meer of mindere mate de verschillende (en onderling samenhangende) componenten van bereikbaarheid: (a) een *transport component,* die de reistijd, -kosten en moeite beschrijft, en de waardering ervan door personen en bedrijven, (b) een *ruimtelijke component*, die de omvang en ruimtelijke spreiding van activiteiten weergeeft, (c) een *tijdscomponent*, die de tijdsrestricties van activiteiten (bijv. openingstijden) en personen weergeeft, en (d) een *individuele component*, die de individuele behoeften, capaciteiten en mogelijkheden weergeeft.

Deze studie heeft als doel het analyseren van de geschiktheid van bereikbaarheidmaten voor het beoordelen van de bereikbaarheidseffecten van ruimtelijk-infrastructurele scenario’s, en de daaraan gerelateerde sociale en economische effecten. Bereikbaarheid wordt hierbij gedefinieerd als *de mate waarin de ruimtelijk-infrastructurele constellatie mensen (of goederen) in staat stelt om activiteiten (of bestemmingen) te bereiken met een bepaalde (combinatie van) vervoerwijze(n).*

Deze studie bestaat uit twee onderdelen. In de eerste plaats wordt een uitgebreide literatuurstudie beschreven, waarin bereikbaarheidsmaten worden beoordeeld op (a) theoretische en methodologische aspecten, i.c. de wijze waarop de vier onderscheiden componenten van bereikbaarheid zijn meegenomen, (b) de interpreteerbaarheid, (c) databehoefte, en (d) de bruikbaarheid voor de beoordeling van de ruimtelijk-infrastructurele

scenario’s. In de tweede plaats zijn drie case studies uitgevoerd waarin de (ontwikkeling van de) bereikbaarheid van werkgelegenheid per auto en openbaar vervoer in Nederland is onderzocht. De analyses zijn uitgevoerd voor: (1) het jaar 1995, (2) een ‘Trend scenario’ voor de periode 1995-2020, waarin het ruimtelijk beleid (AcVINEX) en historische ruimtelijke trends zijn doorgetrokken, (3) een ‘Tolerant scenario’ voor de periode 1995-2020, waarin verondersteld is dat de woonvoorkeuren van huishoudens sturend zijn voor de ontwikkeling van de woningvoorraad. De case studies zijn gebaseerd op prognoses van nationaal ruimtelijke modellen (Ruimtescanner, Socrates en Opera) van het RIVM, ABF en TNO Inro en het Landelijk Modelsysteem Verkeer en Vervoer van de Adviesdienst Verkeer en Vervoer. In de case studies zijn de volgende bereikbaarheidsmaten doorgerekend:

- een contourmaat, ofwel een cumulatieve bereikbaarheidsmaat, die het totale aantal banen binnen een bepaalde maximum reistijd (hier: 45 en 60 minuten) berekend;
- een potentiële bereikbaarheidsmaat, die het potentiële aantal banen binnen bereik berekend, waarbij verder weg gelegen bestemmingen minder belangrijk zijn;
- een bereikbaarheidsmaat die is ontwikkeld door Joseph & Bantock (1982), die rekening houdt met concurrentie-effecten vanwege capaciteitsbeperkingen van bestemmingen. De maat is uitgedrukt als een index (rond de 1) en geeft (hier) de verhouding aan tussen de ruimtelijke spreiding van de bereikbaarheid van werkgelegenheid en de beroepsbevolking;
- de (inverse) evenwichtsfactoren van het dubbelbeperkte ruimtelijk interactiemodel, die rekening houden met concurrentie-effecten op zowel de bestemming (banen) als de herkomst (beroepsbevolking);
- een ‘utility’ bereikbaarheidsmaat, die het nut weergeeft (uitgedrukt in kosteneenheden) dat kan worden toegekend aan de potentiële bereikbaarheid van werkgelegenheid.

De resultaten van de literatuurstudie en case studies zijn:

Transportcomponent van bereikbaarheid

De transportcomponent van bereikbaarheid bestaat in het algemeen uit (a) de afstand, reistijd en –kosten en ‘moeite’ om de afstand van een herkomstlocatie naar een bestemmingslocatie te overbruggen, en (b) de waardering van de reistijd, -kosten of moeite voor een bepaalde bestemming; in het algemeen wordt een locatie minder aantrekkelijk naar mate het meer moeite kost om er te komen. Alle bereikbaarheidsmaten nemen één of meerdere elementen van de transportcomponent mee. Op infrastructuur gerichte bereikbaarheidsmaten houden geen rekening met de waardering van de reistijd of –kosten voor een bepaalde bestemming. Verder is de contourmaat een op activiteiten gerichte bereikbaarheidsmaat die geen afstandvervalfunctie hanteert. Dit heeft als nadeel dat alle bestemmingen even belangrijk worden verondersteld, onafhankelijk van de reistijd of -kosten en het type bestemming. Uit de case studies blijkt dat de contourmaat hierdoor niet goed in staat is om de ontwikkeling van bereikbaarheid in de tijd weer te geven. Een kleine reistijdverandering kan er namelijk voor zorgen dat een belangrijke bestemming wel of niet in de bereikbaarheidsmaat wordt meegenomen.

Ruimtelijke component van bereikbaarheid

De ruimtelijke component van bereikbaarheid bestaat uit (a) de omvang en ruimtelijke spreiding van bestemmingen en het aanbod van activiteiten op deze bestemmingen, alsmede de kenmerken van die activiteiten, bijvoorbeeld de locaties van werkgelegenheid en het type werkzaamheden, (b) de omvang en ruimtelijke spreiding van de vraag naar activiteiten, bijvoorbeeld de woonlocaties van de bevolking, en (c) de confrontatie tussen het aanbod van activiteiten en de vraag ernaar, ofwel het al dan niet optreden van concurrentie effecten. Zo kunnen werknemers concurreren om banen, en kunnen werkgevers concurreren om werknemers.

Op infrastructuur gebaseerde bereikbaarheidsmaten houden geen rekening met de ruimtelijke spreiding van activiteiten, in tegenstelling tot de op activiteiten en nut gerichte benaderingen. Dit kan grote gevolgen hebben voor de conclusies. Als bijvoorbeeld de op infrastructuur gerichte bereikbaarheidsmaten ‘reiskosten op het wegennet’ of ‘congestie’ worden gehanteerd, dan lijkt bijvoorbeeld de Randstad de slechts bereikbare regio in Nederland. Een op activiteiten gerichte benadering geeft een tegengesteld beeld: het aantal activiteiten (bijv. arbeidsplaatsen) dat bereikt kan worden vanuit is juist het grootst.

In de case studies zijn twee bereikbaarheidsmaten doorgerekend die rekening houden met concurrentie-effecten: de bereikbaarheidsmaat van Joseph & Bantock, en de evenwichtsfactoren van het ruimtelijk interactiemodel. De evenwichtsfactoren voldoen het beste als bereikbaarheidmaat voor het evalueren van bereikbaarheid van werkgelegenheid: deze maat houdt rekening met de samenhang tussen de concurrentie op het aanbod van activiteiten (banen) en de vraag naar deze activiteiten (beroepsbevolking). Uit de case studies blijkt dat het meenemen van concurrentie-effecten een duidelijke invloed heeft op het resultaat: de bereikbaarheid van werkgelegenheid volgens de (inverse) evenwichtsfactor is in (centrum) stedelijke gebieden circa 20 tot 30% hoger dan de potentiële bereikbaarheidsmaat (hoge mate van concurrentie vanwege de relatief grote beroepsbevolking binnen bereik), terwijl in rurale en perifere gebieden de bereikbaarheid volgens de evenwichtsfactor gemiddeld ruwweg twee keer zo groot is (lage mate van concurrentie vanwege de relatief kleine beroepsbevolking).

De ruimtelijk-infrastructurele ontwikkelingen volgens het trend scenario en het tolerante scenario laten echter zien dat de ruimtelijke spreiding van bereikbaarheid van werkgelegenheid en de mate van concurrentie niet sterk wijzigt: de huidige nationale ruimtelijke structuur blijft dominant. In meer extreme ruimtelijke scenario’s kan het belang van het meenemen van concurrentie-effecten wel toenemen.

Tijdscomponent van bereikbaarheid

De tijdscomponent van bereikbaarheid is gericht op de beschikbaarheid van activiteiten in de tijd, en de tijden waarop individuen participeren in activiteiten. De tijd-ruimte benadering van bereikbaarheid richt zich vooral op de tijdscomponent, terwijl de andere benaderingen tijdsaspecten niet of alleen impliciet meenemen (bijvoorbeeld door onderscheid te maken tussen reistijden in en buiten de spits). Nadelen van de tijd-ruimte benadering van bereikbaarheid zijn echter dat de aanvullende databehoefte momenteel nog erg groot is (zie onder databehoefte) en dat tijd-ruimte modellen (vooralsnog) geen rekening houden met concurrentie-effecten op bestemmingen of activiteiten.

Individuele component van bereikbaarheid

De individuele kenmerken van personen zijn van grote invloed op bereikbaarheid: individuele behoeften, capaciteiten en mogelijkheden zijn van grote invloed op het niveau en de waardering van bereikbaarheid. Als bijvoorbeeld iemand met een laag opleidingsniveau dichtbij een omvangrijk kantorencomplex woont, waar echter alleen hoog opgeleide banen worden aangeboden, dan is voor deze persoon de bereikbaarheid van werkgelegenheid laag. De tijd-ruimte benadering en de op nut gerichte benaderingen richten zich op bereikbaarheid op het niveau van het individu of huishouden (microniveau), terwijl geografische bereikbaarheidsmaten bereikbaarheid op macroniveau analyseren. In de praktijk zal het verschil tussen de twee benaderingen niet zo groot te zijn: bereikbaarheid kan in beide benaderingen worden geanalyseerd voor (een selectie van) sociaal-economische bevolkingsgroepen. Uit de case studies blijkt dat het meenemen van sociaal-economische kenmerken van grote invloed is op het resultaat. Zo laten de bereikbaarheidspotentiaal en de evenwichtsfactoren zien dat bereikbaarheid van banen fors afneemt als de ‘match’ tussen het opleidingsniveau van de beroepsbevolking en het gevraagde opleidingsniveau van banen wordt meegenomen. De ‘utility’ bereikbaarheidsmaat laat zien dat het (gemiddelde) nut van bereikbaarheid van banen voor de gehele beroepsbevolking anders is dan wanneer dit per inkomensklasse wordt berekend.

Interpreteerbaarheid en theoretische aspecten

Er lijkt een soort uitruil te bestaan tussen de interpreteerbaarheid cq. communiceerbaarheid van een bereikbaarheidsmaat en de (theoretische) geschiktheid voor de evaluatie van ruimtelijk-infrastructurele varianten. Op infrastructuur gerichte bereikbaarheidsmaten, zoals congestiekansen en gemiddelde snelheid op het wegennet zijn relatief goed communiceerbaar, maar zijn minder geschikt als bereikbaarheidsindicator voor ruimtelijk-infrastructurele scenario’s. Op activiteiten gerichte bereikbaarheidsmaten zijn zeer geschikt om ruimtelijk-infrastructurele scenario’s te beoordelen, maar zijn ook moeilijker te interpreteren: een verandering van bereikbaarheid kan namelijk het gevolg van zijn zowel ruimtelijke als infrastructurele veranderingen (wijziging reistijden of –kosten). In dit rapport is de interpreteerbaarheid verbeterd door de invloed van de afzonderlijke componenten op de ontwikkeling van bereikbaarheid afzonderlijk weer te geven: (a) ruimtelijke veranderingen, (b) infrastructurele ontwikkelingen en (c) vertragingen en congestie.

Verder maakt het incorporeren van concurrentie-effecten een bereikbaarheidsmaat theoretisch beter, maar ook complexer te interpreteren. De ‘utility’ bereikbaarheidsmaat heeft een sterke theoretische basis (in de economische theorie), maar is relatief lastig te interpreteren. In essentie is de ‘utility’ maat te beschouwen als een indicator voor de *waardering* van bereikbaarheid, niet voor bereikbaarheid zelf. De case studies laten zien dat de resultaten afwijken van de op activiteiten gerichte bereikbaarheidsmaten. In tegenstelling tot potentiaalmaten laat de ‘utility’ bereikbaarheidsmaat afnemende meeropbrengsten zien: een toename van de bereikbaarheid levert in gebieden met weinig banen binnen bereik (bijv. perifere gebieden) relatief grotere ‘baten’ op dan een verdere toename van bereikbaarheid in gebieden waar al veel banen binnen bereik waren (bijv. centrum stedelijke gebieden). Met andere woorden: tussen het niveau van bereikbaarheid van activiteiten en de waardering ervan bestaat een niet-lineair verband.

Data behoefte

De in dit rapport berekende op activiteiten en nut gerichte bereikbaarheidsmaten zijn berekend met bestaande datasets (zoals het Onderzoek Verplaatsingsgedrag) en nationaal ruimtelijke en transport modellen. De aanvullende databehoefte is hierdoor beperkt. Naar mate de uitwerking van de verschillende componenten van bereikbaarheid toeneemt, neemt ook de databehoefte toe. Met name voor de tijd-ruimte benadering bestaat een grote additionele databehoefte: bestaande datasets (zoals het OVG) geven bijvoorbeeld geen informatie over individuele tijdbudgetten. Mede hierdoor is deze benadering vooralsnog niet geschikt om op nationale schaal de bereikbaarheidseffecten van ruimtelijk-infrastructurele scenario’s te berekenen.

Conclusies voor de beoordeling van ruimtelijk-infrastructurele scenario’s

Deze studie is gericht op het beoordelen van de geschiktheid van bereikbaarheidsmaten als ‘intermediaire’ en als ‘finale’ indicator. Een bereikbaarheidsmaat geeft als ‘intermediaire’ indicator (beleids-)relevante informatie over het functioneren van de ruimtelijk-infrastructurele constellatie. Uiteindelijk gaat het echter bij een effectenbeoordeling van ruimtelijk-infrastructurele scenario’s om de ‘finale’ effecten op ecologisch, economisch en sociaal gebied. In dit rapport zijn derhalve bereikbaarheidmaten ook beoordeeld op hun geschiktheid voor het evalueren van de economische en sociale gevolgen van bereikbaarheid. De conclusies zijn als volgt:

Bereikbaarheid als intermediaire indicator

Op activiteiten gerichte bereikbaarheidsmaten zijn zeer geschikt om ruimtelijk-infrastructurele scenario’s te beoordelen: deze bereikbaarheidsmaten zijn namelijk zowel gevoelig voor ruimtelijke als infrastructurele wijzigingen. Binnen de op activiteiten gerichte bereikbaarheidsmaten is er echter niet één bereikbaarheidsmaat die het meest geschikt is: alle maten hebben in theorie en in de praktijk voor- en nadelen. In het algemeen is de keuze voor een bereikbaarheidsmaat is afhankelijk van het studiedoel en –object. Samengevat:

- voor de analyse van bereikbaarheid waarbij *geen concurrentie-effecten* optreden, of niet relevant gevonden worden, is een potentiaalmaat een geschikte bereikbaarheidsmaat;
- voor de analyse van bereikbaarheid waarbij *concurrentie-effecten op de bestemming* optreden, bijvoorbeeld vanwege capaciteitsbeperkingen zoals bij scholen en

gezondheidsvoorzieningen, is de bereikbaarheidsmaat van Joseph en Bantock een geschikte bereikbaarheidsmaat;
- voor de analyse van bereikbaarheid van werkgelegenheid, waarbij *concurrentie-effecten effecten zowel op de bestemming als op de herkomst* optreden (banen resp. beroepsbevolking), zijn de evenwichtsfactoren van het ruimtelijk interactiemodel een geschikte bereikbaarheidsmaat.

De tijd-ruimte benadering is een theoretisch zeer geschikte benadering voor de beoordeling bereikbaarheidseffecten van ruimtelijk-infrastructurele scenarios, aangezien deze op het niveau van individuen of huishoudens wordt berekend en rekening houdt met (tijds-) beperkingen. Vooralsnog is deze benadering echter, vanwege de grote databehoefte, nog niet geschikt om op nationaal niveau ruimtelijk-infrastructurele scenario's te beoordelen. Verder benaderen tijd-ruimte maten bereikbaarheid vanuit de vraagkant (individu) en wordt in deze benadering vooralsnog geen rekening gehouden met concurrentie-effecten.

De 'utility' benadering van bereikbaarheid is in deze studie meegenomen als bereikbaarheidsmaat. In essentie is deze maat echter niet te beschouwen als een maat voor bereikbaarheid, maar als een maat voor de *waardering* van bereikbaarheid. Met andere woorden: de maat is als 'intermediare' bereikbaarheidsindicator niet zeer geschikt, maar wel als (input voor) een 'finale' indicator (zie onder).

Bereikbaarheid als economische indicator

In de economische literatuur bestaan ruwweg drie benaderingen voor de evaluatie van economische gevolgen van bereikbaarheid: (a) de kosten-baten analyse (KBA) met consumentensurplus of maatschappelijke welvaart als indicator, (b) de productiefunctie benadering met economische groei als indicator, en (c) een benadering met werkgelegenheid als indicator. In het algemeen wordt de kosten-baten methode als primaire methode gezien voor de evaluatie van de *gebruikersbaten* van bereikbaarheid. Uit de literatuur blijkt dat op nut gerichte bereikbaarheidsbaten gebruikt kunnen worden als basis voor het berekenen van het zogenoemde consumentensurplus binnen de KBA-systematiek. Dit heeft, ten opzichte van een standaard KBA, waarin reistijdwinst als indicator voor bereikbaarheid geldt, een aantal mogelijke voordelen. De belangrijkste zijn:

- de economische baten van bereikbaarheid kunnen zowel het resultaat zijn van ruimtelijke als infrastructurele veranderingen;
- ruimtelijke ongelijkheid ('spatial equity') kan beter in kaart worden gebracht, omdat bereikbaarheidwinst kan worden berekend per regio;
- concurrentie-effecten kunnen in de economische waardering van bereikbaarheid worden meegenomen door het consumentensurplus te berekenen met behulp van de evenwichtsfactoren van het ruimtelijk interactie model.

Een belangrijk nadeel van deze benadering is dat voor een theoretisch correcte berekening van dit consumentensurplus een verkeersmodel nodig is dat rekening houdt met de terugkoppelingen tussen ruimtelijke ontwikkelingen en het transportsysteem. Aangezien het afleiden van de gebruikersbaten van bereikbaarheid met behulp van een 'utility-based' bereikbaarheidsmaat en een ruimte-verkeer interactiemodel, voor zover bekend, nog niet eerder in Nederland is toegepast, is verder onderzoek noodzakelijk om de meerwaarde hiervan, als aanvulling op bestaande evaluatiemethoden, te bepalen.

Er zijn in de literatuur zeer weinig studies bekend die de *niet-gebruikersbaten* van infrastructuur of bereikbaarheid hebben onderzocht als onderdeel van een economische evaluatie. Niet-gebruikersbaten van bereikbaarheid kunnen bestaan uit 'option values' en 'bequest values'. Een 'option value' is het waarderen van het in de toekomst kunnen bereiken van bestemmingen, bijvoorbeeld een winkel- of natuurgebied. Een 'bequest value' is het waarderen van de bereikbaarheid van bestemmingen voor anderen, bijvoorbeeld het feit dat een openbaar-vervoerhalte dichtbij een woning deze beter bereikbaar maakt voor bezoekers. Alhoewel het economische waarderen van niet-gebruikersbaten complex is, lijkt verder onderzoek naar het belang ervan wenselijk.

Bereikbaarheid als sociale indicator

Op activiteiten en nut gebaseerde bereikbaarheidsmaten kunnen bruikbaar zijn in de evaluatie van de sociale gevolgen van ruimtelijk-infrastructurele varianten. Drie dimensie van sociale (on)gelijkheid kunnen worden geanalyseerd: (a) ruimtelijke ongelijkheid ('spatial equity') door het analyseren van bereikbaarheid naar regio, (b) sociale ongelijkheid ('social equity') door het analyseren van bereikbaarheid van verschillende sociaal-demografische groepen, bijvoorbeeld opleidingsniveau, en (c) economische ongelijkheid ('economic equity') door het vergelijken van bereikbaarheid van verschillende inkomensgroepen. De keuze voor een bereikbaarheidsmaat impliceert echter een bepaalde normatieve behandeling van sociale ongelijkheid. Als namelijk een bereikbaarheidspotentiaal wordt gebruikt, dan wordt impliciet verondersteld dat ieder individu dezelfde rechten heeft (de zogenoemde 'equal share approach'), bij een op nut gebaseerde maat wordt verondersteld dat de 'kosten' van de een kunnen gecompenseerd door de 'baten' van de ander, zonder rekening te houden met individuele verschillen in het marginale nut van geld (de zogenoemde 'utilitarian approach').

Samengevat kan worden geconcludeerd dat de huidige (voornamelijk op infrastructuur gerichte) beoordeling van de bereikbaarheidseffecten van (ruimtelijk-)infrastructurele plannen, projecten en/of scenario's kan worden verbeterd, gebruik makende van bestaande ruimtelijke en verkeersgegevens en/of –modellen. De op activiteiten gerichte benadering is zeer geschikt om de bereikbaarheidseffecten te beoordelen, waarbij de verschillende componenten van bereikbaarheid (de transport-, ruimte, tijds- en individuele componenten) op bevredigende wijze kunnen worden meegenomen, en is bovendien geschikt om sociale effecten ('equity') te beoordelen. De op nut gerichte benadering van bereikbaarheid kan als basis worden gebruikt voor de economische waardering van bereikbaarheid.

Summary and conclusions

Accessibility is a concept that has taken on a variety of meanings, including “the amount of effort for a person to reach a destination” or “the number of activities which can be reached from a certain location”. Furthermore, accessibility has been operationalised in several ways. This report identifies three basic perspectives on measuring accessibility:

(1) *Infrastructure-based accessibility measures* founded on the observed or simulated performance of the transport system. This type of measure is used in transport and infrastructure planning. Common measures are “level of congestion” and “travel speed”;
(2) *Activity-based accessibility measures* founded on the distribution of activities in space and time. Two approaches are seen in urban planning and geographical studies: (i) “geographical” measures, representing accessibility at a location (or zone) to all other destinations, the most common being contour measures and potential accessibility measures, and (ii) “space–time” accessibility measures, representing the potential of activities in which individuals can participate given (predefined) time constraints.
(3) *Utility-based accessibility measures* founded on the benefits people derive from access to the spatially distributed activities. This type of measure has its origin in economic studies.

Four (interdependent) components determining accessibility are also identified: (1) a *transport component*, reflecting the travel time, costs and effort to travel between an origin and destination location, (2) a *land-use component*, reflecting the spatial distribution of (supplied) activities at destinations (e.g. jobs, schools, shops) and the demand for those activities (e.g. workers, pupils, inhabitants) (3) a *temporal component*, reflecting the time restrictions of individuals and availability of activities at different times of the day, and (4) an *individual component*, reflecting the needs, abilities and opportunities of individuals.

This study is aimed at analysing the capacity of accessibility measures to evaluate the accessibility impacts of national land-use and transport scenarios, and related social and economic impacts. In this study, accessibility is defined as *the extent to which the land-use transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s).*

A two-part approach was chosen to meet the aim of this study. Firstly, an extensive literature study is described in which accessibility measures are reviewed according to their (a) theoretical and methodological soundness, i.e. the capacity for handling the four identified components of accessibility, (b) their interpretability, (c) data need and (4) the capacity to use them in evaluations of land-use and transport changes, and related economic and social impacts. Secondly, activity- and utility-based accessibility measures are computed in case studies aimed at analysing their capacity for evaluating accessibility impacts of land-use and transport changes. Three case studies analysing job accessibility by car and public transport in the Netherlands for were conducted for: (1) (the base year) 1995, (2) a Trend, or “business-

as-usual", scenario, representing the continuation of (restrictive) Dutch land-use policies and historical land-use trends for the 1995-2020 period, and (3) a Tolerant scenario, representing a land-use scenario where consumers' housing preferences are assumed to determine land-use developments for the 1995-2020 period. The scenarios are based on calculations using national land-use models (i.e. the models Land Use Scanner, Socrates and Opera) and the National Model System for Transport (NMS) from the AVV Transport Research Centre of the Ministry of Transport, Public Works and Water Management.

The following accessibility measures have been computed in the case studies:

- A contour measure, estimating the total number of jobs which can be reached within a maximum travel time of 45 and 60 minutes.
- A potential accessibility measure, estimating the potential number of jobs within reach, weighted by their travel time away.
- The accessibility measure, developed by Joseph & Bantock (1982), which is able to estimate job accessibility incorporating job competition effects. The measure computes the number of jobs accessible per worker.
- The inverse balancing factor (a_i) of the doubly-constrained spatial interaction model, estimating potential job accessibility (corrected for the interdependent competition effects) between jobs and on the working population.
- A utility-based accessibility measure, estimating the utility people derive from potential accessibility to jobs, using an impedance function for travel cost.

Results of the study follow below.

Transport component of accessibility

The transport component of accessibility generally consists of (a) distance, travel time, travel costs and travel effort between an origin and a destination, (b) perception and valuation of the impedance of a given origin–destination combination, i.e. the attractiveness of a destination as a function of the amount of travel time, cost and effort necessary to get there. All accessibility measures found in the literature incorporate more or less the elements of the transport component. *Infrastructure-based accessibility measures* focus on one element of the transport component, e.g. average travel time or travel speed. *Activity- and utility-based measures* usually incorporate travel distance, travel time or costs as transport elements. The *contour measure*, one of the most popular activity-based accessibility measures does not incorporate an impedance function to weigh opportunities according to their travel time or cost away. This has the methodological disadvantage that one incorrectly assumes that all opportunities are equally desirable, regardless of the time spent in travel or the type of opportunity accessed. Moreover, the case studies show that the contour measure is not very capable of explaining changes in accessibility in time as the result of the (arbitrary) maximum travel, i.e. the measure shows an extreme spatially differentiated picture of the development of job accessibility for the Trend and Tolerant scenarios for 1995-2020 because a relatively small travel-time change may result in the inclusion or exclusion of a job location from the accessibility value of an origin location.

Land-use component of accessibility

In general, the land-use component of accessibility consists of: (i) the number and spatial distribution of supplied destinations and their characteristics, e.g. the location of offices, schools and their attractiveness, capacity, etc., (ii) the spatial distribution of the demand for activities and their characteristics, e.g. locations of dwellings and their inhabitants, and (iii) the confrontation between “demand” and “supply”, or, in other words, competition effects. Competition may occur both on supplied opportunities (e.g. competition on jobs among workers) and on the demand for those opportunities (e.g. competition on workers among employers).

Infrastructure-based accessibility measures do not incorporate a land-use component, in contrast to activity- and utility-based. This can lead to different conclusions. For example, in the Netherlands, employment is concentrated in the highly urbanised western part of the Netherlands (the Randstad). In this area, the main road network is heavily congested during peak hours. From an infrastructure-based accessibility measure such as “average speed on the main road network”, one may conclude that the level of accessibility in the Netherlands is lowest in the Randstad, whereas from an activity-based accessibility measure (e.g. the number of jobs within 45 minutes travel time by car) one may conclude that the Randstad area shows the highest level of (job) accessibility of the Netherlands, despite the higher average travel times as a result of congestion.

In the case studies, two accessibility measures are applied in which incorporate competition effects are analysed: (i) Joseph & Bantock’s accessibility measure, and (ii) the inverse balancing factor (a_i) of the doubly constrained spatial interaction model. *Joseph & Bantocks’ measure* is shown to be not very capable of analysing job accessibility, i.e. the measure is expressed as an index, showing the (im)balance between the spatial distribution of job accessibility and accessibility to the working population (within the catchment area of job locations). The measure can thus be essentially interpreted as a measure of competition, not as a measure of accessibility. Furthermore, the measure does not account for the alternative job locations that workers have within reach; in other words, the measure does not account for the competition in the working population among employers. In the case of job accessibility, the accessibility measure should ideally incorporate both the competition within the working population and the competition for jobs. The *inverse balancing factors* of a doubly constrained spatial interaction model handles such a(n) (iterative) computational procedure and overcomes the disadvantages of Joseph and Bantocks’ measure.

The case studies show that job accessibility in central and suburban areas for 1995 and 2020 can decrease by 20-30% as a result of job competition among workers and more than double in peripheral areas. However, the land-use and transport changes according to the Trend and Tolerant scenarios for the 1995-2020 period do not radically change the current spatial distribution job accessibility and related job competition; the current urbanisation pattern in the Netherlands remains dominant. The inclusion of competition effects will become more important for more “extreme” land-use scenarios.

Temporal component of accessibility

The temporal component of accessibility involves (i) the availability of activities at different times of the day or week, season, year, etc. and (ii) the times in which individuals participate in specific activities. The *space-time accessibility approach* is the only approach focusing on the time component of activities. Space–time activity measures indicate the possible space–time paths of individuals or households between locations, given household activities to be performed and time-constraints. Infrastructure-based, other activity-based measures and utility-based measures handle the time component only implicitly, i.e. travel time and costs may vary in time (e.g. between peak hours and off-peak hours). Unfortunately, incorporating the temporal component in a theoretically satisfying manner requires additional data collection, i.e. time budgets are not available from standard revealed preference travel data. As a result, applications of space-time accessibility measures have been, up to now, often restricted to a relatively small region and a small subset of the population. This makes the accessibility measures difficult to apply on the national level (which is included in the aim of this study). Other accessibility measures handle the temporal component only implicitly. In the case studies, where accessibility is analysed at the national level, the temporal component is handled only by using peak hour and off-peak hour travel times.

Individual component of accessibility

An individual's characteristics (needs, abilities, and opportunities) play an important role in determining accessibility. Space–time accessibility measures and utility-based measures are disaggregate approaches focusing on an individual's accessibility. In contrast, geographical accessibility measures (e.g. contour and potential accessibility measures) analyse accessibility at a location, where all individuals in the same location have the same accessibility. However, in practical applications of accessibility measures, the contrast is often not so large. That is, accessibility is analysed for different population groups, depending on selected socio-economic characteristics. The case studies show that the development of job accessibility significantly changes if differences between socio-economic groups are accounted for. The potential accessibility measure and the inverse balancing factor clearly showed that job accessibility growth is overestimated if the match between workers education skills (two educational levels are used) and job requirements ("occupational match") is not accounted for. Furthermore, socio-economic developments have a large impact on the development of the utility-based accessibility measure, i.e. the utility level and development of utility is not the same when computed for the entire population as when computed for segments (by income group) of the population. Thus the differentiation of the population by socio-economic characteristics results in significant changes in average job accessibility and related utility, which is the result of a more accurate estimation.

Interpretability and theoretical soundness

There seems to be trade-off between the "common-sense" interpretability and theoretical/methodological soundness of the measure. Infrastructure-based accessibility measures, such as average speed on the road network, are relatively easy to interpret but are less capable of evaluating accessibility impacts of land-use transport scenarios. Activity- and utility-based accessibility measures are more appropriate indicators but are less easy to interpret. In other words, a change in accessibility may be the result of land-use changes, transport changes, or both. The case studies show that interpretability of activity-based measures with the data available can be improved by estimating the contribution of land-use changes and transport changes (travel-time changes as a result of delays and congestion and/or travel-time changes as a result of changes of the infrastructure supply) to the development of job accessibility. The results show that for the Tolerant and Trend scenarios for the Netherlands for the 1995-2020 period, land-use changes and travel-time changes (due to increased congestion), are equally important, and that, on the national level, the contribution of infrastructure expansions to job accessibility growth is relatively small.

Furthermore, accessibility measures with a better theoretical basis (utility-based measures), and measures which are methodologically improved to account for competition around opportunities (balancing factors) are less easy to interpret. The case studies show that the simplest activity-based accessibility measure, the contour measure, is not very capable of explaining changes in accessibility in time. Furthermore, the results of the utility-based measures contrast with the activity-based measures (i.e. contour measure, potential measure, and inverse balancing factor). In other words, the measure shows diminishing returns: the marginal benefits decrease as job accessibility further increases. If job accessibility changes at locations with a low accessibility level this results in a relatively large utility change, whereas a change at locations with an already relatively high accessibility level, results in a relatively small utility change. Thus, the utility-based accessibility measure suggests that the (economic) benefits are higher if job accessibility is improved for inhabitants in relatively job-poor areas (e.g. peripheral areas outside the Randstad), in preference to further increasing job accessibility for inhabitants living in already relatively job-rich areas (e.g. central and suburban areas in the Randstad).

Data requirements

In general, all activity-based accessibility measures can be estimated using standard revealed preference data or existing land-use and transport models, except space-time measures. In general, space-time accessibility measures are difficult to operationalise and apply as a practical accessibility measure for analysing accessibility on the national level. Note that the plausibility of the result also depends on the theoretical basis and practical limitations of the land-use and transport models used.

Conclusions related to the evaluation of land-use transport scenarios

This study focused on (a) analysing accessibility measures as *intermediate indicators* for the evaluation of impacts of changes within the land-use and transport system, and (b) analysing accessibility measures as a *final indicator* for evaluating impacts outside the land-use transport system; accessibility as an economic and social indicator. The conclusions follow:

Accessibility as an intermediate indicator

In summary, activity-based accessibility measures are effective measures for analysing accessibility impacts of land-use transport scenarios: a change in accessibility may be the result of land-use changes, transport changes, or both. However, the literature study clearly shows that there is no first-best activity-based accessibility measure. Each accessibility measure has its theoretical and practical advantages and disadvantages. As a result, the choice of an accessibility measure for analysing the impacts of a land-use or infrastructure project, plan or scenario depends on the study object. In summary:

- ☐ For the purpose of analysing accessibility to destinations where *no competition effects occur* or competition effects are not a subject of interest, the potential accessibility measure can be considered as an appropriate and practical accessibility measure;
- ☐ Joseph & Bantocks' measure is appropriate for analysing accessibility to destinations where *competition effects occur on destination locations* (e.g. nature areas), or capacity limitations of supplied opportunities are the subject of interest (e.g. in the analysis of recreational facilities or health-care facilities);
- ☐ The inverse balancing factor is an appropriate measure for analysing job accessibility, where *competition effects occur on both destination and origin locations* (job and working population, respectively). The inclusion of competition effects in analysing job accessibility become more important when "extreme" land-use policy scenarios are analysed.

Space-time accessibility measures are theoretically very capable of analysing the accessibility impacts of land-use transport scenarios, i.e. accessibility is analysed at the individual or household level, incorporating time constraints. However, in current practice, the space–time approach can not yet be applied to forecast accessibility impacts on the national level due to the large (additional) data requirements.

The utility-based approach has in this study been used as an accessibility measure. However, the measure estimates the utility (or benefits) accruing to accessibility, and can thus essentially be interpreted as a measure of how accessibility is *valued* by individuals, not as a measure of accessibility. In other words: this measure is more appropriate (as input) for analysing the economic impacts of accessibility scenarios (see below).

Accessibility as an economic indicator

Accessibility changes as a result of changes in the transport system or land uses may have different economic impacts. In the literature, different approaches for analysing economic impacts of infrastructure and accessibility exist. Basically, three approaches can be identified, in which different accessibility measures may play a role: (i) a social cost–benefit analysis (CBA) of transport projects, (ii) a production function approach with GDP as the main object, and (iii) an approach focusing on employment effects. In general, cost–benefit analysis can be considered the primary method for evaluation of the *user benefits* of accessibility changes of land-use and transport projects or scenarios, i.e. the CBA methodology is consistent with micro-economic theory, and a typical transport project can be justified if sufficient user benefits are generated. In theoretical studies, utility-based measures are shown to be related to the concepts of consumer surplus and consumer welfare used in CBA. In other words, utility-based accessibility measures interpret accessibility as the benefit that people achieve from accessing opportunities. Furthermore, the difference in consumer surplus, which is relevant in economic evaluations, can be estimated as the difference between two accessibility scenarios (e.g. one base situation and one reflecting a policy change) using a utility-based accessibility measure. The changes in utility can be converted to monetary units to derive economic welfare changes using the concept of compensating variation from economic theory. This approach may have important benefits, see below:

- The economic benefits of improved accessibility can be analysed as a result of (a) changes of the transport system (e.g. travel time and/or costs), and (b) changes in the physical location of land uses. In traditional cost–benefit analysis land-use changes are not incorporated because travel time and/or costs are used as an accessibility measure.
- The utility-based measure incorporates a land-use component, i.e. the research area is split up in regions. By allocating the user benefits of changes in accessibility to regions one can analyse which (groups of) individuals located in certain regions “win” or “lose” as a result of land-use and/or transport investments. Thus, this measure of consumer surplus may be used to analyse social (“equity”) impacts (see below).
- Consumer surplus can be estimated in relation to the balancing factors of the doubly constrained spatial interaction model, thus incorporating competition effects on the demand and supply side.

A disadvantage of this approach is that the theoretically correct use of utility-based accessibility measures for measuring consumer surplus of a land-use transport scenario requires a transport model which properly forecasts the combined land-use transport equilibrium, including land-use and transport feedback. However, the application of approach in the case studies was beyond the scope of this study. Further research is necessary to apply this approach to economic evaluations of transport projects or scenarios.

In the production function and employment approaches contour measures and potential accessibility measures may be used as input for the analysis. These measures can be used as an indicator of the market area for companies, which is considered a determinant for regional economic production. However, the relationships between infrastructure improvements, accessibility and economic development are theoretically complex, and empirical evidence is still weak and disputed. As a result, the production function approach might over- or under-estimate the impact of accessibility improvements on economic development. Further research is necessary to determine how this approach can be used to examine the wider economic impacts of accessibility improvements.

To the authors’ knowledge, no studies have been conducted to examine the *non-user* benefits people derive from accessibility. Non-user benefits may include an option value and a bequest value. Option value refers to goods or services that non-users may benefit from having them available as a backup for another good or service, or available in the future.

Accessibility may also have an option value: people not only value a transport mode for the actual use in accessing destinations, but probably also for accessing opportunities in the future. Bequest values refer to goods or services for which individuals are willing to pay to assure these services are available to other people. Accessibility may also have a bequest value: people may value public transport for making their homes accessible to visitors (who do not own cars). In practice it will probably be very difficult to include non-user values in economic evaluations of accessibility changes. Non-user values can probably be qualitatively analysed by Stated Preference studies, however, a plausible quantitative estimation of non-user values in economic evaluations of land-use infrastructural changes will probably be difficult to derive. Further research will be necessary to analyse the value added of including non-use values in economic evaluations of accessibility scenarios.

Accessibility as a social indicator

Activity-and utility-based measures may form a useful tool in social evaluations of land-use and infrastructure plans, projects and/or scenarios. Firstly, (changes in) the level of access to opportunities can be analysed, e.g. the differences in access to opportunities by car and public transport. Secondly, three dimensions of equity can be analysed, i.e. *spatial equity* can be analysed by estimating accessibility by region; *social equity* can be analysed by estimating accessibility for population groups stratified by socio-demographic characteristics (e.g. age, educational level, gender, household structure) and *economic equity* can be analysed by computing accessibility for income groups.

In principle, several activity-based accessibility measures can be used for the analysis of the spatial, social and economic equity of a given resource distribution. However, the choice of an accessibility measure implies a particular treatment of equity and also affects the conclusions. If an activity-based measure is used to derive an average accessibility levels, an “equals-share approach” is taken, i.e. all individuals are equally weighted. If a utility-based accessibility measure is used, a “utilitarian approach” is taken, assuming that the marginal utility of money is constant between individuals. For example, a 1% accessibility increase for high-income groups at the cost of a 1% decrease for low-income groups yields positive net benefits. Both approaches will lead to different aggregate results and thus “normative” conclusions on (changes in) social equity of accessibility.

In summary, the current Dutch practice of evaluating the (infrastructure-based) accessibility impacts of (land-use) transport projects, plans or scenarios can be improved by estimating activity-based accessibility measures, using existing land-use and transport data, and/or models. Activity-based accessibility measures are very well able to analyse accessibility impacts, satisfactorily incorporate the different components of accessibility (i.e. the transport, land-use, temporal and individual components) and serve as a useful tool for analysing social impacts. Utility-based accessibility measures may provide a useful basis for economic evaluations of land-use transport scenarios, but further research is necessary to analyse the added value to existing evaluation methods.

1. Introduction to the report

1.1 Setting the scene

Accessibility as a notion of the extent to which the transport system enables people to participate in activities is a fundamental but often neglected concept in transport analysis and planning. Despite its primacy to human activities, many transport plans and evaluation methods focus on measuring or maximising the transport systems' throughput or the level of service of transport infrastructure. That is, accessibility is often evaluated using *infrastructure-based accessibility measures* such as 'congestion levels' and 'average travel speed on the road network'.

This report focuses on two other, complementary, perspectives on accessibility that have developed in literature: *activity-based* and *utility-based accessibility measures*. The report consists of two parts:

The first part, Literature Review, presents a literature study on accessibility measures. Accessibility measures are reviewed according to their advantages and disadvantages related to (a) theoretical and methodological aspects, (b) their interpretability, (c) data need and (d) their usability in evaluations of land-use and transport changes, and related economic and social impacts.

In the second part of the report, Case Studies, several accessibility measures are applied to analyse the accessibility impacts of two land-use scenarios for the Netherlands for the period 1995-2020: (1) a Trend scenario representing the continuation of (restrictive) Dutch land-use policies, (2) a Tolerant scenario representing a land-use scenario where consumers' housing preferences are assumed to determine land use development. The scenarios are based on calculations using national land-use models and a national transport model. The report focuses on job accessibility by car and public transport.

1.2 Research context

This report is the first study report within the framework of the first authors' PhD research programme 'Ecological, Social and Economic Evaluation of Transport Scenarios: An Integral Approach' which is set up to develop, apply and evaluate methodologies for the integral assessment of the expected ecological, economic and social consequences of land-use transport scenarios (see Geurs, 2000). The development and evaluation of accessibility measures plays a central role in the research programme. This is because accessibility plays an important role within the land-use transport system and has significant economic and social implications. This can be illustrated by Figure 1.1, which presents a conceptual model to explain the functioning of the land-use transport system, the role of accessibility and its relationships with the ecological, socio-cultural and economic systems (see also Geurs, 2000).

The central part of the conceptual model is formed by the ***land-use transport system***, i.e. the interdependent system of land use and transport (e.g. see also Wegener & Fürst, 1999). The ***land-use system*** comprises (a) the spatial distribution of land uses (e.g. locations of houses, enterprises, schools, shops and the characteristics of the land use, such as density, diversity and design), (b) the locations of human activities (e.g. living, working, shopping, education or leisure), (c) the two-way interaction between land-uses and activities: the spatial distribution of activities co-determines the need for land uses; land-uses co-determine the location of activities. The ***transport system*** comprises (a) travel demand, i.e. the volume and characteristics of travel and movement of goods, (b) infrastructure supply, i.e. the physical characteristics of infrastructure (e.g. road capacity, speed limits), the characteristics of infrastructure use (e.g. distribution of traffic levels over time, the time-table of public transport), and the costs and prices of infrastructure, vehicles and fuels, and (c) the two-way interaction between travel demand and infrastructure supply: infrastructure supply determines travel demand (via time, costs and/or other aspects) and travel demand determines the level-of-service of supplied infrastructure. The land-use system and transport system interact in a two-way direction: (a) the spatial distribution of activities co-determines the need for travel and movement of goods in the transport system to

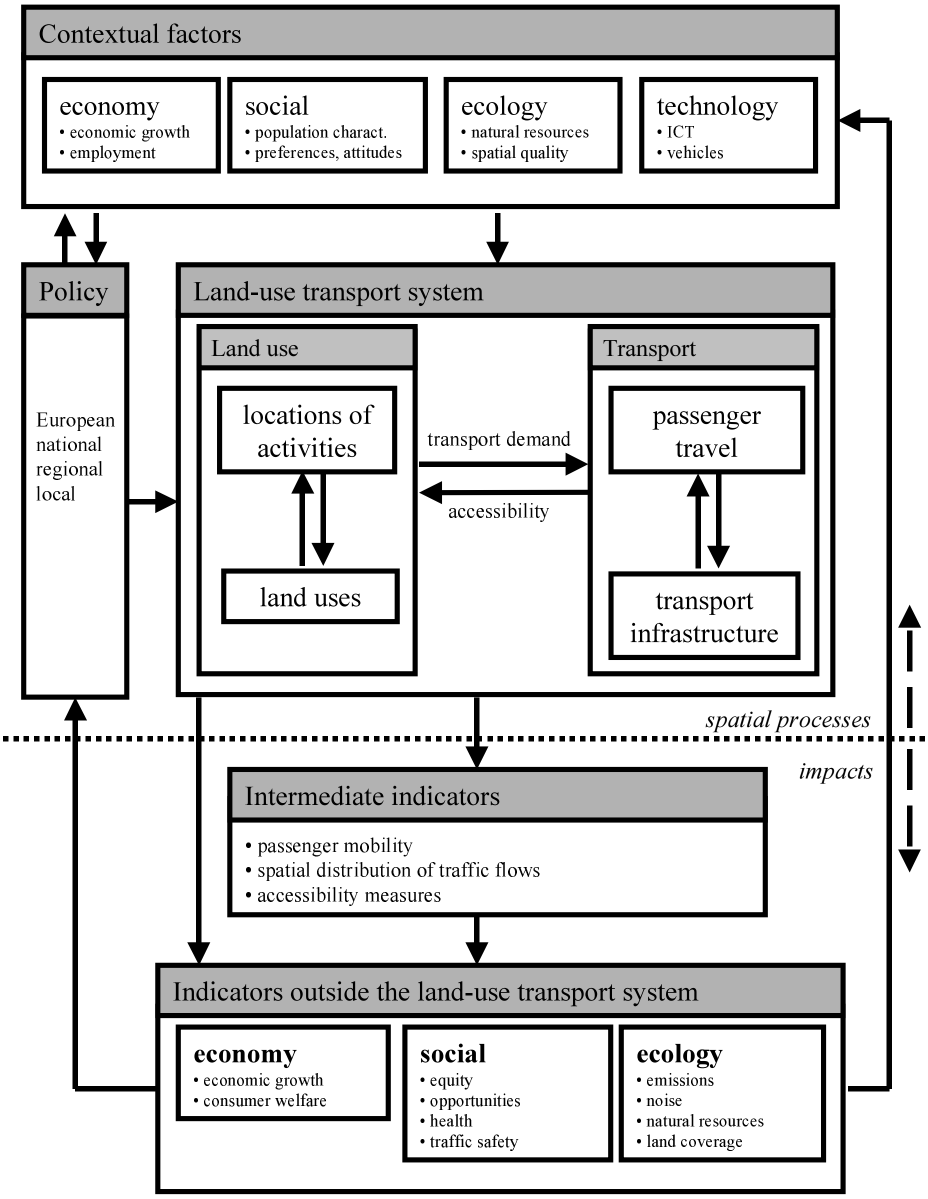


Figure 1.1: A conceptual model for the functioning and evaluation of the land-use transport system

overcome the distance between the locations of activities, (b) the accessibility of locations co-determines location decisions of households and enterprises and results in changes of the land-use system.

Contextual factors factors co-determine the functioning and impacts of the land-use transport system. Contextual factors can be described by: (a) the characteristics of the economy, e.g. the level of economic growth, (b) the socio-demographic and socio-cultural characteristics of the population, e.g. the age and income distribution of the population, including (travel) needs, preferences and attitudes of the population, (c) characteristics of the ecology/environment, e.g. the quantity of natural resources such as fossil fuels, the ecological/environmental quality of an area, and (d) the level of technology development, e.g. information and communication technology (ICT), vehicle technology. Furthermore, ***policy developments*** (e.g. investments in transport infrastructure, fuel taxes, location policies) influence the land-use transport system directly and indirectly (via the contextual factors).

The sum of the land-use transport system, contextual factors and policy can be described as ***spatial processes.*** The research programme focuses on the development and application of methodologies for the evaluation the ***impacts*** of these spatial processes. Indicators for the evaluation of these impacts can be split up into two groups: indicators within the land-use transport system, described as intermediate impacts, and indicators outside the land-use transport system. ***Indicators within the land-use transport system*** comprise mobility indicators (e.g. number of passenger kilometers by mode), the spatial distribution of traffic flows, and accessibility measures, i.e. infrastructure-based, activity-based and utility-based accessibility measures. ***Indicators outside the land-use transport system*** can be grouped into three categories for measuring: (1) economic impacts, e.g. the accessibility of an area influences the economic activity in that area, (2) social impacts, e.g. the land-use transport system can co-determine (a) equity aspects, e.g. distribution of costs, benefits and opportunities among groups of people or regions, (b) people’s opportunities, e.g. the level of accessibility influences the number of social and economic opportunities people can take advantage of, (c) health and traffic safety, e.g. the spatial distribution of traffic influences people’s exposure to emissions, noise and road, and (d) other social factors such as the level of social cohesion in a community or cultural identity, and (3) ecological impacts, e.g. the land-use transport system has impacts on the number of natural resources, the global environment (e.g. greenhouse gas emissions) and the regional/local environment (e.g. noise and emission impacts on ecosystems).

Note that these impacts interact to a certain degree with the contextual factors and the development of policies aiming to changes the economic, ecological or social impacts of the land-use transport system.

In summary, this study focuses on (a) reviewing and applying accessibility measures as intermediate indicators for the evaluation of impacts of changes in the land-use and transport system, and (b) reviewing accessibility measures for their capability of evaluating economic and social impacts. Note that this study does not include an evaluation of ecological impacts; these impacts are related the existence of infrastructure or mobility changes, and are not very relevant for the analysis of activity-based accessibility.

1.3 Structure of the report

The rest of the report is structured as follows. Part I, Literature Review, reviews the literature on accessibility and relationships to travel behaviour, land use, and social and economic impacts. Part I is divided into the following eight sections:

- Section 2: gives an introduction to the literature review.
- Section 3: describes the different components of accessibility.
- Section 4: reviews accessibility measures found in the literature, discussing the operationalisation and applications of these measures.
- Section 5: describes the relationships between accessibility, travel behaviour and land use.
- Section 6: describes how accessibility measures can be used for economic evaluations of land-use and infrastructural changes.
- Section 7: describes the use of accessibility measures for social evaluations of land-use and infrastructural changes.
- Section 8: presents the synthesis of the review. Accessibility measures are selected for the application in case studies (Phase II) based on criteria of interpretability, responsiveness to land-use and transport changes, theoretical foundation and data need, and capacity for social and economic evaluation.

Part II, Case studies, is divided into six sections:

- Section 9: gives an introduction to the case studies.
- Section 10: describes the methodology behind the construction of two land-use infrastructural scenarios.
- Section 11: describes the application of several accessibility measures for 1995.
- Section 12: describes accessibility impacts of a Trend scenario using several accessibility measures.
- Section 13: describes accessibility impacts of a Tolerant land-use scenario using several accessibility measures.
- Section 14: presents the conclusions of Part II.

Part I: Literature review

2. Introduction to the literature review

2.1 Introduction

This section overviews accessibility measures, and their operationalisation and applications found in both Dutch and international literature studies. The literature study is aimed at reviewing accessibility measures for their capability of analysing accessibility impacts of land-use and transport plans, projects or scenarios, and related social and economic impacts. For this purpose, aaccessibility measures are reviewed according to their advantages and disadvantages related to (a) theoretical and methodological aspects, i.e. the capability for handling the different components of accessibility, (b) their interpretability, (c) data need and (4) their usability in evaluations of land-use and transport changes, and related economic and social impacts.

This introductory section gives a short introduction to the different groupings and components of accessibility, the definition of accessibility used in this study, and the aim of the literature review. The different components of accessibility are further described in Section 3. Section 4 describes and reviews accessibility measures found in the literature, categorised by the different perspectives on accessibility. Furthermore, Section 5 describes the relationships between accessibility, travel behaviour and land use. Section 6: describes how accessibility measures can be used as a basis for economic evaluations of land-use and infrastructural changes. Section 7 describes the use of accessibility measures for social evaluations of land-use and infrastructural changes. Finally, Section 8 presents the conclusions of the literature review.

2.2 Perspectives and components

Accessibility is a concept used in a number of fields such as transport planning, urban planning, geography and marketing. Accessibility has taken on a variety of meanings (see Pirie, 1979; Jones, 1981; Hilbers & Verroen, 1993; MuConsult, 1994; Martellato *et al*., 1995 for an overview) including the amount of effort for a person to reach one or more locations, the opportunities for activity available in a geographical location, or the freedom of individuals to participate in activities in the environment.

Accessibility measures can be categorised in several ways. Here, three basic perspectives on measuring accessibility are identified:

(1) *Infrastructure-based accessibility measures*. These measures are used to analyse the (observed or simulated) performance of transport infrastructure. Typical measures are “average speed on the road network”, “level of congestion” or "average delays". This type of accessibility measure is usually used in transport studies and infrastructure planning;

(2) *Activity-based accessibility measures.* These measures are used to analyse the range of available opportunities with respect to their distribution in space and the travel impedance between origins and destinations. Activity-based measures can be further subdivided into geographical (or potential) and time-space measures:
  (a) Geographical accessibility measures analyse accessibility on a macro-level. A typical measure is "number of jobs within 30 minutes travel time". This type of measure is often used in urban planning and geographical studies;
  (b) Time-space measures analyse accessibility at micro-level. These include "the activities in which an individual can participate at a certain time". This type of measure is used in time geography;

(3) *Utility-based accessibility measures*. These measures are used to analyse the benefits individuals derive from the land-use transport system. This type of measure is typically used in economic studies.

Note that combinations of infrastructure- and activity-based measures are also used, especially in urban planning. Typical measures are "distance from housing locations to public transport infrastructure" or "distance or travel time from working locations to a roadway junction".

Identifying the different components of accessibility can make a further grouping of measures. Four types of components can be identified:

a) A *transport component* reflecting the disutility that individuals or groups experience in bridging the distance from their origin to destination using a specific transport mode, expressed in amount of time, cost and/or effort;
b) A *land-use component* reflecting the magnitude, quality and character of activities found at each destination (e.g. jobs, homes, recreational facilities) and this component's distribution in space;
c) A *temporal component* reflecting the availability of opportunities at different times of the day (e.g. opening hours of shops) and the times at which individuals participate in certain activities (e.g. work, recreation);
d) An *individual component* reflecting the needs, abilities and opportunities of individuals. People's needs depend on characteristics such as age, income, educational level and home situation. Abilities depend on people's physical state (may depend on age, physical disabilities) and access to transport modes (e.g. possession of a driver's license and car). Opportunities depend on people's income, travel budget, educational level, etc.

Table 2.1 presents the components per type of accessibility measure in a matrix. The table shows that a transport component is included in infrastructure-, activity- and utility-based accessibility measures. Infrastructure-based measures, which examine the performance of transport infrastructure, do not include a land-use component. That is, infrastructure-based measures are not sensitive to changes in the spatial distribution of activities. Note that, infrastructure-based measures do include a spatial component, i.e. travel times or costs differ by infrastructure type (e.g. motorway, urban road) and the location of infrastructure (e.g. urban area, rural area). Activity- and utility-based measures are sensitive to both land-use and transport changes, e.g. accessibility at a location may improve as a result of an increase of activities, reduced travel times, or both. The temporal component is explicitly handled in time-space measures, and is generally not considered in infrastructure-based or utility-based measures, or handled only implicitly. The individual and temporal components of accessibility are strongly related in time-space measures, i.e. time-space measures examine whether individual or household activity programmes can be carried out given the location of activities and time restrictions.

Table 2.1: Type of accessibility measures and components

component measure		transport component	land-use component	temporal component	individual component
infrastructure-based measures		average travel time; travelling speed; vehicle hours lost in congestion		peak hour period 24-hr period	trip-based stratification (e.g. home-work, business trips)
activity-based measures	geographical measures	travel time and/or travel costs between locations of activities, typically using a distance decay function	distribution of opportunities in space (e.g. number of jobs per zone or grid)	travel time and costs may differ between hours of the day, between days of the week, or seasons	stratification of the population (e.g. by income, educational level)
	time-space measures	travel time	distribution of opportunities in space	temporal constraints for activities and time available for activity participation are accounted for	accessibility is analysed at individual or household level
utility-based measures		travel costs between locations of activities, using a distance decay function	distribution of opportunities in space	travel time and costs may differ between hours of the day, between days of the week, or seasons	utility is estimated for population groups or at individual level

2.3 Definition of accessibility used in this study

In literature, many definitions of accessibility are used in the literature (see, for example, Pirie, 1979; Jones, 1981; Hilbers & Verroen, 1993, Hagoort, 1999 for overviews). The definition used will depend on the goal of the study. This study was aimed at development and application of accessibility measures as an indicator for the social and economic consequences of alternative land-use transport systems. This means that accessibility should relate to the role of the land-use transport system in society, i.e. giving people the opportunity to participate in activities in different locations. Thus accessibility has been used here to refer to:

The extent to which the land-use transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s).

This definition incorporates the components of accessibility as described in the previous section, i.e. comprising a transport component (the ease - amount of time, cost and effort - of reaching destinations), a land-use component (spatial distribution and characteristics of potential destinations), a temporal component (availability of activities throughout the day), and an individual component (individual valuations of the components).

2.4 Focus of the literature review

The literature study is aimed at reviewing accessibility measures according to their advantages and disadvantages related to (a) theoretical and methodological aspects, (b) their interpretability, (c) data need and (d) their usability in evaluations of land-use and transport changes, and related economic and social impacts. The literature study focuses on activity-based and utility-based accessibility measures. These measures fit within the aim and definition of accessibility used in this study (see above). Firstly, activity- and utility-based measures are sensitive to both changes in transport (e.g. infrastructure investments) and land-use changes (e.g. compact urban development), thus allowing the accessibility impacts of changes in the land-use transport system to be evaluated. Secondly, activity- and utility-based measures relate to the opportunities supplied by the land-use transport system and can therefore be seen as a useful base for social and economic evaluations of transport scenarios.

Furthermore, the literature study focuses on accessibility measures for passenger travel. Section 4.7 is devoted to accessibility measures for freight travel.

3. Components of accessibility

3.1 Introduction

This section describes the different components of accessibility. Section 3.2 describes the transport component, Section 3.3 the land-use component, Section 3.5 the temporal component and Section 3.5 the individual component. Finally, Section 3.6 presents an overview and describes the relationships between the different components.

3.2 The transport component of accessibility

3.2.1 Introduction

In general, the transport component consists of three elements: (i) the supply of infrastructure, its location and characteristics (e.g. maximum travel speed, number of lanes, public transport timetables, travel costs), (ii) the demand for passenger and freight travel, (iii) the characteristics of resulting infrastructure use; this is the outcome of the confrontation between infrastructure supply and travel demand, resulting in the spatial distribution of road traffic, and the travel time, costs and effort to reach a destination. Figure 3.1 shows the transport component schematically.

The elements time, costs and effort (see Section 3.2.2) can describe the influence of the transport component on accessibility. Note that, infrastructure-based measures include a spatial component, travel times or costs may differ by infrastructure type (e.g. motorway, urban road) and the location of infrastructure (e.g. urban area, peripheral area) as a result of the spatial distribution of traffic.

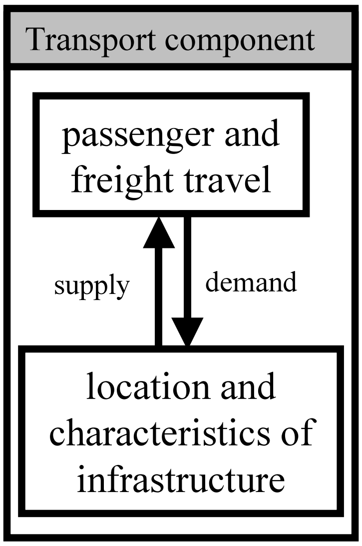


Figure 3.1: The transport component of accessibility

3.2.2 Time, cost and effort

The ease with which one can travel between an origin and a destination location consists of many different elements which are valued differently by individuals. These elements can be grouped into three categories: (a) the amount of travel time, (b) travel costs, and (c) travel ‘effort’. Table 3.1 gives an overview of elements. For example, the travel time for a typical car trip has the following time components: walking to the parking place, car travel time (depending on distance, speed limits, road traffic level), congestion time, finding a parking place near the destination and walking to the destination. The total car trip costs consist of fixed costs (e.g. driver's licence, car purchase, insurance) and variable costs (e.g. fuel, maintenance). The category travel effort, or convenience, comprises elements as comfort, reliability, the level of stress, and accident risks. Clearly, some of the aspects of the 'effort' elements are the most difficult to estimate in quantitative terms, e.g. level of comfort, stress, status. In general, activity-based accessibility studies use travel distance or travel time as transport elements. Some of these studies aggregate the different time elements into a total travel time, sometimes using a monetary value of times for different types of travellers and trip purposes (e.g. AVV, 1998). In transport models a generalised cost function of travel time and distance is normally used to estimate the level of spatial interaction between origins and destinations. An example of a generalised cost function is:

$$c_{ij} = v_m t_{ijm} + c_m d_{ijm} + u_m k_{ijm} \qquad \text{(Equation 3.1)}$$

where t_{ijm}, d_{ijm} and k_{ijm} are travel time, travel distance and convenience of travel from location i to j by mode m, respectively, and v_m, c_m and u_m are value of time, cost per kilometre and disutility of inconvenience of mode m, respectively. In addition, there may be a fixed travel component as well as a cost component. These elements may, for example, take into account network access at either end of a trip, waiting and transfer times at stations, waiting times at borders and congestion. For example, the Netherlands National Model System for Traffic and Transport (NMS) (Gunn, 1994; HCG, 1997) estimates the probability that travellers will choose a certain travel mode and destination at the origin using, for example, the components: travel time (including delays), and parking, road pricing and kilometre costs (e.g. fuel costs) for the car mode, and the components: travel time, waiting time, walking time and ticket costs for the rail mode.

Table 3.1: Elements within the transport component of accessibility

mode elements	Car	public transport	bicycle/walking
time	walking to parking place in vehicle travel time congestion time finding a parking place walking to destination	hidden waiting time travel time of access/egress mode waiting time at station in vehicle travel time transfer time	travel time bicycle parking
costs	fixed costs fuel costs maintenance costs parking costs road-pricing costs	costs of tickets/fares	fixed costs maintenance costs
effort	level of (dis)comfort physical effort reliability stress accident risk information status	level of (dis)comfort physical effort reliability stress accident risk social safety information status	level of (dis)comfort physical effort social safety

Source: based on Hilbers & Verroen, 1993; MuConsult, 1994

3.2.3 Distance decay

It has long been understood that the interaction between two locations declines with the increasing disutility (distance, time, and costs) between them. In general, the perception and valuation of the distance between an origin and a destination differ according to:

- Transport modes, i.e. car, public transport, non-motorised modes;
- Purpose of trip, e.g. home-work, non-home work, social;
- Characteristics of the household, e.g. income, educational level;
- Characteristics of the destination, i.e. its uniqueness and attractiveness (e.g. large shopping facilities in the city centre have a different distance decay than local grocery outlets).

Several forms of distance decay functions are used in accessibility studies:

- A negative power or reciprocal function (i.e. $F(d_{ij}) = d^{-\alpha}$), which has, for example, been used by Hansen, 1959; Patton & Clark, 1970; Davidson, 1977 and Fotheringham, 1982.
- A negative exponential function (i.e. $F(d_{ij}) = e^{-\beta d}$), which has, for example, been used by Wilson, 1971; Dalvi & Martin, 1976; Martin & Dalvi, 1976 and Song, 1996);
- A modified version of the normal or Gaussian function (i.e. $F(d_{ij}) = 100*e^{-d^2/u}$), where u is a constant. This function has, for example, been used by Ingram, 1971 and Guy, 1983;
- A modified (log)logistic function (Bewley & Fiebig, 1988) (i.e. $F(d_{ij}) = 1+e^{a+b*\ln d}$), where a and b are constants. This function has been used by Hilbers & Verroen (1993).

Figure 3.2 gives an example of the distance decay of a negative power function, a Gaussian function and a logistic function.

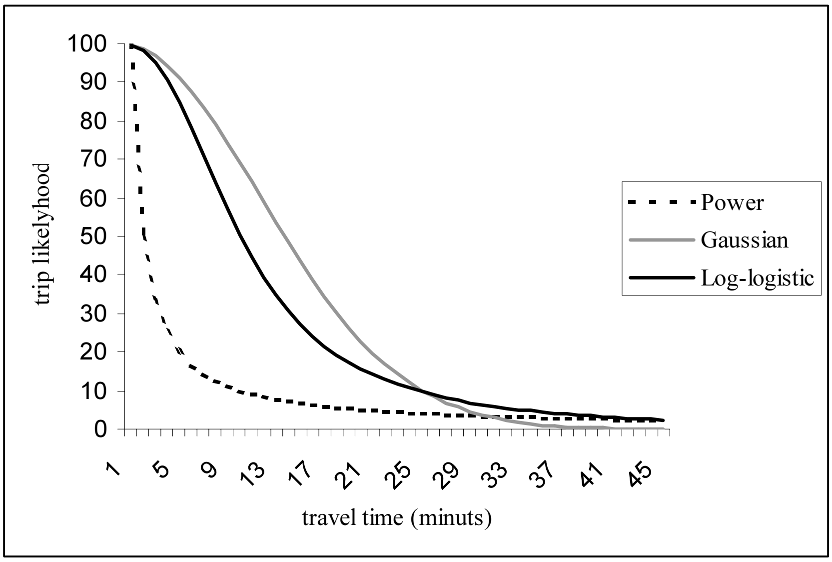


Figure 3.2: Examples of distance decay functions.

The choice of which specific distance decay function to use in an accessibility measure depends on (a) the specific characteristics of the function and (b) the study area and the 'fit' on empirical data. Some functions are less appropriate for describing distance decay. The following aspects are relevant (see also Hilbers & Verroen, 1993):

1. The steepness of the function. A negative power and a negative exponential function decay very rapidly, suggesting a strong sensitivity to short distances. From a behavioural point of view, a very strong decay at short travel distances or times does not seem realistic, i.e. the perception of distance will probably not be very different between a 3-minute and a 6-minute trip. Fotheringham (1982) states that a power function gives a more accurate description of the perception of distance at an *interurban* level than an exponential function, which may be more accurate on an intra-urban level. Hilbers & Verroen (1993) state that, in general, a conventional logistic function will give a better behavioural explanation of distance decay because of its S-shaped form;
2. The functions' point of inflection. Some functions (such as the conventional logistic function) have a fixed point of inflection halfway the maximum trip likelihood. This implies that the perception of distance is assumed to be same for short and long travelling distances;
3. The value of the trip likelihood at zero distance. For the estimation of the trip likelihood it is necessary that the function reaches the maximum trip likelihood when the distance is zero.

Several authors have compared the shape of the functions to empirical data. Ingram (1971) states that negative power and exponential functions tend to decay too rapidly in comparison to empirical data and finds a modified Gaussian form superior. In the Netherlands, Hilbers and Verroen (1993) analysed several distance decay functions and found a modified logistic function fitting the best to travel data from the Dutch National Travel Survey. For the estimation of accessibility measures in this report, the correlation of several distance decay functions (i.e. negative power, negative exponential, Gaussian and log logistic functions) on empirical travel data was estimated using a recent Dutch National Travel Survey (see section 9.2).

Note that some authors (e.g. Hilbers & Verroen, 1993) refer to contour measures (measures in which no distance decay is assumed – see Section 4.3.3) as potential accessibility measures, whereas potential measures (using a distance decay function – see Section 4.3.4) are referred to as actual accessibility measures. In this report, actual accessibility measures refer to the transport component, describing actual or simulated travel behaviour only.

3.3 The land-use component of accessibility

3.3.1 Introduction

The distribution of opportunities in space influences the level of accessibility. Clearly, if, for example, all jobs and dwellings are equally distributed over a certain area, every inhabitant has the same level of job accessibility. In contrast, if all jobs are clustered in the (city) centre of a given area, then people living near to (city) centre have a high level of access to jobs and people at living on the periphery, a low level.

In general, the land-use component of accessibility can be split up into two elements: (i) the spatial distribution of supplied destinations and their characteristics, e.g. the location of offices, schools and their attractiveness, capacity, etc. and (ii) the spatial distribution of the demand for activities and their characteristics, e.g. locations of dwellings and their inhabitants. Figure 3.3 shows the land-use component of accessibility schematically.

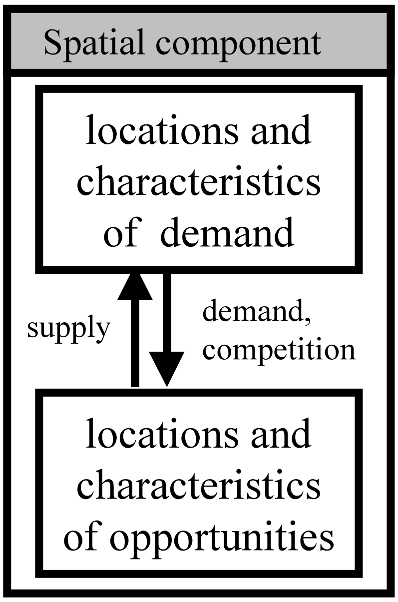


Figure 3.3: The spatial component of accessibility

Clearly, the distribution of supplied opportunities influences the level of accessibility to those opportunities. The spatial distribution of the demand (e.g. inhabitants) for opportunities also influences accessibility, if the opportunities have capacity limitations. This is for example the case for jobs, schools and hospitals. In other words: competition effects, which are the result of the interaction between the demand for and supply of opportunities, may also influence the level of accessibility to certain opportunities. Thus, competition is a relevant aspect to consider in accessibility analysis as part of the land-use component of accessibility.

3.3.2 Demarcation of the research area

In handling the land-use component of accessibility the demarcation of the total research area as such and the area within the research area must be decided. The total area taken into account in an accessibility study is obviously an important choice, and depends on the aim of the study. In many studies the spatial demarcation coincides with the borders of a country, resulting in low accessibility levels of regions near borders. This demarcation may be questionable in an international setting, i.e. regions having a low accessibility level in a national context may have a high accessibility level in an international context.

In the demarcation of regions or nodes within the total research area three approaches can be identified:

1. An approach using network nodes or centroids to represent cities or regions;
2. A approach using raster-based GIS technology;
3. A combination of zones and raster-based GIS.

Most of the accessibility studies cited in this report (see Section 4.4.2) are based on network nodes or zones. A nodal system introduces the problem of the demarcation of area (see Rietveld & Bruinsma, 1998), and has the disadvantage that the spatial organisation within the chosen zones is ignored. To overcome the demarcation problem, geographical studies sometimes use raster-based GIS, in which the spatial units are exogeniously given. For example, on a local scale, Ritsema van Eck & De Jong (1999) analysed accessibility to retail services in the city of Utrecht in the Netherlands, using a contour measure implemented in a geographical information system (GIS). On a regional scale, for example, Ritsema van Eck & De Jong (1996) analysed job accessibility in the Utrecht region estimating a contour measure using a GIS. On a national scale, Calvo *et al*. (1993) developed a system of accessibility indicators (contour measures and potential measures) for Spain based on raster cells of 5-km in width. Synthetic raster data are constructed by allocating population data to the raster cells based on assumptions on the decreasing density with distance from the centres of the municipalities.

The most straightforward method for including the spatial distribution of activities within regions or zones is to increase the number of areas. However, this is not always possible due to a lack of data. A combination of zones and raster-based GIS is also sometimes used to overcome this problem. Land-use data from GIS or remote sensing images are then used as ancillary information to derive a more disaggregate estimation of the accessibility measures. For example, Spiekermann & Wegener (1994; 1996; 1999) disaggregate land-use data for 200 European regions into 70,000 raster cells of 10 km in width. A synthetic raster is generated using microsimulation in combination with a raster-based GIS. Accessibility measures (contour measurers, potential measures) are estimated for raster cells, which can be aggregated to the European regions. The accessibility indices are presented as three-dimensional accessibility surfaces, where the elevation of the surface of each point indicates the magnitude of accessibility at that point (see Figure 3.4). Another

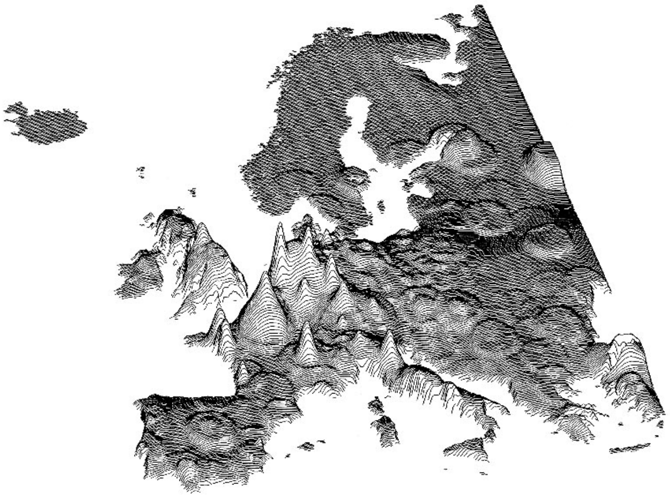


Figure 3.4: Potential accessibility to the population by rail in Europe in 1993 (Spiekerman & Wegener, 1994).

example is the Dutch Environment Explorer (RIVM, 1998; White & Engelen, 2000), a national land-use model using a regional system-dynamics model to allocate land uses and activities on a subprovincial level (40 regions) and the cellular automata technique to simulate spatial processes on a local level (using 500 meter grids). At the moment of writing, the Environment Explorer is being elaborated with a state-of-the-art transport model (AGV, 2001), estimating passenger mobility (car and public transport) and potential accessibility measures for the Netherlands on a level of 345 zones. The model is thus able to compute accessibility on a regional, zonal and grid level.

3.4 The temporal component of accessibility

The temporal component of accessibility involves (i) the availability of activities at different times of the day or weeks, seasons, years, etc. and (ii) the times in which individuals participate in specific activities. The time component and land-use component of accessibility are interdependent because individuals can only be at one location at a given time and travel consumes time. There are several authors who highlight the importance of considering a temporal component besides transport and land-use components (e.g. see Burns, 1979; Kitamura & Kermanshah, 1984). The temporal component of accessibility originates from the space-time studies of the urban activity system from Hägerstrand (1970) and Chapin (1974). The space-time prisms used in these studies can be regarded as accessibility measures, i.e. they give the potential areas which can be reached given predefined time constraints. In potential accessibility measures, the temporal component is usually implicitly dealt with by differing the transport component throughout the day.

3.5 The individual component of accessibility

The characteristics of individuals play an important role in the level of access to social and economic opportunities. In psychological studies related to passenger mobility (e.g. see Vlek & Steg, 1996) three groupings of determinants are often identified: needs, abilities and opportunities. In relation to accessibility, these characteristics can be summed up as below.

Needs people have for travel and access to opportunities depend on such characteristics as age, income, educational level, phase in life, and household situation. For example, households with children will have a need for access to schools, higher educated people will have a need for specific job opportunities, older people will have a higher demand for access to health care, etc.

Abilities of people are related to level of physical capacity (e.g. cognitive, sensory, intellectual or physical disabilities) and to specific skills needed to access a transport mode (e.g. qualifications to drive a car). For example, people without a driver’s license only have access to job opportunities which can be reached by public transport or non-motorised modes, and disabled people need specific services for accessing public transport.

Opportunities of people are related to income and travel budgets, e.g. 80% of the lowest income groups (less than 15,000 Euro per year) in the Netherlands currently do not own a car, and are thus dependent on public transport and non-motorised modes of transport.

The analysis of differences in access to opportunities between various subgroups (e.g. by age, gender, ethnicity or educational level) is an important concern in geographical research. See for example Kempers-Warmerdam, 1988; Hanson, 1995; Hanson & Pratt, 1990; Ihlanfeldt, 1993; Kwan, 1998; McLafferty & Preston, 1992; Shen, 1998. In general, the individual component of accessibility is incorporated into accessibility measures by stratifying the population according to a selection of relevant characteristics (e.g. age, gender).

3.6 Overview of components

The previous sections described how the four components (the transport, spatial, temporal and individual component) are related to accessibility. However, the components are also related to each other. Figure 3.5 shows the relationships between the four components and accessibility and between the components.

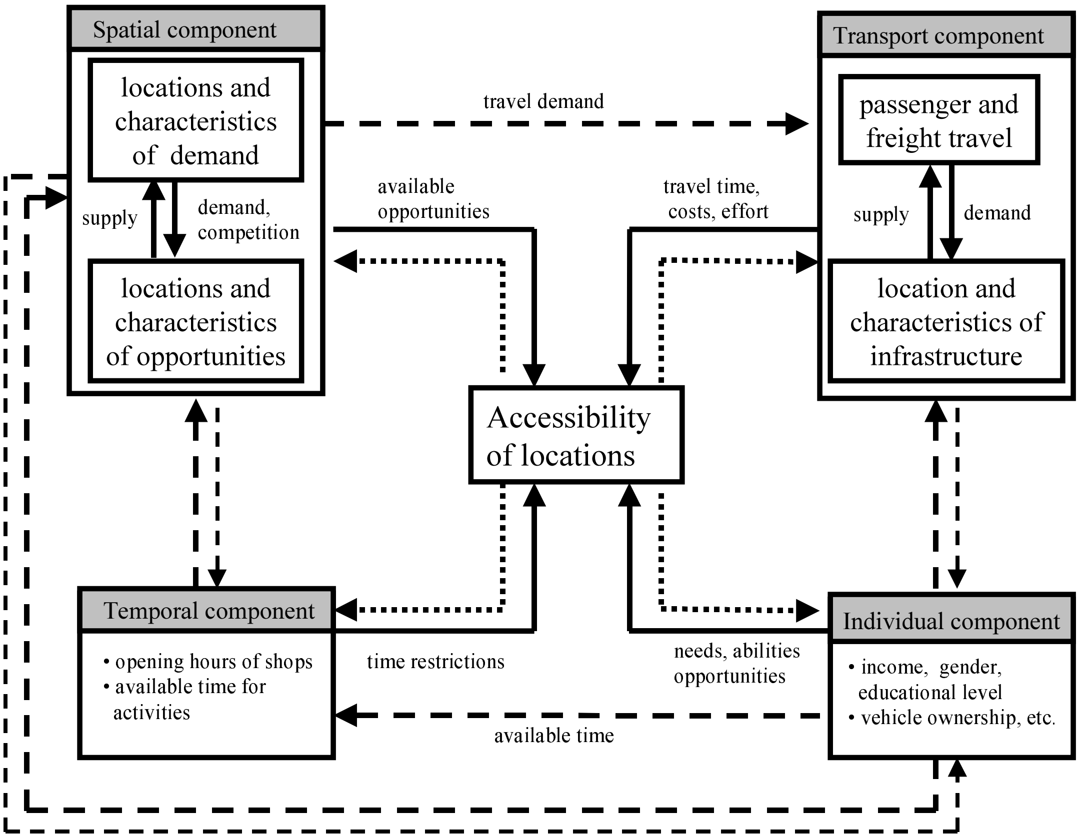


Figure 3.5: Relationships between components of accessibility

Figure 3.5 shows that accessibility of a location is the result of the four components: the land-use components influences accessibility by determining the availability of activities, the transport components by travel time, costs and effort, the individual component by people's needs, abilities and opportunities and the temporal component by time restrictions of opportunities and individuals or households.

Furthermore, accessibility may also influence the components (feedback relationships): accessibility is a location factor for inhabitants and firms (relationship with land-use component) and influences travel demand (transport component), peoples' economic and social opportunities (individual component) and the time needed for activities (temporal component).

Finally, the components are also related: the land-use component (distribution of activities) is an important factor determining travel demand (transport component) and may also introduce time restrictions (temporal component) and influence peoples opportunities (individual component). The individual component (e.g. income, educational level) also influences travel demand (transport component), the available time for activities (temporal component), and the demand for opportunities (land-use component).

4. Overview of accessibility measures

4.1 Introduction

This section gives an overview of accessibility measures, grouped by the different perspectives on accessibility. Section 4.2 describes “infrastructure-based” accessibility measures, Section 4.3 “activity-based” measures and Section 4.4 “utility-based” measures. Section 4.5 presents an overview of references to accessibility studies found in literature.

Furthermore, Section 4.6 discusses methods for incorporation of demand and supply characteristics into activity-based accessibility measures, e.g. socio-economic characteristics of the population and competition effects.

Finally, Section 4.7 describes accessibility measures for freight transport.

4.2 Infrastructure-based accessibility measures

Infrastructure-based accessibility measures, such as journey times, congestion and operating speed on the road network, currently play an important role in transport policies related to accessibility. In national transport policy plans of European countries, improving accessibility (as measured by infrastructure-based accessibility measures) is generally considered to be important for economic development and/or to reduce the economic deprivation of regions and/or population groups. See Ypma (2000) for a recent overview of infrastructure-based accessibility measures used in transport policies in the European Union, Belgium, Germany, the United Kingdom, France, Spain and Denmark and the Netherlands. For example, the UK Transport 2010 policy plan was evaluated using congestion and total vehicle hours saved as accessibility measures (DETR, 2000).

In the Netherlands, infrastructure-based accessibility measures have played and still play a very important role in national transport policies (see B&A, 2000 for an overview). In the 1990ies the accessibility indicators used in national transport policies (SVVII, 1990) were:
(a) a congestion probability of 2-5% on (certain links of) the main road network;
(b) a travel-time ratio of 1.5 between public transport and car traffic;
(c) the number of trains delayed.
In the recently published Dutch National Traffic and Transport Plan (NVVP, 2001) the accessibility indicator ‘congestion probability’ is replaced by ‘travel speed’. The goal is to achieve a minimum of 60 km/hour on the main motorway network during peak hours.

Furthermore, comparative studies of infrastructure between regions or countries often use simple accessibility measures considering the transport infrastructure in an area, such as the total length of motorways, the number of railway stations (see for example V&W, 1995).

Infrastructure-based accessibility measures may result in different conclusions on accessibility than activity-based measures, which incorporate both the transport and the land-use component of accessibility. For example, Linneker & Spence (1992) show for the UK that if access costs (in terms of value of time costs and vehicle operation costs per kilometre) are used as an accessibility measure, inner London will have the lowest average accessibility of jobs and Scotland the highest of the UK, whereas if a (market-)potential accessibility measure is used, inner London will have the highest average accessibility of jobs (despite the higher travel cost) and Scotland the lowest. This can also be illustrated for the Netherlands. In the Netherlands, a large amount of employment is concentrated in the western part of the Netherlands (the Randstad Area). In this area, the main road network is heavily congested during peak hours. Thus, from the infrastructure-based accessibility measure "level of congestion", it can be concluded that the level of accessibility in the Netherlands is lowest in the Randstad (see Figure 4.1). From a potential accessibility measure (i.e. the number of jobs within 45 minutes travel time by car during the peak period), it can be concluded that the Randstad Area shows the highest level of (job) accessibility of the Netherlands (see Figure 4.2), despite the higher average travel times as a result of congestion.

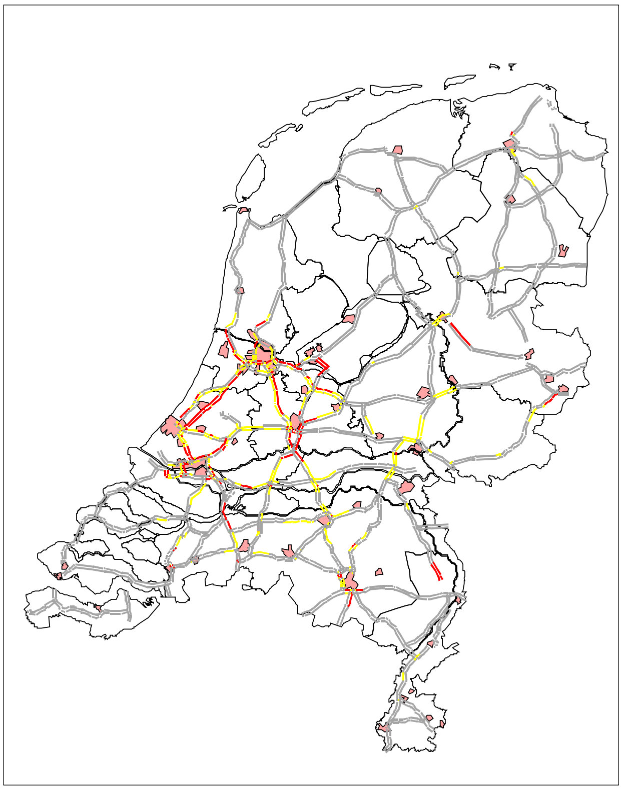


Figure 4.1: Traffic level/road capacity ratio on the main road network during peak hours in 1995 (red=heavily congested, yellow=some congestion, grey=no congestion)
Source: AVV (2000)

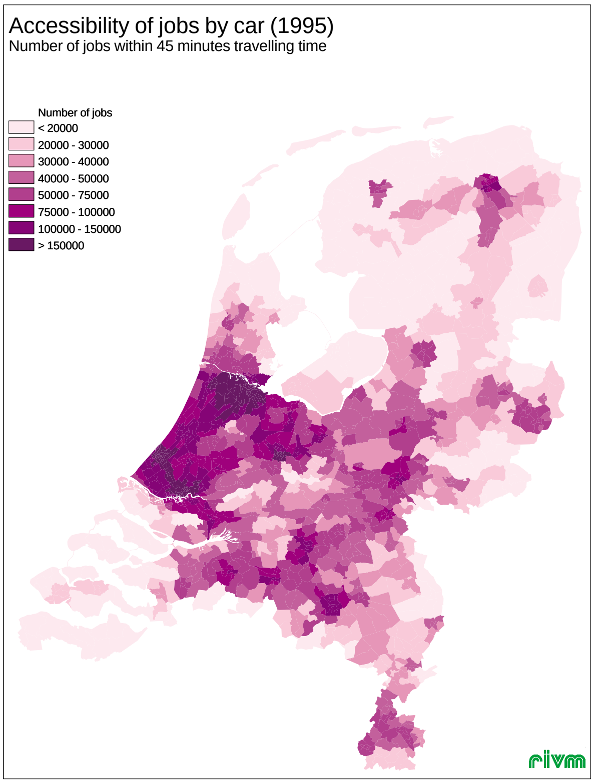


Figure 4.2: Accessibility of jobs within 45 minutes travel time by car in 1995 (morning peak hour)
Source: Geurs & Ritsema van Eck (2000).

In the transport literature frequent references on the need for a "paradigm shift" in land-use transport planning and performance measurement are seen from traditional infrastructure-based measures to activity-based accessibility measures (e.g. see Brand, 1991; Ewing, 1993; Cervero *et al.*, 1997). Infrastructure-based accessibility measures provide valuable information on the level of service of infrastructure in an area, but fail to recognise that destinations of interest may lie far away from that area. Furthermore, effects of improved level of services of infrastructure on land-use patterns are not considered, e.g. increased vehicle speed tends to increase urban sprawl (Ewing, 1993). Activity-based measures have the advantage that the efficiency of both land-use patterns and transport network configurations are reflected in the measure. In this report, activity-based accessibility measures are seen as a complement to transport planning's more traditional infrastructure-based measures of performance.

4.3 Activity-based accessibility measures

4.3.1 Introduction

There are several types of activity-based accessibility measures used in urban and transport planning studies. This section describes the following measures:
(1) distance measures (Section 4.3.2);
(2) contour measures (Section 4.3.3);
(3) potential measures (Section 4.3.4);
(4) measures based on balancing factors of spatial interaction models (Section 4.3.5);
(5) measures derived from time-space geography (Section 4.3.6).

Each measure will be shortly described, after which references to applications are given; finally, the advantages and disadvantages of the measure are described. An overview of references to applications of each type of accessibility measure is found in Table 4.1.

4.3.2 Distance measures

Description
The simplest of distance measures is the "relative accessibility" measure developed by Ingram (1971). Relative accessibility is defined as the degree to which two places or points on the same surface are connected. The simplest measure of relative accessibility is the straight line between two points, but infrastructure-based accessibility measures (average travel times, average speed) between two locations can also be a measure of relative accessibility.

Applications
Relative accessibility measures are often used in land-use policy and geographical studies as standards for the maximum travel time or distance to a location or to transport infrastructure,

e.g. each inhabitant must be able to reach a hospital within 30 minutes travel time, or each inhabitant must have a bus stop within 500 metres from their homes. Examples of distance measures can be found in early Dutch Spatial Planning Plans (VROM, 1976).

Advantage/disadvantage

A distance measure is a very simple accessibility measure combining the location of an activity with the transport system. The measure can be used if the destination is known, e.g. in the case of a visit to a town hall. If more than two possible destinations are analysed (the accessibility of one place or point to all other places), a contour measure can be derived (Ingram uses the term ‘integral accessibility’).

4.3.3 Contour measures

Description

The contour measure (also called an 'isochronic measure’, ‘cumulative opportunities’, ‘proximity distance’ or ‘proximity count’) is a measure often used in urban planning and geographical studies. The measure indicates the number of opportunities reachable within a given travel time or distance. This measure indicates that accessibility increases if more opportunities can be reached within a given travel time or distance. This increase can be the result of a change in the ease of reaching destinations (e.g. a shortening of travel times due to infrastructural improvements) and/or land-use changes (e.g. more destinations within reach).

The contour measure does not discount opportunities over distance; in consequence, the level of accessibility at an origin increases if the maximum distance or time chosen increases. Breheny (1978) identifies three types of contour measures:

a) fixed costs: number of opportunities accessible within a fixed cost limit;
b) fixed opportunities: the (average or total) time or cost required to access a fixed number of opportunities
c) fixed population: the average (over the population) of the number of opportunities available within various fixed travel costs.

Applications

Early studies modelled accessibility as cumulative functions of opportunities that could be reached within a predefined time (e.g. see Wickstrom, 1971). Later, many authors analysed accessibility by using contour type of measures, including analyses of accessibility of jobs, population, retail services, public services, health services, education and recreational facilities (see Table 4.1 for an overview). A number of studies represent variations on the concept of ‘daily accessibility’ developed by (Törnqvist, 1970), The rationale of this accessibility indicator is derived from the case of a business traveller who wishes to travel to a certain city, conduct business there and return the same day. Maximum travel times of 3 to 5 hours (one-way) are used. Several accessibility studies have used this concept; see, for example, Erlandsson & Törnqvist (1993), Lutter *et al*. (1993), Chatelus & Ulied (1995), Spiekermann & Wegener (1994, 1996, 1999) and Vickerman *et al*. (1999).

Several studies analyse contour measures with fixed opportunities, estimating the travel time or cost to reach a fixed number destinations. This measure is sometimes also referred to as a ‘travel cost accessibility measure’. For example, Cauvin *et al.* (1993) estimated rail travel times between 55 cities in Europe in 1987-1988 and 2015. Lutter *et al.* (1992b) calculated average travel times to 194 economic centres in Europe by fastest mode (road, rail, air). Gutiérrez & Urbano (1996) calculated average travel time by road and rail from about 4000 nodes of a multimodal European transport network to 94 agglomerations with a population of more than 300,000. Figure 4.3 illustrates this in the average road travel times in 1992, with the highest level of accessibility around Paris.

A very detailed travel cost study was done by the Austrian Institute of Spatial Planning (ÖIR, 1999). In the study, the average travel time from settlements (of more than 300 inhabitants) to 55 central locations in Austria and neighbouring countries are estimated by road and by public transport using a detailed road network (more than 12,000 links) and detailed public-transport travel time information (including local trams, buses and walkways to stops).

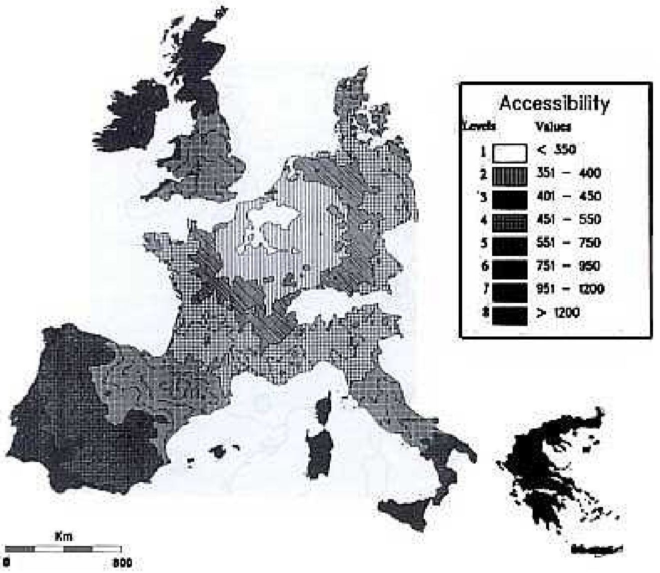


Figure 4.3: Road travel time to economic centres in 1992 (Gutiérrez & Urbano, 1996).

Furthermore, population-weighted forms of contour measures, e.g. the average travelling costs (taken over the population) to reach a given number of opportunities (Breheny, 1978), the average travel costs (over the population) to the nearest opportunity (Selander, 1975), the average number of reachable opportunities within a given travel cost (Wachs & Kumagai, 1973).

Advantages/disadvantages of the measure

Contour measures aim to describe the transport and land-use system from the user’s point of view. They incorporate the transport component (travel time, costs, distance) and the land-use component (location of facilities) but do not attempt to evaluate their combined effect or consider the value people attach to each of these components separately. The main advantage of the measure is that it presents an easily explainable accessibility measure without implicit assumptions about a person’s perception of transport, land use and the interaction of these two. Furthermore, the data for the measure are comparatively readily available, making it possible to study different kinds of access by different types of people for different activities which are relatively undemanding of data (Jones, 1981).

Obvious disadvantages of the contour measure are (a) the implication that all opportunities (e.g. jobs) are equally desirable, regardless of the time spent travelling or the type of opportunity (Vickerman, 1974) (b) the arbitrary selection of the isochrone (or isodistance) of interest and (c) the lack of differentiation between opportunities adjacent to the origin and those just within the isochrone of interest (Ben-Akiva & Lerman, 1979). For the evaluation of land use or infrastructural changes this measure has the disadvantage that improvements of travel times may not lead to an improvement of accessibility index. For example, in the situation where a major infrastructure improvement reduces travel time between two cities from, say, 50 minutes to 15 minutes, this does not change the accessibility index of a contour measure if the maximum travel time is set at 60 minutes, but would strongly change the accessibility index if a maximum of 30 minutes is assumed. To avoid introducing a subjective and sometimes arbitrary spatial boundary, several authors have proposed using potential accessibility measures which allow accessibility to decrease gradually as the travel time to destinations increases.

4.3.4 Potential accessibility measures

Description

The concept of potential has been introduced by the social physics school dating back to the 19th century (Carey, 1858). Stewart (1947, 1948) applied the concept for the first time in a study on population distribution. Subsequently, it has been developed and used in the form of market potentials in location analysis (e.g. Harris, 1954). Hansen (1959) was the first author to use the potential concept to describe accessibility to (employment) opportunities, defining accessibility as ‘the potential of opportunities for interaction’. The measure has the following form:

$$A_i = \sum_j D_j d_{ij}^{-\alpha} \qquad \text{(Equation 4.1)}$$

where A_i is a measure of accessibility at zone i to all opportunities D at zone j, d_{ij} the distance between i and j and α a parameter reflecting distance deterrence. Thus, the Hansen-type accessibility measure estimates the accessibility of opportunities of zone i to all other zones where fewer and/or more distant opportunities provide diminishing influences.

Applications

The Hansen equation has been widely used for analysis of accessibility to different destinations (see Table 4.1 for an overview of references): to jobs (e.g. Linneker & Spence, 1992), population (e.g. Patton & Clark, 1970), retail services (e.g. Guy, 1983), health services (e.g. Kalisvaart, 1998), education (e.g. Pacione, 1989) and recreational facilities (e.g. Vickerman, 1974). Furthermore, building upon the study by Harris (1954), several studies use potential accessibility measures as market potentials, with income or GDP as the destination variable. For example, Clark *et al.* (1969) analysed economic potentials to measure a region’s attractiveness for the manufacturing industry by taking regional income and costs of distance in Europe. Keeble *et al.* (1988, 1981) analysed the centrality of economic centres in Europe using a potential measure with GDP as destination activity. As an illustration, Figure 4.4 shows the economic potential of Europe according to Keeble *et al.* *(*1988). Other examples of potential accessibility to GDP in European regions are from Simmonds & Jenkinson (1993; 1995) and Copus (1997). An example of an income potential comes from Capineri (1996), who analyses rail accessibility for municipalities in Italy using the population weighted by per capita income as a destination variable.

Furthermore, in practical applications, the original Hansen equation has been adapted or further specified in different ways. Four types of adaptations can be identified:

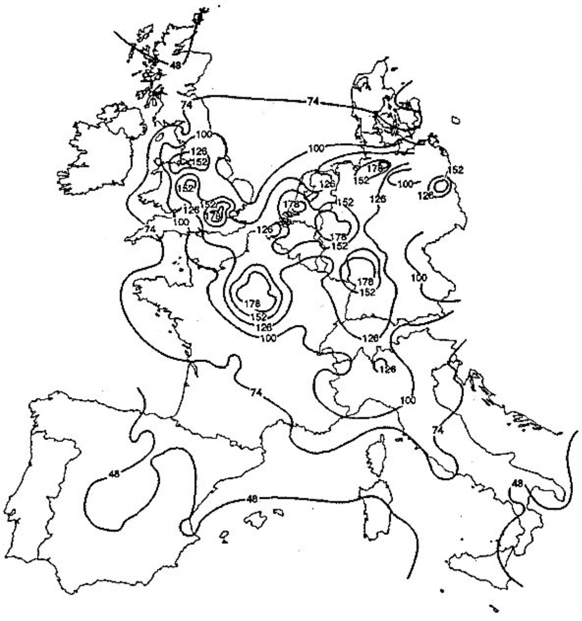


Figure 4.4: Economic potential in Europe (Keeble *et al.*, 1988).

Firstly, alternative distance decay functions are used. Hansen originally used a power function adopted from Newton's law of gravity. Alternative distance decay functions include negative exponential functions (e.g. Dalvi & Martin, 1976, Handy, 1994), Gaussian functions (e.g. Ingram, 1971) and logistic functions (Hilbers & Verroen, 1993) (see also Section 3.2.3).

A general description of a potential accessibility measure is as follows:

$$A_i = \sum_j D_j F(c_{ij}) \qquad \text{(Equation 4.2)}$$

where c_{ij} is the generalised cost between i and j (see Equation 2.1) and $F(c_{ij})$ is the impedance function. Forthwith, Equation 4.2 will be called the 'basic potential accessibility measure'.

Secondly, the potential accessibility measure is normalised or weighted, for example, according to the total number of opportunities in the zone of origin (see, for example, Dalvi & Martin, 1976; Tagore & Sikdar, 1996), to residents of the entire study area (see Scheider & Beck, 1974) or the mean accessibility value for the entire study area (Handy, 1994).

Thirdly, potential accessibility is analysed for different transport modes and/or socio-economic groups (see for example Black & Conroy, 1977; Wachs & Kumagai, 1973). Multi-modal accessibility can also be analysed by aggregating accessibility measures across modes. There are essentially two ways of aggregating:

- The fastest or lowest-cost mode is used, i.e. the impedance of the fastest mode or the mode with the lowest cost between an origin and destination is used, ignoring all other modes in that relationship;
- The logsum impedance, i.e. the composite or logsum impedance of all modes is used. This form of averaging has the characteristic that the result is always equal to or less than the minimum of the characteristics being averaged. Furthermore, the removal of a mode with a higher cost (e.g. closure of a rail line) does not result in a – false – reduction in aggregate travel cost. A logsum impedance is theoretically only consistent for potential accessibility measures; it cannot be used for contour measures (e.g. daily accessibility or travel cost accessibility) (Wegener *et al.*, 2000a). The following equation gives the composite or logsum cost c_{ij} (Williams, 1977b):

  $$\bar{c}_{ij} = -\frac{1}{\beta} \ln \sum_{m} e^{-\beta . c_{ijm}} \qquad \text{(Equation 4.3)}$$

  where c_{ijm} represents the (generalised) cost of travel by mode m between i and j and β a parameter indicating the sensitivity to travel cost.

A number of studies use composite impedance for analysing potential accessibility. For example, Simmonds & Jenkinson (1993, 1995) estimated an economic potential for European regions with GDP as destination variable and composite travel times for road, rail and air travel as impedance. Furthermore, Fürst *et al.* (1999, 2000) estimated population potentials for more than 200 European regions using composite travel times for road and rail, and for road, rail and air as impedance.

Finally, potential accessibility measures can be adapted by holding the mass (land use) or the travel impedance constant, when accessibility changes over time are analysed. For example, Rietveld & Bruinsma (1998) analysed the development of potential accessibility to employment for the 1970-1990 period, keeping land-use changes constant. Furthermore, Geurs & Ritsema van Eck (2000) analysed the separate influence of land-use changes (population and employment increase and the spatial distribution) and transport changes (congestion, infrastructure expansions) on the development of the potential accessibility measure for the 1995-2020 period. This improves the interpretability of the potential accessibility measure.

Advantages/disadvantages of the measure

The main advantages of the basic potential accessibility measure are that:

- The measure corresponds with a concept that most non-specialists would accept; it denotes the “range of choice” offered by the land-use transport system in the form of a sum of potential destinations (Koenig, 1980). However, the results are – compared to contour measures - less easily explainable because the opportunities are weighted according to their distance away.

- The data requirements for assessing accessibility developments are modest, i.e. accessibility can be easily calculated with data from existing land-use and transport models.

Although potential accessibility measures have been widely used, the measure has some more or less serious drawbacks, i.e.

- The self-potential (the number of opportunities within origin zone i weighted by the average travel time or distance within that zone) may have an important influence on the calculation of the potential values. The functional form leads to heavy weighting for internal accessibility, especially in zones with greater mass, e.g. the contribution of a city to its own accessibility may be considerable for large cities. The use of small zones or areas leads to less dependence on the self-potential and provides a good way to avoid this problem (Frost & Spence, 1995). Alternatively, Bröcker (1989) suggests to modify the standard potential formula to handle the region to which the potential refers as continuous space with equally distributed density of mass, contrast to handling regions as being points in discrete space;
- The measure represents accessibility at a *location* (or zone) to all other destinations. The measure does not account for the characteristics of the individuals for whom the accessibility is being estimated; all individuals in the same location have the same level of accessibility, despite the fact that they may perceive the set of destinations and travel impedance quite differently (Ben-Akiva & Lerman, 1979). For example, if residents of an area are closely situated to a large number of job opportunities, but they do not have the skills or education to qualify for the job, they will still have a low job accessibility level. This drawback can probably be largely overcome if the accessibility measure is disaggregated according to socio-economic characteristics. In general, some differentiation of individuals and households by selected characteristics should result in more accurate accessibility measures (Handy & Niemeier, 1997). See also Section 4.6.3;
- Basic potential accessibility measures show the spatial distribution of provided destinations (e.g. jobs, shops), but do not account for the spatial distribution of the demand for those opportunities (e.g. inhabitants). Thus, implicitly it is assumed that the (distribution of the) demand does not affect the accessibility level of the opportunities. In other words, no competition effects are assumed to be present. However, in reality, countries are characterised by an uneven spatial distribution of people, firms and activities, and competition effects do occur, e.g. in cities where the number of jobs is high, the demand for those jobs is also large. Shen (1998) states that if the spatial distribution of the demand (e.g. workers who are suitable for a job) is not uniform, this accessibility measure generates an inaccurate or even misleading result. Furthermore, the measure does not account for possible capacity limitations of the supplied opportunities; implicitly assuming no capacity limitations of the available opportunities. However, in reality this may be the case for major recreational or commercial facilities (such as national parks and regional shopping malls), but not for opportunities such as jobs (each job is only for one worker at any given moment in time) (Morris *et al.,* 1979; Shen,

1998). In short, the measure may not be an appropriate accessibility measure for opportunities if competition on those opportunities exist. See also Section 4.6.2;

- The basic accessibility potential may lead to unsatisfactory conclusions when used without sufficient care to aggregate individual accessibility levels (Koenig, 1980). This is illustrated in Box 4.1;
- The distance decay function used has a significant influence on the accessibility measure. For plausible results, the form of the function should be carefully chosen, and the parameters of the function should be estimated using recent empirical data of spatial travel behaviour in the study area. Furthermore, the distance decay function should reflect the characteristics of the supplied opportunity (e.g. local shop, large shopping malls) and characteristics of the demand (socio-economic characteristics of the population, e.g. income, educational level). In addition, in literature on (gravity based) spatial interaction models, several authors indicate that the distance-decay function depends on the spatial configuration of the research area for which the functions have been estimated (see, for example, Ewing, 1986; Fotheringham, 1982; Gordon, 1985). This implies that care must be taken when the empirically derived distance decay functions are used in the evaluation of alternative land-use scenarios describing a spatial distribution of activities and travel patterns very different from the current situation.

Box 4.1: Aggregation of individual accessibility levels using potential measures

If a potential accessibility measure is used to evaluate alternative scenarios using an average individual accessibility level, unsatisfactory results may be derived. Take the following example, where two alternatives: (1 and 2) are evaluated for two locations (area A and B) – see the table below. Area A shows a balance between the number of inhabitants and jobs (10,000 inhabitants have 10,000 jobs within reach), area B clearly not (1,000 inhabitants have 10 jobs within reach). In alternative A, 1000 jobs are added to the central area of town A, in alternative B to the small village B. If a basic potential accessibility indicator is used to calculate an average accessibility score for the population, alternative 1 (average accessibility score (A_i) of 10,001) is preferred over alternative 2 (score of 9183 - see the table below). Clearly, this gives an unsatisfactory result; in alternative 2, job accessibility is actually higher (than alternative 1) because of the better balance between inhabitants and jobs. Thus where the potential measure is used as an accessibility measure, the concentration of opportunities (e.g jobs) in areas with large numbers of inhabitants (e.g. inner cities) will result in a higher average accessibility index than a more equal distribution of opportunities over space, which may not be a realistic result.

		Inhabitants	Jobs	Potential accessibility A_i
reference situation	area A	10000	10000	10000
	area B	1000	10	10
	total	11000	10010	10010
	average accessibility A_i			*9092*
alternative 1	area A	10000	11000	11000
	area B	1000	10	10
	total	11000	11010	11010
	average accessibility A_i			*10001*
alternative 2	area A	10000	10000	10000
	area B	1000	1010	1010
	total	11000	11010	11010
	average accessibility A_i			*9183*

4.3.5 Inverse balancing factors

Description

Gravity models explaining the level of spatial interaction between locations became widely used in the 1950s and 1960s (see Nijkamp & Reggiani, 1992 for an overview). Wilson (1967; 1970; 1971) provided the first theoretically valid derivation of the model from statistical information-minimising (or entropy-maximising) principles. Wilson (1971) introduced the well-known family of four types of spatial interaction models: (1) a production-constrained model, (2) an attraction-constrained model, (3) a doubly constrained model, and (4) an unconstrained model.

The balancing factors - also called competition factors - of the doubly constrained spatial interaction models can be considered accessibility measures (e.g. Wilson, 1971; Kirby, 1970). The doubly-constrained spatial-interaction model (or: production-destination constrained model) has the following form:

$$T_{ij} = a_i\, b_j\, O_i\, D_j\, F(d_{ij}) \qquad \text{(Equation 4.4)}$$

where:

T_{ij} = the magnitude of flow (e.g. trips) between zones i and j;

$a_i\, b_j$ = balancing factors that transforms the activity units into the flow units

$O_i\, D_j$ = the number of activities (e.g. the number of inhabitants, jobs) in zones i and j

$F(d_{ij})$ = a (negative) function F, reflecting the friction imposed by the infrastructure connecting zones i and j.

The balancing factors a_i and b_j are equal to:

$$a_i = \frac{1}{\sum_{j=1}^{n} b_j D_j F\left(d_{ij}\right)} \qquad \text{(Equation 4.5)}$$

$$b_j = \frac{1}{\sum_{i=1}^{m} a_i O_i F\left(d_{ij}\right)} \qquad \text{(Equation 4.6)}$$

The value of balancing factor a_i serves to ensure that the magnitude of flow (e.g. trips) originating from zone i equals the number of activities in zone i (e.g. inhabitants). The value of balancing factor b_j ensures that the magnitude of flow (e.g. trips) destined at zone j equals the number of activity (e.g. jobs) in zone j. The balancing factors are mutually dependent, so they have to be estimated iteratively: first make B_j equal to 1 in (Equation 4.5) to calculate A_i, replace A_i in (Equation 4.6) to calculate new values of B_j, and repeat this process until a numerical equilibrium is reached. The balancing factor a_i in a *doubly* constrained model can be considered an accessibility indicator, i.e. the factor represents the competition of destinations available to origin i as perceived by the residents of origin i. Opportunities (e.g. jobs) which are well accessible have an attraction factor of a_i smaller than 1, because the number of trips attracted should be reduced to equal the number of opportunities; implying a high level of competition. As an accessibility measure, the inverse of the balancing factor is more appropriate, where accessibility increases if a_i increases. Note that a_i and b_j are relative terms. However, the balancing factors can be transformed to a potential accessibility measure: if, after the necessary number of iterations to achieve an equilibrium state, a_i is multiplied by the average (over all zones) of b_j (or b_j is multiplied by the average of a_i), then the balancing factors express the number of activities within reach (see for an application Part II of this report: case studies).

A doubly constrained spatial interaction model is used in situations where both the origins O_i (e.g. residences) and destinations D_j (e.g. workplaces) are fixed. In terms of accessibility this corresponds to the case where competition exists both on the origins and the destinations, e.g. employers compete for employees (origins) and employees compete for jobs (destinations). A *singly* constrained spatial interaction model corresponds to the case where the origins of the flows are fixed (e.g. residences), but not the destinations (e.g. shops). In terms of accessibility, this corresponds to the case where competition only exists in the origins, not the destinations (e.g. shops compete for customers, but customers do not compete for shops). The balancing factor a_i of a *singly* constrained model has the following form.

$$a_i = \frac{1}{\sum_{j=1}^{n} D_j F(d_{ij})} \qquad \text{(Equation 4.7)}$$

Note that the general form of the singly constrained spatial interaction model is similar to the (inverse of) the basic potential accessibility measure (Equation 4.2), although their history and derivation is different. However, their aims and thus the detailed forms differ. In particular, the aims of the distance decay functions differ. In a spatial interaction model the distance decay function can be interpreted as the decay in the amount of travel as travel costs increase; in a potential accessibility measure, the function can be interpreted as the decline in a person's perception of the attractiveness of an opportunity as the costs of reaching it increases. These functions are distinct, although probably related (Jones, 1981).

Applications

In the literature, not many studies were found using (inverse) balancing factors of a *doubly* constrained spatial interaction model as an accessibility indicator. Examples are from Hamerslag (1986), Fotheringham (1986), Fotheringham & O'Kelly (1989) and Reggiani (1985). The balancing factor of a *singly* constrained model has been used, for example, as an accessibility measure in early studies on shopping patterns (Lakshmanan & Hansen, 1965), hospital use by patients (Morill & Kelly, 1970), employment and population accessibility (Dalvi & Martin, 1976; Martin & Dalvi, 1976) and, more recently, for a study on mobile communication flows (Matthes, 1994).

Box 4.2: Example of inverse balancing factors as an accessibility measure

Suppose two areas, A and B, have such distances and a distance decay function that the distance decay function equals 1 for the intra-zonal distances (within A and within B) and 0.1 for the inter-zonal distances (between A and B and vice versa). Suppose area A_1 has 1000 jobs equal to the working population and area B_1 has 100 jobs equal to the working population. The potential accessibility index then gives an accessibility index of 1010 for area A_1 and 200 for area B_1 (see the table below). Although the number of jobs and the working population are in balance, the balancing factors differ from the basic potential accessibility index, i.e. the balancing factor (after 10 iterations) for jobs for area A_1 is lower (950) and for B_1 higher (346). Apparently it is more advantageous for a small working population (area B) to have access to a relatively large number of jobs (area A) than the other way around. Note that the balancing factors for jobs and employment have the same ratio, reflecting that jobs and employment follow the same distribution.

If the distribution of the working population changes (and the number of jobs and working population are no longer in balance), the potential accessibility measure does not change (the distribution of the demand is not taken into account), whereas the balancing factors do. Suppose area A_2 has 1000 jobs and a working population of 900 people, and area B_2 has 100 jobs and a working population of 200 people: the job surplus in area A_2 results then in a higher balancing factor for jobs in A_2 (1023) compared to the basic potential accessibility index and the shortage of jobs in B_2 results in a lower balancing factor for jobs (188). Note that the balancing factors for employment do not have the same ratio, reflecting the spatial mismatch in jobs and working population. In fact, the balancing factor for the working population in A_2 is smaller than in B_2. The relative surplus of jobs in B_2 (the number of jobs is twice the number of workers) compensates for the smaller absolute number of jobs.

In conclusion, the balancing factors of a doubly constrained interaction model give a more realistic accessibility index if the demand for opportunities is not equally distributed in space and competition effects occur.

	A_1	B_1	A_2	B_2
number of jobs	1000	100	1000	100
working population	1000	100	900	200
potential accessibility measure	1010	200	1010	200
inverse balancing factors for jobs (a_i)	950	346	1023	188
inverse balancing factor for the population (b_j)	1.08	0.39	0.99	1.15

Advantage/disadvantage of the measure

The main advantage of using the inverse balancing factors of a *doubly* constrained spatial interaction model is that the measure accounts for competition effects. The balancing factors of a doubly constrained model will provide a more realistic accessibility estimate (compared to the basic potential accessibility measure) in the case of competition for both the demand and supply of opportunities, e.g. in the case of job opportunities where employers 'compete' for workers and workers 'compete' for jobs (see a further discussion on competition effects Section 4.6.2). Furthermore, Neuburger (1971) noted that the inverse balancing factors can also be interpreted as an indicator of economic benefit (see for a discussion Section 6.2.2). The disadvantage of the measures is that the accessibility measure is not easily explained, as it is the result of an iterative process incorporating both the locations of demand and supply weighted by a distance decay function.

The balancing factor of a *singly* constrained model has the same advantages and disadvantages as the basic potential accessibility measure (see Section 4.3.4), i.e. the measure will provide realistic results in the case where there is no competition within the opportunities (i.e. no capacity limits) supplied, or where suppliers of opportunities compete for the demand, e.g. retail and recreation facilities.

4.3.6 Accessibility measures from space-time geography

Description

The temporal component of accessibility involves the availability of activities at different times of the day and the times in which individuals participate in specific activities. In space-time geography, the time component and land-use component of accessibility are considered equally important. Accessibility is analysed from the viewpoint of individuals, i.e. space-time measures examine whether and how observed or assumed individual or household activity programmes can be carried out, given time restrictions using space-time prisms to describe the travel patterns in space and time. These space-time prisms can be regarded as accessibility measures, i.e. they give the potential areas of opportunities which can be reached given predefined time constraints (Dijst & Vidakovic, 1997).

The activity-based approach can also be related to the random utility concept (see Ettema & Timmermans, 1997; Kraan, 1996; Miller, 1999). Several activity-based models have been developed – mainly in the United States - based on principles of utility-maximising behaviour (see Veldhuisen *et al.* (2000) for a recent overview). In this approach, one estimates the utility or benefit perceived by an individual by implementing an activity programme (out of a set of available activity programmes) (see further Section 4.4).

Applications

Several models have been developed for the analysis of space-time travel patterns of individuals. Working from Hägerstrand's study (1970), the Lund school of geography developed the well-known Program Evaluating the Set of Alternative Sample Paths (PESASP) which enumerates *possible* space-time paths or schedules between two predetermined locations, given activities to be performed and physical environmental constraints (Lenntorp, 1976). The PESASP model has, for example, been used to study public transport in urban areas (Lenntorp, 1978), daily living conditions in regions, re-allocation of services (Mårtensson, 1978) and job accessibility of women stratified into life-cycle groups (Pickup, cited in Jones, 1981).

A similar model is the Reach Simulation Program developed in the Netherlands (Huigen, 1986), which has been used to study access to services (education and services) for various groups of inhabitants in rural areas (Huigen, 1986) and basic services (shops, post offices, health and cultural services) for elderly people in rural areas (Kempers-Warmerdam, 1988). More recently, the Model of Action Space in Time Intervals and Clusters (MASTIC) has

been developed to study the effects of time and transport policies on accessibility; it has been applied to study access to different activities such as jobs, shops, schools, cultural and recreational facilities in towns in the Netherlands (Dijst, 1995; Dijst & Vidakovic, 1997).
In general, the space-time framework is difficult to operationalise and apply (in its classical form) as an accessibility measure. To overcome some of the operational difficulties, some studies have developed methods to analyse space-time accessibility measures using network-based GIS procedures. For example, Miller (1991) developed an operational method for implementing network-based space-time prisms using GIS procedures, showing that these measures can be used to evaluate the performance of the transport system. Kwan (1998) estimated three space-time accessibility measures (the number of feasible space-time prisms, the weighted sum of opportunities contained in the prisms, and the length of the network arcs) using network-based GIS methods and a travel diary dataset containing about 50 households in Columbus, Ohio, USA. The results are compared with several potential accessibility measures and contour measures. The most important difference in results is that the space-time accessibility measures are able to reveal differences in individual accessibility, where geographical accessibility measures ascribe the same accessibility level to all persons, or all persons within the same socio-economic group, having the same origin location.

Advantage/disadvantages of the measure
The space-time geographical approach to accessibility is based on a large range of transport, land-use, individual, and organisational factors influencing a person's ability to take part in necessary or desired activities, and thus a person's access to opportunities. It is a disaggregate approach allowing personal characteristics to be taken into account. This disaggregate approach is also the main disadvantage of space-time accessibility measures, i.e. it describes accessibility of individuals given their time-budgets and restrictions, and requires large amounts of data and effort to be implemented an activity-based accessibility measure. Using existing revealed preference data is usually not sufficient, for example individuals' time budgets are not available from these data (Thill & Horowitz, 1997). The applications are often restricted to a relatively small region and a small subset of the population because of the large data requirements. Therefore it is difficult to aggregate the results to evaluate accessibility to certain opportunities for the whole population on a national level, which is the aim of this study. However, at the moment there are modelling efforts concerned with developing (simplified) activity-based models using readily and generally available statistical information (e.g. existing land-use data and travel surveys) only – see Veldhuisen *et al.* (2000).

Another disadvantage is that space-time accessibility measures focus on the demand side only, i.e. the measures show possible space-time schedules between possible locations of activities given time restrictions. The accessibility measures found in the literature do not include competition effects on the opportunities. For the space-time accessibility studies found in the literature this may not be a problem, because the studies are mostly restricted to consumer services for which competition on the demand side is not very relevant (e.g. retail services). Interestingly, none of the space-time accessibility studies was found to analyse job accessibility - for which competition effects are relevant. Thus, for the analysis of accessibility to opportunities on which competition occurs (e.g. jobs, hospital beds, school places), space-time accessibility measures have the same disadvantages as the basic potential accessibility measure, i.e. the spatial distribution of the demand is not accounted for (see Section 4.3.4).

4.4 Utility-based accessibility measures

4.4.1 Description

Another perspective on accessibility is given by utility-based accessibility measures, which are founded in economic theory. Utility-based accessibility measures interpret accessibility as the outcome of a set of transport choices. Utility theory addresses the decision to purchase one discrete item from a set of potential choices, all of which satisfy essentially the same need (Greene & Liu, 1988), and can be used to model travel behaviour and the (net) benefits of different users of a transport system. The utility-based approach to accessibility asserts that accessibility should be measured at the individual level and that the computation of individual accessibility should account for users' characteristics (e.g. income and demographic variables) in addition to modal or link characteristics (e.g. speed, travel costs) (Banister & Berechman, 2000).

The prime assumptions of the utility-based approach are found in Koenig (1980):
(a) People associate a cardinal utility with each alternative they are facing and choose the alternative associated with the maximum utility to them as individuals;
(b) As it is not possible to evaluate all factors affecting the utility associated with each alternative by a given individual, this utility can be represented as the sum of a non-random (deterministic) component and a random (stochastic) component.

If it is assumed that each alternative k in a choice set has total utility U_k and that each individual 'n' will select the alternative that maximises the total utility, then a simple definition of accessibility is Ben-Akiva & Lerman (1979):

$$An = E\ (\text{Max}\ Uk) \qquad \text{(Equation 4.8)}$$

where E denotes the expected value. This value can also be interpreted as a measure of spatial surplus in the context of the location of public facilities (Leonardi & Tadei, 1984) or as an accessibility measure or the preference of a given accessibility pattern (Ben-Akiva & Lerman, 1979). A stochastic specification of utility U attached by person n located at i to an opportunity at j is as follows:

$$U_{ij} = V_{ij} - \beta c_{ij} + \varepsilon_{ij} \qquad \text{(Equation 4.9)}$$

where

V_{ij} = a utility or value of making the trip ij for person n, which is deterministically known,

c_{ij} = costs of the trip ij, e.g. travel time, travel costs,

β = a cost sensitivity parameter

ε_{ij} = a random term

This utility function serves as a starting point for giving accessibility a basis in utility theory (e.g. see Williams & Senior, 1978; Bröcker, 1989). If it is assumed that an individual assigns a utility to each destination choice in a choice set and selects the alternative which maximises his or her utility, accessibility can then be defined as the denominator of the multinomial logit model, also known as the logsum (Neuburger, 1971; McFadden, 1981, Ben-Akiva & Lerman, 1985). The logsum serves as a summary measure indicating the desirability of the full choice set (Small, 1992):

$$A_n = \ln(\sum_k e^{V_k}) \qquad \text{(Equation 4.10)}$$

where A_n is a measure of accessibility, V_k is the indirect, or observed, utility portion of the total utility of choice k (i.e. a combined mode-destination choice) for a person n, and the random term is assumed to be Weibull distributed. Equation 4.10 can be rewritten in relation to a potential accessibility measure using a negative exponential distance decay function. Accessibility of a person n (A_n) can thus be interpreted as the benefit an individual living in area i derives from opportunities D which can be reached at j, given the cost to get there (c_{ij}) (see Neuburger, 1971; Wilson, 1976; Williams, 1977; Leonardi, 1978); Ben-Akiva & Lerman, 1985; Small, 1992)

$$A_n = \frac{1}{\beta} \ln \sum_j D_j e^{-\beta . c_{ijm}} \qquad \text{(Equation 4.11)}$$

where β is a travel cost sensitivity parameter. The measure is expressed in travel cost units (by dividing it through the travel cost parameter). Note that Equation 4.11 is a monotone-increasing function of the potential accessibility measure (using a negative exponential distance decay function).

4.4.2 Relationship with space-time accessibility

The activity-based approach can also be related to the random utility concept (see Ettema & Timmermans, 1997; Kraan, 1996; Miller, 1999). Several activity-based models have been developed – mainly in the United States - based on principles of utility-maximising behaviour (see Veldhuisen *et al.*, 2000 for a recent overview). In this approach, one estimates the utility or benefit perceived by an individual by implementing an activity programme (out of a set of available activity programmes). An individual time-space utility function is specified as following (Burns, 1979; Hsu & Hsieh, 1997):

$$u_{ij}(a_k, T_k, t_k) = a_k^{\alpha} T_k^{\mu} e^{-\beta t_k} \qquad \text{(Equation 4.12)}$$

Where u_{ij} is the utility of participating in an activity at location k, a is the attraction of the activity location, T is the time available for activity participation, and t is the travel time required. In relationship with Equation 4.11, the expected maximum utility of the opportunities within the space time prism can be specified, based on logit decision process, as following (Miller, 1999):

$$U = \frac{1}{\beta} \ln \sum_{k=1}^{m} e^{(a_k^{\alpha} T_k^{\mu} e^{-\beta t_k})} \qquad \text{(Equation 4.13)}$$

where U is the benefit of the space-time prism defined by fixed activities i and j and time budget ($t_j - t_i$).

4.4.3 Relationship with consumer surplus and welfare

There is a close relationship between the measurement of accessibility, utility and economic analysis. Random-utility theory provides a direct link to traditional microeconomic theory which is based on the assumption that consumer preferences may be used to derive an indicator of value based on the net benefits associated with a particular option. Several authors (for example, Williams &Senior, 1978; Ben-Akiva &Lerman, 1979; Ben-Akiva &Lerman, 1985; Jara-Díaz & Farah, 1988; Small, 1992) note a correspondence between expected maximum utility and a classic benefit measure in microeconomic theory, namely consumer surplus. Consumer surplus is defined as the difference between what a consumer is prepared to pay for a quantity of goods (equal to the total benefit obtained from that good) and the amount he or she actually has to pay. In this case the goods are trips and the gross benefit of a trip is the gross benefit obtained at the destination of the trip (Jones, 1981). The indirect, or observable, utility function can be viewed as the demand curve for a particular alternative in which a change in choice attributes, for example, a price increase, results in a change in consumer surplus.

In the literature, several authors describe the theoretical relationships between accessibility, random utility theory and consumer surplus, or more specific, the relationship between different forms of the gravity model (unconstrained, singly and doubly constrained) and the basic accessibility potential and consumer surplus. Well-known theoretical studies from the 1970s and 1980s are taken from Neuburger (1971), Cochrane (1975), Williams (1976), Erlander (1977), Leonardi (1978) and Williams & Senior (1978).

See Section 6.2.2 for a further description of the relationships between utility-based accessibility measures and economic welfare.

4.4.4 Applications

Despite the many theoretical studies, the utility concept of accessibility is not very often used in practical accessibility studies. An example is from Koenig (1980), who applied a basic potential accessibility measure and an accessibility measure based on logsum values to analyse accessibility changes as a result of road investment alternatives in Le Mans (France). In this study, utility was converted to monetary values (in French francs per person per year). A Dutch application of a logsum as a measure of accessibility is taken from Le Clercq & Brohm (1982). More recently, Borgia & Cappelli (1994) applied a multimodal accessibility indicator defined, as the logsum of the net benefits of modal accessibility, to Italian regions. The net benefit of a mode was measured as the negative exponential of travel time to seven major cities minus the monetary cost of travel. Another example is from Sweet (1997), who analysed accessibility based on logsum values to analyse job accessibility in London by car and public transport. In Sweet’s study, the logsum is expressed in minutes of generalised time by dividing the utilities by a scaling factor. Niemeier (1997) and Handy & Niemeier (1997) provides an interesting approach for using consumer surplus as an accessibility measure to estimate the value people attach to job accessibility (see also Section 6.2). One result is that the result is different when computed for the entire sample than when computed for various marked segments. Another example is from Levine (1998), who used a utility-based accessibility measure to assess the impact of commuting time on residential location decisions.

Furthermore, logit-based transport models can also be used to derive a logsum accessibility measure. For example, Cascetta & Biggiero (1997) computed accessibility measures using the logsum measure from an Italian passenger transport model. For the Netherlands, the National Model System (NMS) could also be used to analyse logsum accessibility measures at a disaggregate level (i.e. the NMS uses 490 socio-economic groups) (see HCG, 2000). However, to the author's knowledge, this approach has not yet been applied for the Netherlands.

4.4.5 Advantages/disadvantages of utility-based measures

An important advantage of the utility-based measures is that it has a sound theoretical basis, i.e. the random utility theory on which these measures are based provides a direct link to traditional micro-economic welfare theory. Furthermore, the measure has a better behavioural basis than the basic potential accessibility measure, i.e. utility-based measures represent accessibility of individuals at a location, whereas potential accessibility represent accessibility of a location or zone, (implicitly) assuming all individuals in the same location have the same level of accessibility. Another advantage of utility-based measures is that they do not result in the unrealistic outcomes when aggregating individual accessibility – see Box 4.3.

The disadvantage of a utility-based accessibility measure is that the measure is not easily interpreted and that the formulation cannot be explained without reference to relatively complex theories (behavioural models of destination choice or consumer's surplus) (Koenig, 1980). Furthermore, it is difficult to compare different utility functions, for example, by region or neighbourhood (Handy & Niemeier, 1997).

Furthermore, Sweet (1997) argued that logsum values are difficult to interpret in terms of accessibility, because the logsum gives the *total* utility associated with an alternative (e.g. destination), which includes not only (a) the disutility of travel in accessing the destination, but also (b) the utility associated with the destination. As a result, it can be difficult to interpret values of logsum in terms of the spatial separation measures involved. Sweet suggests that total utility can be partitioned into three additive partial utilities as follows:

$$V_{in} = \tilde{V}_i + \tilde{V}_n + \tilde{V}_{in} \qquad \text{(Equation 4.14)}$$

where

V_{in} = the *total* utility or benefit for a person n in accessing a facility or destination i

$\tilde{V}_i$ = a utility component that varies only with the alternative i, therefore representing the utility intrinsic to the characteristics (e.g. size or attractiveness) of destination i.

$\tilde{V}_n$ = a utility component that varies only with the individual traveller n, representing the traveller's perception of utility, e.g. influenced by socio-economic characteristics

$\tilde{V}_{in}$ = a utility component that varies only with the joint effects of different travellers or destinations, representing the effort of the transaction involved when individual n chooses to access destination i. This component is a residual utility,

defined by $\tilde{V}_{in} = V_{in} - \tilde{V}_i - \tilde{V}_n$

Sweet states that the logsum of the transaction component $\tilde{V}_{in}$ (called the 'centred logsum') is a more appropriate measure of accessibility, representing the travel component of a consumers' surplus measure of benefit. The breaking down of accessibility into different components has also been suggested by Geurs & Ritsema van Eck (2000). To improve interpretability, they estimated the separate influence of land-use changes (changes in the number and spatial distribution of activities), infrastructural changes (travel time changes as a result of transport investments and congestion) and an interaction component on the development of the potential accessibility measure for the period, 1995-2020. The separate contributions of land-use and infrastructural changes to the changes of the accessibility measure can also be expressed in terms of utility by taking the natural logarithm of the these indexes (using Equation 4.11).

The interpretation of the consumer surplus can also be improved if it is converted into monetary values. This is explained in Section 6.2, where the possible use of utility-based accessibility measures in the economic evaluation of transport scenarios is described.

Box 4.3: Aggregation of individual accessibility levels using utility-based accessibility measures

In contrast to the basic potential accessibility measure, a utility-based measure of accessibility does not lead to unrealistic results when used to aggregate individual accessibility levels. This can be illustrated with the example of the two alternatives (1 and 2) and areas (A and B) from Box 4.1. Here, utility is estimated using a utility-based accessibility measure (using Equation 4.11; no distance decay), and consumer surplus (ΔCS) is interpreted as the difference between two accessibility scenarios (using Equation 4.13). The utility-based accessibility measures shows that the utility level of the already job-rich area A does not increase much with an additional increase in jobs (from 9.2 to 9.3 in alternative 1), whereas the utility level of area B sharply increases (from 2.3 in the reference situtation to 6.9 in alternative 2). As a result, consumer surplus for alternative 1 is smaller than for alternative 2. Thus, the utility-based accessibility measure suggests that it is better to increase the job accessibility of poorly-served inhabitants located in area B than to increase the job accessibility of the inhabitants in the job-rich area A. This result contrasts with the basic potential accessibility measure A_i which would, in this case, result in less realistic results.

	inhabitants	jobs	A_i	$\ln(A_i)$
reference situation				
area A	10000	10000	10000	9.2
area B	1000	10	10	2.3
tot	11000	10010	10010	11.5
average			9092	
alternative 1				
area A	10000	11000	11000	9.3
area B	1000	10	10	2.3
tot	11000	11010	11010	11.6
average A_i			10001	
ΔCS (alternative 1 – reference situation)				953
alternative 2				
area A	10000	10000	10000	9.2
area B	1000	1010	1010	6.9
tot	11000	11010	11010	16.1
average A_i			9183	
ΔCS (alternave 2 – reference situation)				4,615

4.5 Overview of references

Table 4.1 gives an overview of references found in the literature categorised by type of accessibility measure and the type of opportunity analysed. Although the overview is not considered to be exhaustive, it does allow the following conclusions:

- The more or less “common sense” measures of accessibility - cumulative opportunities and the basic potential accessibility measure – are used the most in practical applications of activity-based accessibility measures.
- Mathematically more complex measures (i.e. inverse balancing factor) or measures with a better theoretical (i.e. utility-based measures) or behavioural underpinning (i.e. space-time measures) are much less used in practical applications, although these measures are superior from a theoretical point of view.
- Most of the activity-based accessibility measures are used to analyse accessibility to jobs and the population; there are much fewer studies analysing accessibility of other destinations (e.g. retail, public and health services). An exception is the space-time accessibility measure, which is only used for analysis of non-work destinations (e.g. shops, schools, and public services).

Table 4.1: Overview of applications of activity-and utility-based accessibility measures to passenger transport by opportunity and measure type

	Cumulative opportunities	potential of opportunity	singly-constrained	doubly-constrained	other measures including competition	space-time measures	utility-based measures
Jobs	Wickstrom, 1971 Wachs & Kumagai, 1973 Popper & Hoel, 1976 Black & Conroy, 1977 Breheny, 1978 McKenzie, 1984 Ritsema van Eck & De Jong, 1996 Bruinsma & Rietveld, 1997 Gutiérrez & Gómez, 1999 Van Ham, Hooimeijer & Mulder , 2001	Hansen, 1959 Linneker & Spence, 1992 Hilbers & Verroen, 1993 Bruinsma & Rietveld, 1993 Tagore & Sikdar, 1996 Cervero *et al.*, 1997 Zhang *et al.*, 1998 Levinson, 1998 Rietveld & Bruinsma, 1998 Gutiérrez & Gómez, 1999 Geurs & Ritsema van Eck, 2000 RIVM, 2001	Dalvi & Martin, 1976 Martin & Dalvi, 1976 Wilson, 1982	Reggiani, 1985 Hamerslag, 1986	Weibull, 1976 Shen, 1998 Hagoort, 1999		Koenig, 1980 leClercq & Brohm, 1982 Sweet, 1997 Niemeier, 1997 Handy & Niemeier, 1997 Levine, 1998
Population	Rich, 1979 Lutter et al., 1992b Cauvin et al., 1993 Erlandsson & Lindell, 1993 Mclaughlin, 1995 Song, 1996 Chatelus & Ulied, 1995 Spiekermann & Wegener, 1994, 96,99 Schürmann *et al.*, 1997 Gutiérrez & Gómez, 1999 Perrels *et al.*, 1999 Vickerman *et al.*, 1999	Stewart, 1947, 1948 Ingram, 1971 Patton & Clark, 1970 Patton, 1976 Calvo et al., 1993 Hilbers & Verroen, 1993 Spiekermann & Wegener, 1994, 96 Schürmann et al., 1997 Song, 1996 Levinson, 1998 Gutiérrez & Gómez, 1999 Vickerman *et al.*, 1999 Fürst *et al.*, 1999, 2000 Wegener *et al.*, 2000	Dalvi & Martin, 1976 Martin & Dalvi, 1976	Fotheringham, 1986 Fotheringham & O'Kelly, 1989	Fotheringham, 1986 Fotheringham & O'Kelly, 1989		
Retail services	Guy, 1983 Ritsema van Eck & De Jong, 1999	Guy, 1983 Vickerman, 1974 Handy, 1994	Huff, 1964 Lakshmanan & Hansen, 1965		Ritsema van Eck & De Jong, 1999	Huigen, 1986 Kempers-Warmerdam,1988 Dijst, 1995	
Public services		Talen & Anselin, 1998				Lenntorp, 1978 Mårtensson, 1978 Huigen, 1986 Kempers-Warmerdam,1988 Dijst, 1995	
Health service	Wachs & Kumagai, 1973 Kalisvaart, 1998	Kalisvaart, 1998	Morill & Kelly, 1970	Fotheringham & O'Kelly, 1989	Knox, 1978 Joseph & Bantock,1982 Joseph & Phillips, 1984 Kalisvaart, 1998	Kempers-Warmerdam,1988	
Education	Breheny, 1978 Van Dinteren *et al.*, 1989	Pacione, 1989			Breheny, 1978	Huigen, 1986 Dijst, 1995	
Recreation	Sherman *et al.*, 1974	Vickerman, 1974				Dijst, 1995	
Other (e.g GDP, land use areas)	Gutiérrez *et al.*, 1996	Harris, 1954 Clark *et al.*, 1969 Keeble *et al.*, 1981, 1988 Simmonds & Jenkinson, 1993, 1995 Schürmann *et al.*, 1997 Capineri, 1996 Copus, 1997	Fotheringham, 1982 Matthes, 1994	Fotheringham, 1982	Fotheringham, 1982	Kwan, 1998	Borgia & Cappelli, 1994 Cascetta & Biggiero, 1997 Miller, 1999

4.6 Improving activity-based accessibility measures

4.6.1 Introduction

The most popular activity-based accessibility measures, i.e. the contour measure and the potential accessibility measure, estimate the potential number of opportunities that can be reached from a location. However, several studies have shown that accessibility can be estimated more realistically if one accounts for:

- The level of competition for an opportunity, e.g. competition on jobs, school places, hospital beds;
- The characteristics of the supplied opportunities and the demand for these opportunities, e.g. the match between the educational level of the working population or and individual and the job position(s) offered by employers;

The following subsections describe the methods for incorporating these aspects as found in the literature.

4.6.2 Competition on opportunities

There are several authors who try to incorporate the degree of competition for an opportunity (e.g. work, school, public playgrounds and health-care services) into a potential accessibility measure. The literature cites three approaches to handle competition effects:

A) An approach taking the origin location as point of departure. In this approach the quotient of opportunities (e.g jobs) within reach and the potential demand of these opportunities from each *origin* (zone) i is estimated;

B) An approach taking the destination location as point of departure. In this approach the quotient of opportunities from origin i within reach (supply potential) and potential demand of these opportunities from each *destination* (zone) j (i.e. the catchment area of opportunities) is estimated;

C) An approach taking competition on both origin and destination locations into account: the balancing factors of the doubly constrained spatial interaction model

A. Competition based on origin locations

In the literature, there are a number of authors who tried to incorporate the effects of competition on opportunities in accessibility measures by dividing the opportunities within reach (supply potential) from origin i by the demand potential from origin i (demand potential). Examples are taken from Weibull (1976) and Knox (1978). Weibull (1976) developed an accessibility measure to estimate the accessibility of job opportunities that combines a job potential (A_i) and a population potential (P_i). The form of the equation is as follows:

$$I_i = \frac{\sum_{j=1}^{n} D_j F(d_{ij})}{\sum_{j=1}^{n} O_j F(d_{ij})} = \frac{A_i}{P_i} \qquad \text{(Equation 4.15)}$$

Where:

D_j = the number of job opportunities

O_j = the number of inhabitants

$F(d_{ij})$ = a distance decay function

Furthermore, Weibull used travel time by car and public transport to indicate the distance decay, using maximum travel times of 18, 30 and 45 minutes. A high value of I_i (> 1) implies a low level of job competition (i.e. the job potential is greater than the population potential), a low value (< 1) implies a high level of job competition. Knox (1978) has applied a similar approach for estimating accessibility to general practitioners (family doctors). In addition to Weibull, Knox produces a 'final index of accessibility' by scaling the potential for the size of surgery facilities (A_i) and the population potential (P_i) as a percentage of their respective highest estimated values. An important disadvantage of Weibull's measure is that it is expressed as a relative index (more or less than 1). As a result, the accessibility index of, for example, a city centre can be the same as a rural area (i.e. both areas can have the same ratio of jobs and population), although the central area is probably considered to be more attractive.

A somewhat different measure is taken from Joseph & Philips (1984), who developed a 'location quotient' incorporating the demand (population) and supply (availability) aspects of general practitioners. The location quotient is calculated as follows:

$$LQ_i = \frac{GP_i / P_i}{\sum_i GP_i / \sum_i P_i} \qquad \text{(Equation 4.16)}$$

where:

LQ_i = location quotient for region i

GP_i = the number of general practitioners in region i

P_i = the population of region i

A location quotient greater than 1.0 means that a region has more than its 'fair' share of general practitioners relative to its share of the total population, conversely, a value less than 1.0 means that an area has less than its 'fair' share.

Weibull's (1976) and Knox' (1978) approach to handling competition seems to be simple and effective. However, it does have an important methodological drawback resulting from spatial differences between the 'catchment areas' of opportunities at the destination and the potential demand at the origin location. Firstly, by dividing the number of opportunities within reach (supply) by the number of inhabitants within reach (demand), inhabitants living outside the ‘catchment area’ of the destination are assumed to compete for that destination. This is illustrated in Figure 4.5. Inhabitant (or competitor) C_A is implicitly assumed to compete for destination D_2 and D_1, although destination D_1 is actually out of reach for C_A. Secondly, by dividing the two attraction potential measures at the same location, not all potential competitors for an opportunity are accounted for. This effect is also illustrated in Figure 4.5: for an inhabitant living in origin O and wanting to access destination D_1, only one competitor within reach of D_1 is accounted for (competitor C_B), whereas the two other competitors (C_B and C_C) not within reach of the origin, but within the ‘catchment area’ of the supplier (destination) are not accounted for. The effect of competitors C_B and C_C on the accessibility level of D_1 for the origin O can be described as an ‘indirect’ competition effect.

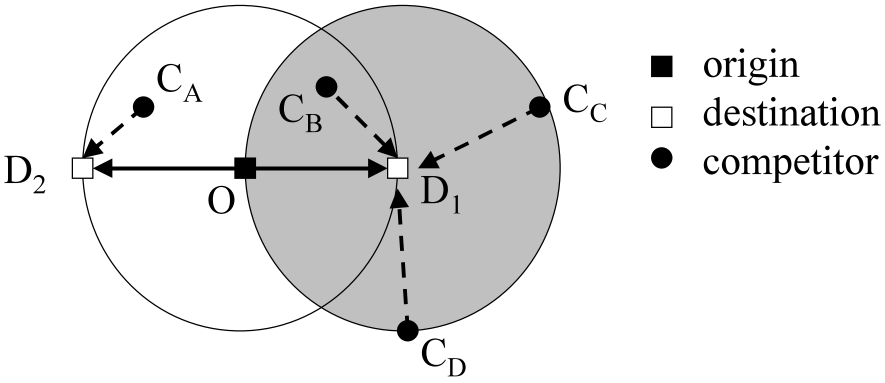


Figure 4.5: Competition by inhabitants for opportunities supplied.

Hagoort (1999) and Van Wee *et al.* (2001) developed an accessibility measure using Weibull’s measure (Equation 4.15) as a “competition” factor to correct the basic potential accessibility measure. The following measure is proposed:

$$A_{CF_i} = A_i * CF_0 \qquad \text{(Equation 4.17)}$$

where:

= potential accessibility of job opportunities at zone i, corrected for competition

A_i = the basic accessibility potential (equivalent to Equation 4.2)
CF_0 = a competition factor (equivalent to Equation 4.15)

The effect of ‘indirect’ competition is incorporated by introducing ‘extensions’ in the competition factor, by including not only zones k for the competition of zone j but also zones l around zones k. The competition factor (CF) can be corrected for the effect of indirect competition as follows:

$$CF_1 = \frac{\sum_{j=1}^{n} O_j F(d_{ij}) * CF_0}{\sum_{j=1}^{n} O_j F(d_{ij})} \qquad \text{(Equation 4.18)}$$

Hagoort (op cit.) states that the optimal number of extensions can not be empirically derived. In general, the effect of an additional ‘extension’ decreases as the number of extensions increase. He suggests that two extensions are probably sufficient to incorporate the effect of indirect competition.

Hagoort's accessibility measure has the advantage that the measure is not expressed as a relative index (with a value of more or less than 1). However, the measure has several disadvantages. Firstly, the measure is difficult to interpret because (a) the measure combines a potential accessibility measure with a “competition factor”, and (b) the measure includes an arbitrary number of ‘extensions’ to incorporate ‘indirect’ competition. Furthermore, the measure has two methodological problems. Firstly, the origin location is taken as a point of departure, not the destination location. As a result, not all potential competitors are incorporated (see Figure 4.5). Secondly, the Hagoort's measure does not incorporate the alternative destination locations that potential competitors may have within reach (see Figure 4.6).

B. Competition based on destination locations

Another approach for handling competition originates from Breheny (1978), who proposed to further develop a contour type of measure for the accessibility of primary schools (i.e. the number of primary schools within 2 miles to account for the effect of potential competitors for school locations. Breheny suggests two accessibility measures:

(a) the number of school locations within two miles of each zone and dividing this by the number of school children within two miles of each school captured,

(b) the number of school locations within two miles of each zone and dividing this by the number of children who could not be accommodated at their nearest school. This measure is expected to give a better measure of likely competitors.

Thus, this potential accessibility measure calculates the number of opportunities within reach of a resident from an origin within a certain travel distance (i.e. the potential demand) divided by the potential number of residents within reach of the same destination (i.e. the catchment area of an opportunity).

Joseph & Bantock (1982) developed a similar type of measure for the potential accessibility to general practitioners. The potential accessibility of origin i tot general practitioners is calculated by dividing (a) the number of general practitioners reachable within a certain travel distance from i by (b) the potential demand within the catchment area of the general practitioner.

$$A_i = \sum_{j=1}^{n} \left[\frac{GP_j}{\sum_{i=1}^{m} P_i F(d_{ji})} \right] F(d_{ij}) \qquad \text{(Equation 4.19)}$$

where:

A_i = potential accessibility of area i to general practitioners
GP_j = general practitioner at area j within range of area i
P_i = the magnitude of the population within the doctor's catchment area
$F(d_{ij})$ = a function of the distance decay between i and j

Joseph and Bantock's accessibility measure can, of course, also be applied to other type of opportunities where competition effects must be accounted for, like jobs or schools. For example, if jobs are taken and 45 minutes is used as a maximum travel time, equation 4.19 will be employed as follows. Firstly, the potential demand for jobs is calculated as the number of inhabitants within 45 minutes of job opportunities in each area modified by their distance away. Secondly, by dividing the potential supply of jobs (number of jobs within 45 minutes from each area modified by the distance away) by the demand (modified by their distance away), a measure of potential accessibility of jobs to the working populations is produced, incorporating a weighted estimate of job availability. Thus, this approach accounts for the effect of competition: working locations near areas with many inhabitants (high level of competition) contribute less to the accessibility measure than working locations near areas with few inhabitants (low level of competition).

More recently, Shen (1998) expanded the Breheny's measure by taking the transport mode into account in the supply potential. The expected value of measured accessibility scores equals the ratio of the total number of job opportunities within reach (job potential) from each origin location i to the total number of people seeking the opportunities (demand potential from each destination location j). Finally, the general measure of accessibility is estimated by calculating a weighted score for each location, where the percentages of people who travel by different modes are used as weights.

In the accessibility measure taken from Joseph and Bantock (1982) and Shen (1998), the (working) population in an area is counted several times as a potential demand for opportunities in surrounding areas. Alternatively, it can also be assumed that for each location the demand is allocated to the nearest supplier of opportunities. Ritsema van Eck & De Jong (1999) use this principle in the accessibility measure called 'proximity count in competition' in the case of drugstore marketing. Kalisvaart (1998) uses this principle in applying the measure from Joseph and Bantock to the case of accessibility of hospitals.

The accessibility measures from Joseph and Bantock and Shen seem to be a plausible for incorporating competition effects. In the case of job accessibility, the measure could be used to estimate the average number of jobs within reach per inhabitant, accounting for potential competition on those jobs. However, the measure does not account for alternative (job) locations within reach of the potential competitors. This can be illustrated by extending Figure 4.5 to Figure 4.6. This figure shows that if more destinations lie within the catchment area of destination D_1 the demand (and competition level) for destination D_1 will be lower than in the case where no alternative destinations exist. In other words: competition effects may occur on both origin and destination locations: workers (at origin locations) compete for jobs at destination locations, where employers (at destinations) compete for workers (at origin locations). This effect is handled by the balancing factors of a doubly constrained spatial interaction model in an iterative procedure.

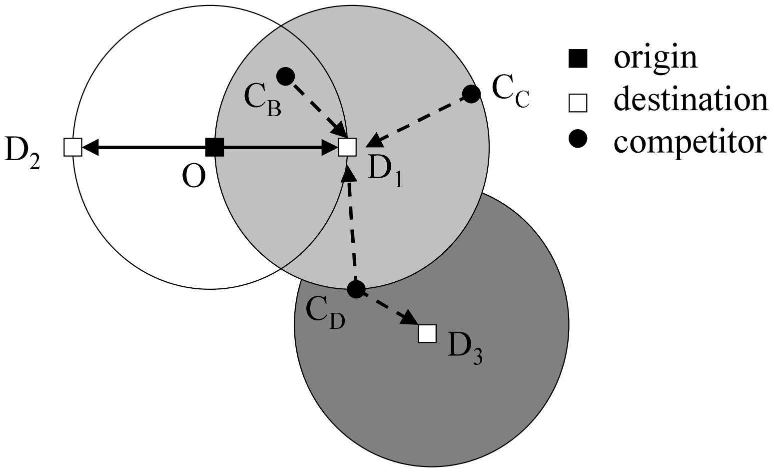


Figure 4.6: Competition on the demand by suppliers.

C. Balancing factors of doubly constrained spatial interaction models

As already described in Section 4.3.5, identifying accessibility with Wilson's doubly constrained spatial interaction model, automatically takes into account the effect of the competition for opportunities, i.e. the doubly constrained model is constrained to estimate fixed numbers of trip origins and trip destinations, e.g. it cannot estimate a greater demand for trips to work in a given zone than the number of jobs in that zone. As the balancing factors are dependent and estimated in an iterative procedure, the model can incorporate the competition of demand on supplied opportunities and the competition of suppliers of opportunities on demand. Note that if balancing factor a_i is calculated for the first time, this is the inverse of the potential accessibility measure (equation 4.2). Note that if the balancing factor b_j is calculated for the first time, this is the inverse of the potential demand (catchment area) of an opportunity (step 1 in the accessibility measure from Joseph and Bantock, 1982).

Thus, the balancing factors are capable to incorporate the interdependent relationship between job competition (at destination locations) and labour force competition (at origin locations). Furthermore, the balancing factors do not have the disadvantage of being a relative index (more or less than 1), such as Weibull's and Joseph and Bantock's measure. The balancing factor for jobs (a_i) is expressed as a potential measure, although the balancing factor is relative to the balancing factor $b_{j.}$

In literature, an adaptation of the balancing factors has been discussed. Fotheringham (1982, 1986) suggests to expand the production-constrained and the doubly-constrained spatial interaction model with a 'competing destination formula' representing the accessibility of destinations to all other destinations. However, for the purpose of using the balancing factors as an accessibility measure Fotheringsham's adaptation does not have a value added, both from a theoretical and practical perspective (see Box 4.4).

Box 4.4: Fotheringham's competing destinations model

Fotheringham (1982,1986) and Fotheringham & O'Kelly (1989) proposed extending Wilson’s (1967, 1971) family of spatial interaction models to consider destination choice where not only opportunities at the destination j are taken into account, but also the opportunities that can be reached from j. According to Fotheringham, the spatial interaction model is mis-specified when destination choice is hierarchical, i.e. the situation where individuals first select a cluster of destinations and then a destination from within that cluster. For example, movers first choose a geographical area, or cluster of destinations, and then choose a specific location within that area. To incorporate this two-stage decision process towards to levels of destinations (j and k), Fotheringham expands both the production-constrained and the doubly-constrained spatial interaction model with a ‘competing destination formula’ (A_{ij}), which represents the accessibility of destinations j to all other destinations, k. Fotheringham’s doubly-constrained model is formed as follows:

$$T_{ij} = a_i\, b_j\, O_i\, D_j\, A_{ij}\, F(d_{ij}) \qquad \text{(Equation 4.20)}$$

$$A_{ij} = \sum_{\substack{k=1 \\ k \neq j}}^{m} D_k F(d_{ij}) \qquad \text{(Equation 4.21)}$$

$$a_i = \frac{1}{\sum_{j=1}^{n} b_j D_j A_{ij} F\left(d_{ij}\right)} \qquad b_j = \frac{1}{\sum_{i=1}^{m} a_i O_i A_{ij} F\left(d_{ij}\right)} \qquad \text{(Equations 4.22 and 4.23)}$$

where T_{ij} is the magnitude of flow (e.g. trips) between zones i and j, a_i and b_j the balancing factors, O_i and D_j the number of activities (e.g. the number of inhabitants, jobs) in zones i and j, A_{ij} the accessibility of destinations j to all other destinations available to origin i, and $f(d_{ij})$ a distance decay function.

On the basis of empirical data, Fotheringham shows that hierarchical decision-making could take place in airline passenger interaction (Fotheringham, 1982) – although Ewing (1986) states that in this case the model is not supported by the data on which it is calibrated - and migration in the UK and the Netherlands (Fotheringham & O'Kelly, 1989). The model has also been applied by others (e.g. Ishikawa, 1987). However, several researchers have expressed reservations about certain aspects of the ‘competing destinations’ model. For example, Gordon (1985) argues that Fotheringham’s model ignores the role of consumer areas (markets) because competition is expressed in terms of accessibility of producer areas (destination) to each other. Thill (1992) argues that the model insufficiently captures the essence of information processes in the formation of choice sets, i.e. the behavioural soundness of the model would require other factors to be considered too, if only for the distance from home. Pooler (1994) argues that the non-spatial component in the destination choice process is much more important than the spatial component, i.e. the decision-making process involves a structured psychological procedure of sifting through complex sets of initial (non-spatial) variables (e.g. budget constraints, past experiences, personal preferences) in order to create more mentally manageable sets, from which particular choices are mode.

A theoretical point is made by Nijkamp & Reggiani (1992), who interpret the competing destination formulation (Equation 4.21) as the inverse balancing factor (b_j) of the conventional doubly constrained interaction model, i.e. factor b_j can be regarded as a measure of accessibility from j to other destinations k (where k, for example, represents a set of subregions in j). Thus, the conventional doubly constrained model incorporates a sequential or hierarchical choice structure and can be compared to a nested multinomial logit (MNL) model. Also Anas (1983) showed that the doubly-constrained spatial interaction model derived by Wilson (1967, 1970, 1971) is identical to a MNL model of joint origin-destination choice. Thus in the case of a production-constrained model, adding Fotheringham’s competing destinations formula to incorporate a hierarchical decision process can improve the result. In the case of a doubly constrained model probably not, because this model theoretically already incorporates a hierarchical choice structure.

Conclusion

In literature, three approaches for handling competition effects in activity-based measures can be identified. Firstly, a number of authors developed accessibility measures incorporating competition effects taking the origin location as point of departure, e.g. Weibull's accessibility measure estimates the average number of jobs within reach from a home location (origin), divided by the number of inhabitants with can be reach from the home location. A second approach is to take the destination location as starting point, e.g. Joseph & Bantock's measure estimates the availability of general practitioners for inhabitants within the catchment area of the general practitioner (destination). A third approach, the balancing factors from Wilson's doubly constrained interaction model, incorporates both competition effects on destinations and origins (see Table 4.2).

Table 4.2: Approaches for handling competition effects

origin locations as point of departure	Weibull (1976), Knox (1978), Joseph & Philips (1984), Hagoort (1999)
destination location as point of departure	Breheny (1978), Joseph & Bantock (1985), Shen (1998), Ritsema & De Jong (1999)
origin and destination locations	Wilson (1971)

Thus, there is not one approach to handling competition effects. The choice of an accessibility measure for analysing the accessibility impacts of a land-use transport project, plan or scenario depends on the study object:

- For the purpose of analysing accessibility to destinations where *no competition effects occur* or competition effects are not a subject of interest, a contour or potential accessibility measure can be used;
- Joseph & Bantocks' measure is appropriate for analysing accessibility to destinations where *competition effects occur on destination locations* (e.g. nature areas), or capacity limitations of supplied opportunities are the subject of interest (e.g. in the analysis of recreational facilities or health care facilities); The accessibility measures which incorporate competition from the origin location (e.g. Weibull, 1976) are not preferable from a methodological point of view, because these measures incorrectly assume competition to be fixed to the origin location;
- The balancing factor (a_i) is an appropriate measure for analysing job accessibility, where *competition effects occur on both destination and origin locations* (job and working population, respectively).

4.6.3 Characteristics of demand and supply

The basic potential accessibility measure represents accessibility at a *location* (or zone) to all other destinations. Thus, the measure does not explicitly account for the characteristics of the individuals for whom accessibility is being estimated or possible restrictions of the supplied opportunities. For example, in the case of job accessibility, if residents of an area are close to a lot of job opportunities but do not have the skills or education to qualify for these jobs, they still have a low level of access to employment. This drawback can probably largely be overcome by stratifying the accessibility measure according to socio-economic characteristics.

In the literature, a number of studies have analysed differences in job accessibility between groups in society (e.g. stratified by income, occupation and educational level), showing that the accessibility level to opportunities heavily depends on socio-economic characteristics of the population. For example, Wachs and Kumagai (1973) estimated an index of accessibility (a contour type of measure) for inhabitants by income class and occupational categories to jobs falling in those categories for Los Angeles. They conclude that the highest income group has a higher job accessibility than the lower and middle-income groups and low-income workers have a higher job accessibility than middle-income groups. This is because higher and lower income communities are located relatively close to downtown Los Angeles, and near industrial job opportunities.

More recently, building upon the work of Wachs and Kumagai, Cervero *et al.* (1997) analysed the accessibility level of residents to jobs in the San Francisco Bay Area between 1980 and 1990 with (a) a basic potential accessibility measure and (b) a potential accessibility measure accounting for the consistency between residents' employment roles and labour force occupational characteristics at workplaces. In the latter case, (origin zone i) proximity to jobs (destination zone j) for any residential zone only contributes to the accessibility index if the occupational roles of employed residents in zone i match the occupational opportunities in zone j. They concluded that the inclusion of occupational matching does affect the results in that disparities in access to jobs between socio-economic groups increase. Namely, accessibility scores increase the most (compared to the basic accessibility measure) for the most job-accessible residential areas and decrease for the least job-accessible; residents of low income, inner-city neighbourhoods generally faced the greatest occupational mismatches.

Shen (1998) analysed car and public transport accessibility of workers categorised by residential location and occupation; groups to employment locations (categorised in the same occupation groups) in the Boston metropolitan area. Shen concludes that workers living near the central business district still have higher employment accessibility than those living in the suburbs, but for low-wage workers car ownership is a much more important determinant for access to employment than the residential location, i.e. only a small percentage of low-wage jobs can be accessed by public transit; low-wage workers living in the inner city have a low average accessibility level due to the low level of car ownership.

Furthermore, Van Ham et. al (2001) analysed regional differences in the match between education and job level in the Netherlands. They showed that the probability of a good match between education and job level increases with job accessibility (number of suitable jobs within reach by car), especially for high-educated workers.

A number of authors also analysed differences between socio-economic groups in accessibility to other opportunities. For example, Wachs and Kumagai (1973) also analysed accessibility to health-care opportunities by car and public transport for neighbourhoods differing in socio-economic composition (i.e. a 'black' and a 'white' neighbourhood). They conclude that the accessibility level to health-care opportunities depend upon the extent to which automobiles are available; many more facilities can be accessed within 15 or 30 minutes travel time by car. As car ownership in the 'black' neighbourhood is low their accessibility level to health-care facilities is also much lower. Other examples include those from Niemeier (1997), who analysed the economic worth of accessibility by income segments and Talen &Anselin (1998) who analysed spatial distribution of public playgrounds in Tulsa, Oklahoma, relative to the targeted constituencies (children) and socio-economic characteristics (race, income).

In conclusion, significant differences may exist in accessibility levels related to socio-economic characteristics of the population and the spatial distribution of the population and supplied opportunities. In general, some differentiation of the demand (individuals or households) and supplied opportunities by selected characteristics results in more realistic accessibility measures. In the case of job accessibility, the incorporation of the consistency between the working population's skills and educational level in residential areas and the labour force occupational characteristics in working areas, adds an important qualitative dimension. The "occupational match" can be easily incorporated into the basic potential accessibility measure; i.e. for any residential zone (origin zone i) jobs within reach (at destination zone j) only contribute to the accessibility measure if the occupational class or educational level of residents in zone i match the occupational class or educational level of job opportunities in zone j.

4.7 Accessibility measures for freight transport

4.7.1 Groupings and components

Accessibility measures for freight transport can be categorised in the same way as accessibility measures for passenger transport (see Section 2.2), i.e. according to measure type (infrastructure-based, activity-based and utility-based measures), and components (transport, spatial, temporal and individual components) (see Table 4.3). A difference with passenger transport is that within the transport component travel costs are usually the subject of main interest and not travel times.

Table 4.3: Type of accessibility measures and components for freight transport

component / measure	transport component	spatial component	temporal component	individual component
infrastructure-based measures	travel time (generalised) travel costs; travelling speed; hours lost in congestion		peak-hour period 24-hr period	stratification e.g. by economic sector, company, type of goods (e.g. low-/ high-value)
activity-based measures	(generalised) travel costs between locations of activities	distribution of opportunities in space (e.g. number of inhabitants per zone)	travel time and costs may differ throughout the day, year, season, etc.	stratification by economic sector (e.g. industry, retail) or company
utility-based measures	(generalised) travel costs between locations of activities	distribution of opportunities in space	travel time and costs may differ throughout the day	stratification by economic sector, company

Infrastructure-based accessibility measures for freight transport are based on the observed or simulated performance of the transport infrastructure. Infrastructure-based accessibility indicators for freight transport can be the same as for passenger transport, e.g. vehicle hours lost in congestion, vehicle speed. *Activity-based* measures for freight transport are seen as an indicator for the size of the market area for suppliers of goods and services. The accessibility measures used can be the same as for passenger travel, but with different travel times and/or costs and distance decay functions. *Utility-based measures* estimate the utility or benefit of moving a good from an origin to destinations for a shipper.

The *transport component* for freight transport comprises time, costs and qualitative aspects (see Table 4.4).

The time component includes waiting times, loading times, transhipment times, congestion and unloading times. Not that the time components are valued differently due to the different costs involved, e.g. the valuation of trip times differs from storage costs. The costs component includes fixed and variable costs, labour costs, etc. The qualitative component includes reliability, accident risks, damage risks, etc. The use of generalised transport resistances, as an aggregate measure of the transport resistance, is similar to the generalised travel times in passenger travel analysis (Goss, 1991). In a generalised cost function several aspects of the time component are included through monetary valuation of travel-time savings (see Blauwens & Voorde, 1988; Gommers, 1993). Another aspect of the time component is the presence of time windows, which may be set by public authorities, e.g. in central urban areas goods may only be delivered to shops at certain times of the day, or private companies.

The *land-use component* of accessibility reflects the magnitude, quality and character of the origins and destinations of freight travel, i.e. the spatial distribution of production (e.g. by economic sector), consumption (inhabitants) and freight distribution activities.

The *temporal component* of accessibility is important for freight transport because travel times and related costs may differ between peak and off-peak hours, between days of the week, between seasons, etc.

Table 4.4: Transport components of accessibility for freight transport

mode component	lorry	rail transport	shipping
time	waiting time loading time trip travel time congestion time unloading time settling documents	waiting time transhipment time trip travel time access mode transhipment time to main mode trip travel time rail transport trip travel egress mode settling documents	waiting time transhipment time trip travel time access mode transhipment time to main mode trip travel time shipping trip travel time egress mode settling documents
costs	fixed costs (taxes etc.) fuel costs depreciation costs maintenance costs labour costs decrease in value of goods interest losses of goods parking costs road-pricing costs transport charges insurance costs	costs of transhipments costs of access/egress modes transport charges decrease in value of goods interest losses of goods insurance costs	costs of transhipments costs of access/egress modes transport charges decrease in value of goods interest losses goods insurance costs
quality	reliability accident risk damage risk information	reliability accident risk damage risk information	reliability accident risk damage risk information

Source: based on MuConsult, 1994

The evaluation of accessibility for freight travel heavily depends heavily on the *individual component* of accessibility, reflecting the characteristics of individual firms. Firms value accessibility differently, depending on the characteristics of the firm (e.g. size, market area), characteristics of produced products and the logistic organisation. Furthermore, the type of cargo transported strongly affects the importance of accessibility. There are several ways of categorising products or goods. For example, goods can be categorised according to their economic value per m^3 and volume per packing unit (ABCD categorisation - e.g. see De Wit & Van Gent (1996):

- A-goods: low value products with a large volume per packaging unit, e.g. bulk goods
- B-goods: high value products with a large volume, per packaging unit, e.g. vehicles;
- C-goods: high value products with a small volume per packaging unit, e.g. electronics;
- D-goods: low value products with a small volume per packaging unit, e.g. clothing.

Another, more complex, categorisation of goods is according to the concept of 'logistic families'. This concept was introduced in the Netherlands (see Wierikx *et al.*, 1993;

Tavasszy *et al.*, 1998) to create a categorisation of firms based on their logistic behaviour. In this concept, goods are categorised according to the following characteristics:
(a) Value density, i.e. the economic value of products per cubic metre;
(b) Packaging density, i.e. the number of packaging units per volume unit;
(c) Perishability, i.e. the period in which a product is technically or economically usable;
(d) Delivery time (days);
(e) Shipment size;
(f) Demand frequency.

Perrels *et al.* (1999) and Bruinsma *et al.* (2000) used this concept to differentiate goods according to economic value. In this study, the generalised costs for a specific origin–destination were estimated using different values of time for 10 goods segments (e.g. from bulk goods to high quality products). The accessibility measures used are estimates of (a) the average transport costs per tonne freight and (b) tonne kilometre for a region in Europe, aggregated over the 10 goods segments and all possible origin-destination combinations for 43 regions in Europe by road transport, rail transport and inland shipping.

4.7.2 Applications of accessibility measures

Infrastructure-based accessibility measures
Several studies use infrastructure-based accessibility measures for freight transport. For example, Mathis (2000) estimates travel time accessibility for heavy trucks from selected locations (Rotterdam, the Ruhr area, Antwerp) to European cities, adhering to the prescribed driving times and speeds. The results are represented as ‘corridors’ showing the number of itineraries (for each origin destination combination) using the same link. Lutter *et al.* (1992) estimates lorry travel times to the nearest road-rail freight terminal at the municipality level, and rail travel time to eleven economic centres in Germany. Furthermore, Visser & Maat (1994, 1996) calculate average travel times between origins and destinations of urban freight travel as a measure of accessibility using a freight transport model.

Activity-based accessibility measures

Cumulative opportunities measures
Cumulative opportunity measures can also be used for analysing freight transport accessibility. For example, Chatelus & Ulied (1995) developed several accessibility measures for the evaluation of the Trans-European Networks. Relevant measures are: (i) the average (generalised) cost to reach a market area (of a certain population size, e.g. 60 million) by lorry. The generalised road transport costs included costs of the driver’s time, cost per kilometre and a fixed-cost component, and (ii) the maximum market area (population) that can be reached in two or three days by the fastest connection using road, rail or combined traffic.

Potential accessibility measures

A number of studies used the basic potential accessibility to analyse freight transport accessibility. For example, Simmonds & Jenkinson (1993; 1995) analyse the “market potential” for the manufacturing and distribution sector for 60 regions in Europe using a basic potential accessibility measure with GDP as the destination variable and composite haulage cost (road and intermodal transport) as the distance variable. The road haulage cost comprises a constant cost factor and varying haulage cost rate (cost per km) reflecting the distance covered on different road types, and, where applicable, ferry tariffs and a cost element representing the driver’s waiting time before boarding and onboard a ferry. For intermodal transport (across the Alps) a cost constant representing the loading/unloading costs for intermodal transport is used, a (lower) varying cost rate per km for the on-train section of travel, and an additional distance to represent the diversion away from the direct route. The following equation is used:

$$A_i = \sum_j b_{ij} . D_j (c_{ij} - q)^{-\alpha} \qquad \text{(Equation 4.24)}$$

where:

D_j = the weight for the importance of the destination, i.e. GDP
b_{ij} = a constant cost factor representing the effects of international borders
c_{ij} = composite cost for road haulage and intermodal haulage
q = a constant cost factor for loading/unloading costs
α = a parameter describing the sensitivity to travel cost

Furthermore, Simmonds & Jenkinson estimate an “economic potential” for each region by multiplying the accessibility value from Equation 4.24 (as a measure of the market for the region’s output) by the existing employment in the relevant sector (as a measure of the region’s capacity for production).

Another example is taken from Visser & Maat (1994; 1996) who calculate the number of companies within a certain travel time using the basic potential accessibility measure. Potential accessibility was also used in the study by Gattuso & Chindimi (1998) on freight transport through the port of Gioia Tuaro in Calabria, Italy.

Combination of infrastructure- en activity-based measures

An example of a combined based measure is the recent study taken from Perrels *et al.* (1999) and Bruinsma *et al.* (2000), who estimated the average transport costs per tonne freight and tonne kilometre (for 10 goods segments) for 43 regions in Europe by road transport, rail transport and inland shipping. Furthermore, Gattuso & Chindimi (1998) analysed average travel times to selected destinations for freight transport through the port of Gioia Tuaro in Calabria, Italy.

Utility-based measures

In theory, utility-based measures can also be applied to freight transport. A simple stochastic specification of utility U attached to the movements of goods from location i to a destination j is as follows:

$$U_{ij} = V_{ij} - \beta c_{ij} + \varepsilon_{ij} \qquad \text{(Equation 4.25)}$$

Where

V_{ij} = utility of moving a good from i to j for a shipper n, which is deterministically known

c_{ij} = (generalised) costs of the trip ij for a good, e.g. travel time, travel costs

β = a cost sensitivity parameter

ε_{ij} = a random term

In practice, the estimation of such a utility function is relatively complex. The utility variable V_{ij} (or willingness to pay) depends on the characteristics of the individual sending goods and the type of goods (see also Section 4.7.1). Probably as a result of this complexity and the lack of usable freight transport models, very few applications of utility-based accessibility measures for freight travel are found. One example is the measure developed by (Perrels et al., 1999), based on a recently developed Dutch national freight transport model (Tavasszy, 1997). The accessibility measure estimates the total generalised cost for accessing all potential destinations (zones). The logistic costs include generalised transport costs, stock costs and warehouse costs and are differentiated by (i) market segment, i.e. 10 types of goods - or logistic families - depending on economic value, frequency, value of time and package size, and (ii) transport mode (road, rail, inland shipping, short-sea shipping, deep-sea shipping). The generalised transport costs comprises two components: (a) transport charges and (b) costs for transport time. The value of time (in guilders per kilogram per hour) is estimated separately for the 10 market segments.

4.7.3 Conclusions

- Compared to passenger transport, much less studies are found that specifically analyse accessibility of freight transport.
- Most accessibility measures developed for passenger transport are also applied to freight transport:
    - ❑ infrastructure-based measures as the (total or average) travel time or costs on the road network or segments of the road network,
    - ❑ activity-based measures, e.g. contour measures and potential accessibility measures (e.g. number of inhabitants or GDP within a certain cost limit). These measure are used an indicator for the size of the market potential for suppliers of goods and services;
    - ❑ utility-based, e.g. average utility of moving goods for a shipper;

- Studies on freight transport accessibility focus on relative simple measures that are easy to interpret. The more complex utility-based measure is used very little in practical applications.
- In practical applications, it seems to be common practice to stratify accessibility measures by economic sector (e.g. services, industry), but not by market segment or type of good, although the latter is an important factor influencing the valuation of accessibility of freight transport by firms and companies.

5. Accessibility, travel behaviour and land use

5.1 Introduction

The previous sections were concerned with reviewing accessibility as an intermediate indicator describing the possible accessibility impacts of changes in the land-use transport system. This section reviews the literature on the wider impacts of accessibility changes by describing relationships between accessibility and (a) travel behaviour and (b) land use. Section 6 is concerned with economic impacts of accessibility changes; Section 7 with social impacts.

5.2 Potential accessibility and travel behaviour

Several authors have empirically analysed possible relationships between potential accessibility to opportunities and travel behaviour in terms of number of trips, trip length and kilometres driven.

A number of authors analyse the relationship between potential accessibility and average trip generation rates. The results tend to be negative. For example, Dalvi & Martin (1976) found that potential accessibility (by car and public transport) to be a rather ineffective method for explaining trip generation in the UK. Williams (1989) also found that 'observed spatial variability in household trip-making behaviour (for households in Hamilton, Ontario, Canada) are, for the most part, a consequence of the socio-economic differences, and are not due to residential accessibility conditions'. Ewing *et al*. (1996) found that residential density, mixed use and accessibility do not have significant, independent effects on household trip rates (for households in Florida, USA), after controlling for socio-demographic variables. Handy (1994) found that for the San Francisco Bay Area the relationship between local and regional accessibility to shops and the number of shopping trips per person was virtually non-existent. A study that did find relationships between potential accessibility and trip generation came from Koenig (1980), who states that accessibility was a good determinant of trip generation for non-working people in Marseilles, France, if one accounts for socio-economic characteristics and if walking trips are included. Within a group showing homogeneous characteristics, the average trip rate (trips to and from home) may double or triple from an area with poor accessibility to an area with good accessibility.

A number of authors analysed relationships between potential accessibility and trip length, hypothesising that accessibility levels will be negatively related to travel distances: high levels of accessibility imply that activities are closer to residences so that minimum distances to activities are shorter. Handy (1994) found that shopping distances decrease with increasing potential accessibility, both on a local and regional level. Another example is from Levinson (1998), who analysed commuting duration in Washington, DC. He concludes that residences with high job accessibility levels have shorter home to work trips, controlling for demographic and socio-economic factors. Moreover, potential accessibility was more effective in explaining average home to work trip distances than the demographic and socio-economic variables.

Some authors analysed the relationship between potential accessibility and average vehicle kilometres per person. For example, Handy (1994) found that by combining trip frequency with trip length to estimate average person kilometres travelled, significant correlations were found for local and regional accessibility to shops; the amount of shopping travel is significantly lower in areas with high accessibility to shops. Kockelman (1997b) concludes that for the San Francisco Bay Area, job accessibility, land-use mixing and land-use balance proved to be highly statistically significant in explaining household vehicle kilometres, controlling for demographic factors. Job accessibility (30 minutes radius) was found to be strongly negatively linked with household car use. Kockelman states that this is probably the result of a direct effect (closer opportunities diminish trip distances) and an indirect effect (high levels of potential accessibility are associated with higher land prices, less convenient parking options, more congestion).

5.3 Land use

Many studies have asserted that household and firm location behaviour depends, to a certain degree, on the level of accessibility to opportunities such as work, shopping, public services (for household) and labour force (for firms). Changes in accessibility levels (as a result of changes in transport infrastructure or land uses) can have a wide variety of effects on households and firms, e.g. re-location decisions of existing households and firms may be influenced, firms may grow or decline and new firms may be attracted. One of the first empirical studies is from Hansen (1959), who examined the relationships between residential development and potential accessibility to employment, population and shopping for the metropolitan area of Washington D.C.

Wegener & Fürst (1999) reviewed literature on the relationship between accessibility and land use and concluded that it tends to be weak. Smits & Korver (1993) reviewed literature on household location choices and concluded that accessibility plays a significant role in location choice behaviour of households. However, the influence on location choice is relatively small compared to other characteristics, especially housing characteristics. Borgers & Timmermans (1993) estimate a model of joint (multi-person) decision making (using a sample of 95 dual earner households in the Netherlands) to analyse the influence of (a) residential characteristics (dwelling type, costs, type of neighbourhood), (b) transport facilities in the neighbourhood (frequency of bus services, availability of railway station, travel time to a major highway) and (c) the travel time from the residential location to the workplace (by car, public transport and bicycle). Borgers and Timmermans conclude that the preference for a particular residential location is highly dependent on the characteristics of the dwelling and its environment, whereas the characteristics pertaining to transportation facilities seem to be less important. On the basis of a Stated Preferences study, Vanderschuren *et al.* (1996) conclude that personal characteristics (e.g. gender, educational level, available budget, phase in life, presence of children) are the most important factors explaining re-allocation of households, although accessibility does play a role.

Wagtendonk & Rietveld (2000) analysed the influence of several location factors in residential housing construction in the Netherlands for the 1980-1995 period, using a logistic multiple regression model (see for an English paper Schotten *et al.*, in prep.) The analysis was carried out for two dwelling types (i.e. single- and multiple-family dwellings) on a 500-meter grid basis. Besides location factors as proximity to other residential areas, distance to highway and rail infrastructure, two potential accessibility measures were included, i.e. job accessibility (number of jobs within 60 kilometres from dwelling locations, weighted by their distance away) and accessibility to nature areas (surfaces of forest areas and wetlands within 15 kilometre from dwelling locations, weighted by their distance away). Wagtendonk & Rietveld conclude that residential construction is significantly related to job accessibility, to a lesser extent, accessibility to nature areas. However, the spatial pattern of existing residential areas and the assignment of a new town status (through land-use policy) were found to be the most important location factors; new residences in the Netherlands tend to be built in the immediate neighbourhood of existing residential areas, and in addition, new towns have played an important role in residential construction between 1980 and 1995.

5.3.1 Potential accessibility and home and office prices

The popularity of urban areas as location sites for offices can be used as an indication for the effect of accessibility on the potential of urban areas to attract new firms and/or to develop in a broader economic sense. The prices for office space may be a proper indication of this popularity, i.e. ideally, office prices reflect the changes in market preferences. There are a number of empirical studies analysing the relationship between accessibility, and office or home prices. For example, Bruinsma (1994) analysed the relationship between the development of office prices and the completion of the Amsterdam Orbital Motorway in the 1987-1991 period. The office prices were significantly related to the distances of the offices to the nearest entry point of the orbital

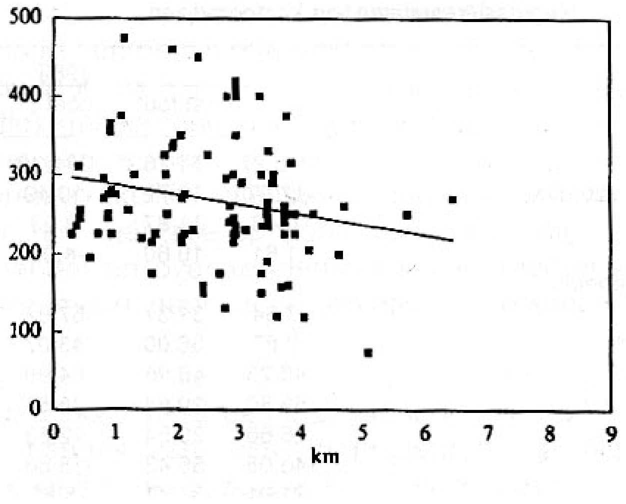


Figure 5.1: Variations in office prices (guilders per m^2) at locations in the Amsterdam agglomeration by road distance (km) to the nearest entry of the Amsterdam orbital motorway in 1991 (Bruinsma, 1994)

motorway (r squared values lie between 0.3 to 0.5). Figure 5.1 shows the negative correlation between office prices and the distance to the nearest entry point of the orbital motorway for 1991. If non-infrastructure factors (status of area and quality of the buildings) are accounted for, the price of offices near a motorway entry are 23 guilders per sq. m higher than locations 1 km away. Bruinsma concludes the orbital motorway to be an important location factor for office firms in the Amsterdam agglomeration. However, the largest effect of the completion of the motorway on office prices is not found in areas where the new segments were constructed, but in highway-connected zones that have already been in use for over 20 years. Interestingly, Bruinsma did not find a clear relationship between the distance to public transport (railway or subway stations) and office prices.

Another Dutch empirical study is from Nyfer (2000), who related a basic potential accessibility measure for the population by car in 1993 for 43 (COROP) regions in the Netherlands (Manshanden, 1996) to the average home price in those regions (1995 prices). Figure 5.2 shows the relationship between the potential accessibility (indexed to the highest score) and average home prices. The figure shows that when a region has a 10% higher relative accessibility level (compared to another region), the average home price is about 3300 Euro higher. However, the relationship seems to be relatively weak as the data in the figure are relatively disperse.

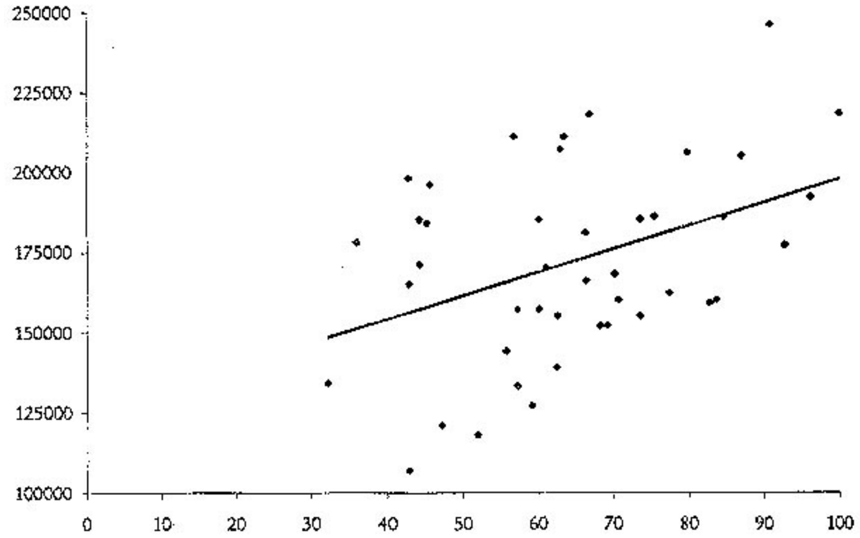


Figure 5.2: Accessibility index and housing prices in 43 regions in the Netherlands in 1995 (guilders) (Nyfer , 2000).

A more complex method for analysing the relationships between access to transport infrastructure and property values is the hedonic price method, which relates the price of a property to a number of attributes or characteristics that theoretically affect its value. Holding other variables constant, the change in the housing price resulting from a change in any particular attribute is called the hedonic or implicit price of an attribute. Cervero (1997) gives an extensive literature review of studies undertaken in Canada and the United States from 1970 to 1996, analysing the effects of different types of transit (conventional light rail and advanced/rapid rail) on different types of land use (single-family/low-density residential areas, multi-family/medium-density residential areas, offices and commercial-retail areas). Cervero concludes that it is difficult to generalise the conclusions because the studies vary widely in methodologies, measurement units, time, context, and spatial extents of measurements, levels of sophistication in controlling for other possible predictors and findings. Empirical evidence on the relationships between transit accessibility and land values should generally only be applied to the area where the study was conducted. The several studies on the impacts of the BART transit system in the San Francisco Bay Area provide consistent results. Cervero estimates that between 1973 (pre-BART) and 1993 (20 years after construction) the 25 BART transit stations generated nearly US$225 million in accessibility and agglomeration benefits; office prices account for the largest benefits (about 40%), followed by suburban single-family homes, suburban retail and urban single-family housing.

Al-Mosaind *et al*. (1993) and Chen *et al*. (1998) state that one of the reasons that hedonic pricing studies may have reached contradictory results is that accessibility to rail may have two different effects on residential property values, i.e. accessibility (distance to railway station) may increase property values, whereas nuisance effects may decrease property values. They analysed the relationship between the distance to railway stations of the light rail transit (LRT) system in Portland, Oregon, and the distance to the line itself as a proxy for nuisance on single-family home values. The positive accessibility effect dominates the negative nuisance effect, which implies a declining price gradient as one moves several hundred metres away from railway stations. This is illustrated in Figure 5.3. Wagtendonk & Rietveld (2000) found the same result in analysing location factors for residential construction in the Netherlands between 1980 and 1995, i.e. the presence of road and rail infrastructure was found to be significantly negatively related with residential construction, whereas the distance to highway access points and railway stations were found to be positively related.

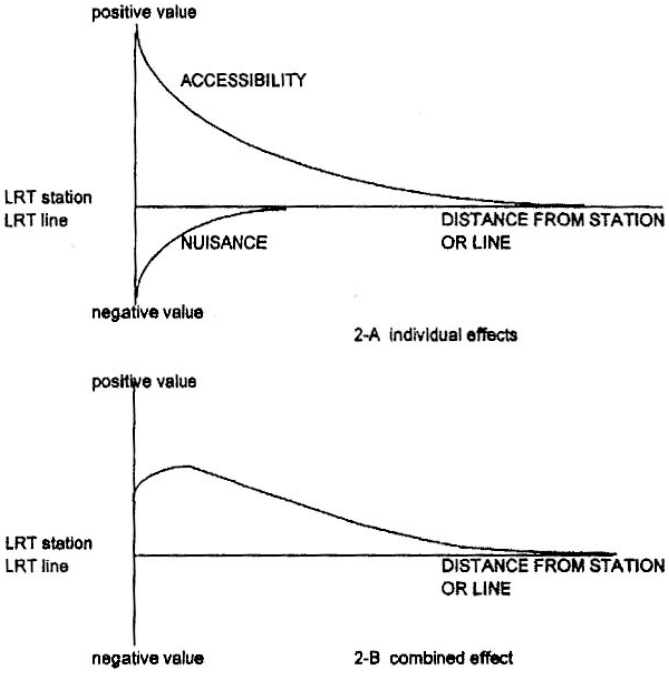


Figure 5.3: Effects of light-rail on single-family housing property values in Portland, Oregon (Chen et al., 1998).

Most hedonic pricing studies measured accessibility to rail stations on the basis of a (straight-line) distance to the station; some studies used travel time or commute costs as the basis. Kockelman (1997a) includes potential accessibility measures, besides dwelling-unit attributes (e.g. dwelling size, number of rooms) and travel attributes (e.g. travel time to work, car ownership), as an attribute in an hedonic pricing model explaining home purchase price and rents in the San Francisco Bay Area. Two accessibility indices were included: (a) potential accessibility to jobs within 30 minutes travel time by car, and (b) potential accessibility to sales and service jobs for non-work trips by walking. Kockelman concludes that the travel-time-to-work variable and the work-accessibility variable are highly statistically significant in explaining home prices and rents. Figure 5.4 illustrates how average home prices in the San Francisco Bay Area vary with job accessibility (number of jobs within 30 minutes travel time by car) and with home-to-work travel times.

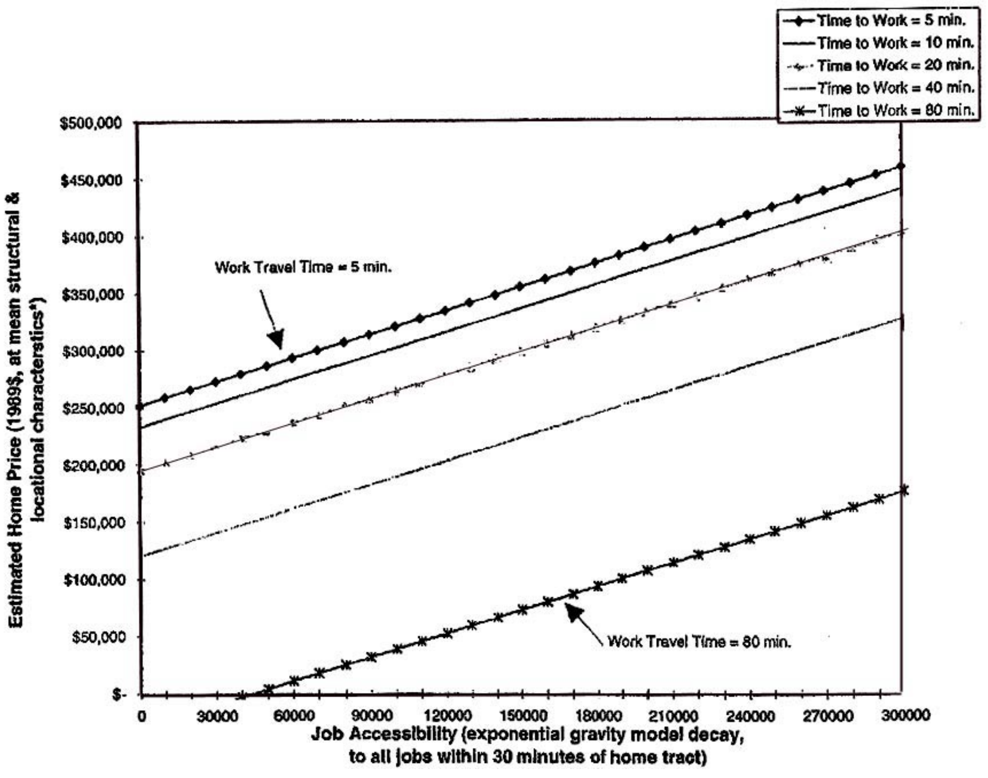


Figure 5.4: Relationship between job accessibility, home-work travel time and home prices in the San Francisco Bay area in 1989 (Kockelman, 1997).

5.3.2 Potential accessibility and locational preferences

Another method for analysing the influence of accessibility on locational preferences and land use is conducting a stated-preference survey among entrepreneurs. Several studies in the Netherlands on the locational preferences of entrepreneurs indicate that accessibility by road to be one of the highest valued locational factors; in particular, locations near an access point of a motorway are highly valued. For example, a survey of 1250 Dutch firms in the Randstad area (the highly urbanised western part of the country, including Amsterdam, Rotterdam, The Hague and Utrecht) analysed the importance of 25 location factors – indicated on a scale from 0 to 10 (NSS, 1991). The survey showed a group of 11 factors clearly having higher scores than the rest. Four relate to the quality of the building and its immediate environment (e.g. representativeness of the building and the direct environment, rent/plot price), one factor relates to the educational level of staff and six factors relate to the quality of infrastructure and communications (e.g. accessibility by road and public transport, parking space, loading/unloading facilities, telecommunication facilities). The most important locational factor was “accessibility by road”. Other examples of surveys showing the importance of (especially) road infrastructure are from Wilson *et al*. (1982), Pellenbarg (1985) and Bruinsma *et al*. (1996). However, the results of these surveys are less extreme: accessibility is not often identified as the ‘most’ or ‘second most’ important factor. Furthermore, good access is seen as a “status determinant” by the entrepreneurs, e.g. some firms want to be located near an international airport or a high-quality public transport terminal, whether or not the employees, customers or clients regularly use these travel modes (Rietveld & Bruinsma, 1998).

Bruinsma & Rietveld (1997) found a strong positive relationship between entrepreneurs’ perception of the attractiveness of cities as a location for firms and population accessibility (using a centrality index) via the road network. Furthermore, a firm’s locational desires are consistent with observed relocation patterns in the Netherlands over the last 15 years (Rietveld & Bruinsma, 1998).

5.4 Conclusions

Potential accessibility and travel

Several authors have empirically analysed possible relationships between potential accessibility to opportunities and travel behaviour in terms of number of trips, trip length and kilometres driven. In general, potential accessibility to opportunities negatively influences average trip length and kilometres travelled for work and non-work trips. Household trip generation rates do not seem to be strongly related to accessibility to opportunities, but to socio-demographic and socio-economic factors.

Potential accessibility and land use

Location behaviour of households and firms is very complex and dependent on far more attributes than those that can be observed and quantified. Household and firm location behaviour depends, to a certain degree, on the level of accessibility to opportunities such as work, shopping, public services and nature areas (for household) and labour force (for firms). An indication of the role of accessibility can be found in home purchase prices and rents, and office prices. Most studies found in the literature successfully relate home or office prices and rents to the (straight-line) distance to road infrastructure (e.g. motorway entry points). The relationship between public transport infrastructure (e.g. railway stations) and home or office prices is often less clear; e.g. the type of public transport plays an important role. A few studies consider potential accessibility to jobs or the population by car an important determinant for prices or rents for homes and offices.

Another indication for the relationship between accessibility and location behaviour is found in surveys of locational preferences of firms. In the Netherlands, potential accessibility to the population can be related to an entrepreneur’s locational preferences.

In general, it can be concluded that locational preferences and location choice of households and firms partly depend on accessibility levels to certain opportunities. However, other characteristics, especially individual characteristics of households and firms and characteristics of the building, are considered to be relatively more important.

6. Accessibility as an economic indicator

6.1 Introduction: methods for analysing economic impacts

This section discusses the use of activity-based accessibility for the economic evaluation of land-use transport plans, projects and/or scenarios. In general, increased accessibility resulting from a transport project is considered an important user benefit for people and firms. A traveller can make a trip at less cost or greater convenience; there might be less congestion, and more destinations may be reached in the same time. For firms: first, a reduction in interaction cost may increase efficiency of production (i.e. time saved can be used in productive activities), and may become more competitive and attract more customers. Secondly, improved commuting conditions may improve the labour market, giving rise to improved productivity (Forslund & Johansson, 1995).

In the literature, basically three approaches for analysing economic impacts of transport investments can be distinguished (Rietveld & Bruinsma, 1998):

(1) A *social cost-benefit analysis* (CBA) with consumer surplus as the main object. This approach is firmly based on efficiency objectives in welfare economics (Mishan, 1976) and has been widely used in various countries (see, for example, Dings *et al.* (1999) and Banister & Berechman (2000) for a description of CBA and applications). In general, a CBA analyses the change in the social welfare for all individual members of a society as a result of a project. Maximum social welfare occurs when the marginal social benefit of the last unit is equal to the marginal social cost (what society must give up to obtain that last unit of output). Benefits (e.g. reduced travel time, waiting and/or queuing time, accessibility improvements) are reflected by willingness to pay, represented by a demand curve. Social opportunity costs (direct and indirect costs, e.g. infrastructure costs, external costs) can be represented by a supply curve. The intersection represents the optimal level of output and price, and gives the economic efficiency of a project. Economic efficiency can also be interpreted as the size of the net benefits received by all members of the community as a consequence of a project;

(2) A *production function approach* with GDP as the main object. Since the 1980s several studies have analysed the contribution of infrastructural improvements on productivity – see, for example, Blum (1982), Aschauer (1989), Nijkamp (1986), Biehl (1986), Johansson (1993) and Forslund & Johansson (1995) In the production function approach, transport infrastructure is considered as a type of capital stock available to a region or country. Production functions are used to give an aggregate view of the contribution of infrastructure to productivity. An increase in productivity due to infrastructural changes may be the result of reduced cost for the collection of inputs and the distribution of outputs, increased opportunities for exploitation of economies of scale, and a better functioning of the housing and labour market. These impacts are often described as the wider or indirect economic impacts of transport projects. See Rietveld & Bruinsma

(1998) and Banister & Berechman (2000) for an overview of applications of this approach.

(3) An approach focusing on *employment* effects of infrastructure investments. Infrastructure investments may have temporary and non-temporary effects on the demand side, i.e. employment from the construction phase and operations and maintenance. Furthermore, non-temporary employment effects on the supply side may occur via (a) substitution and complementarily relationships between labour, private capital and infrastructure, and (b) differences in regional growth rates due to differences in advantages received from infrastructural improvements. This approach is applied especially in countries with high levels of structural unemployment where job creation is considered of prime interest (Rietveld & Bruinsma, 1998).

These three approaches are partly complementary, partly overlapping and partly conflicting (Rietveld & Bruinsma, 1998). The approaches are *complementary* because the CBA approach includes consumer benefits and external costs, elements lacking in the production function and employment approach. The production function approach estimates the contribution of road infrastructure to long-term macro economic benefits in terms of GDP, which is usually not included in a CBA. Additional to CBA analysis, employment may be paid special attention to in situations of chronic unemployment because then the use of observed market wages leads to and underestimate of the net benefits of projects in a CBA, i.e. the wages do not reflect the opportunity cost of labour. In situations of more balanced labour markets there is less reason to focus on employment. The CBA approach partly *overlaps* with the production function approach. Firstly, the benefits of transport investments for business and freight traffic are included in both methods. Secondly, consumer benefits are partly linked with the development of GDP, i.e. besides better opportunities for enjoying more leisure time and increasing their range of consumption activities, the reduction of travel time also gives people better opportunities for working longer (Bruinsma & Rietveld, 2000). The production function approach may be *conflicting* with the employment approach: productivity gains, as studied by the production function approach, may have negative impacts on employment, i.e. substitution effects may lead to a decrease in demand for employment.

This section describes the use of accessibility measures in each of the three approaches. Section 6.2 describes the use of accessibility measures in cost-benefit analysis. Section 6.3 describes studies relating accessibility measures to (regional) economic development. Section 6.3.3 explains relationships between accessibility and employment.

In general, benefits (and costs) from the land-use transport projects occur to both "users" and "non-users". MVA (1991) identifies "travellers" and "non-travellers" corresponding to the movement of people and goods, on the one hand, and those parties involved in the supply, regulation and financing of the system on the other, e.g. transport operators, governments. Eijgenraam *et al.* (2000) identify travellers, people living in the vicinity, regions and the public and private sector as relevant groups in the evaluation of distributional impacts of transport projects. User benefits of transport projects are commonly evaluated with the consumer-surplus approach. The (non-user) benefits for people living in the vicinity of transport projects are usually not included in economic evaluations of infrastructure projects. Non-user values may include (a) an option value and (b) a bequest value. Option value refers to goods or services that non-users may benefit from having available as a backup for another good or service, or having it available in the future: e.g. public transport has an option value to those who would use it if the car broke down. Bequest values refers to goods and services for which individuals (users and non-users) would be willing to pay to assure these services are available *to other people* – living now or in the future: e.g. people value public transport making their homes accessible to (non-car owning) visitors. The relationships between potential accessibility measures and non-user values are described in Section 6.5.

6.2 Accessibility and Cost-Benefit Analysis

6.2.1 Current practice of measuring user benefits in CBA

Using traditional micro-economic welfare theory, the user benefits (e.g. travel timesavings and monetary operating costs) in a cost-benefit analysis (CBA) of transport projects are usually measured by the user's willingness to pay, as reflected by the area under the demand curve. To derive the "net" user benefits of a transport project, the difference in the willingness to pay between the project and an alternative (e.g. the situation without the project) must be derived. At present, the concept of consumer surplus is the most commonly used way to evaluate user benefits in social cost-benefit analysis of transport projects. According to Echenique (1994), the original idea of consumer surplus dates back from Dupuit (1844). Dupuit defined consumer's surplus as 'the excess of the price which (the consumer) would be willing to pay rather than go without the thing, over that which he actually does pay'. A change in consumer surplus is used as the principle measure of the total benefits from a project. Since a transport project may also generate negative impacts such as environmental nuisances, the willingness to pay principle can also be applied to indicate the amount of money consumers are willing to pay to avoid such harmful effects. These values can then be regarded as part of the project's costs.

In standard cost-benefit analysis, a project can be justified if the total (monetary) benefits of all users exceed the total (monetary) costs. The 'Hicks-Kaldor criterion' and the concept of 'Pareto improvement' form the starting points of CBA. The Hicks-Kaldor criterion states that 'winners' of a project are able to compensate 'losers' through financial transfers. The combination of the project and the financial transfers may result in a Pareto improvement, i.e. the welfare of at least one person increases, without reducing welfare for others. If a Pareto improvement is achieved, thus total monetary benefits exceed total costs, the project can be justified from an economic point of view. Note that the *actual* financial compensation is not considered in a CBA (see also Section 7.3.2). Furthermore, in practice, non-economic arguments may also result in transport investments.

In practical cost-benefit analysis of transport projects, consumer surplus is estimated by using the ‘rule-of-half’ formula, which was introduced in London Transport Studies in the 1960s (Tressider *et al.*, 1968). See Box 6.1 for a short description; see, for example, Button (1993) or Johansson (1987) for a more elaborate discussion.

Recently, the present practice of economic evaluations of transport projects in Europe, the United States and Japan were analysed. Dings *et al.* (1999) give an overview of current methodologies used in cost-benefit analysis in Germany, Denmark, France and the UK. A recent special issue of *Transport Policy* comprises nine papers reviewing the present practice of transport project evaluation in France (Quinet, 2000), Germany (Rothengatter, 2000), UK (Vickerman, 2000), European Union member states (Bristow & Nellthorp, 2000), Japan (Morisugi, 2000), United States (Lee, 2000) and developing countries (Talvitie, 2000). Furthermore, Banister & Berechman (2000) give a comprehensive description of cost benefit analysis in transportation. From these overviews it can be concluded that there is a significant degree of agreement on the direct impacts which are to be included in a CBA; most countries place a monetary value on construction costs, vehicle operating costs, time savings and safety. However, the monetary valuation on impacts where no markets are available, such as travel time and accident costs, differ highly between countries.

By far the largest category of direct benefits from any given transport project is travel-time savings. However, there is a range of definitions used for travel-time savings. In general, travel-time savings can be expressed in terms of opportunity costs, i.e. there are alternative – more productive - ways of using the time. Travel-time savings can be expressed in monetary values by values of time, which differ among, for example, individual, purpose of journey (i.e. work or non-work), mode, distance, travel class and type of vehicle (Bristow & Nellthorp, 2000). The value placed on work-time savings will normally aim to reflect the value of the work being done; assuming that time saved is used productively and that the marginal product of labour is reflected in the costs of employment, the gross wage is considered a valid measure. Alternatively, the value of timesavings to the employer and employee can be estimated and combined. The latter method is used in Sweden and the Netherlands for business trips (see AVV, 1998). Nellthorp *et al.* (1998) shows the range of values for EU countries (after adjustments to a common base year and definition); the time value is 6.3 to 23 Euro per hour, largely the result of variations in wage levels (see Figure 6.1).

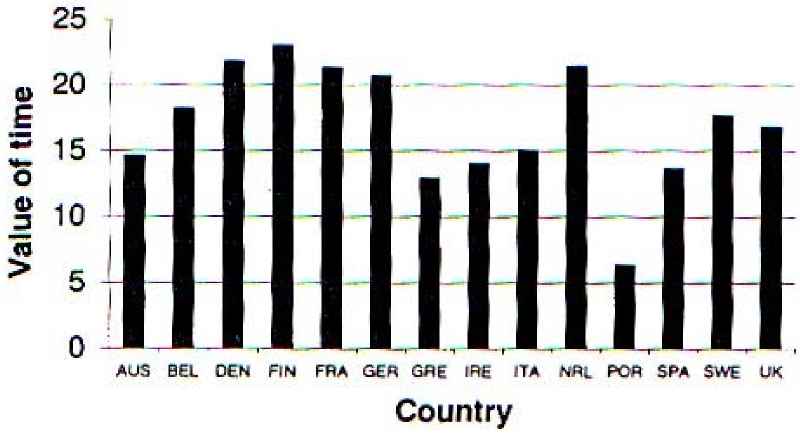
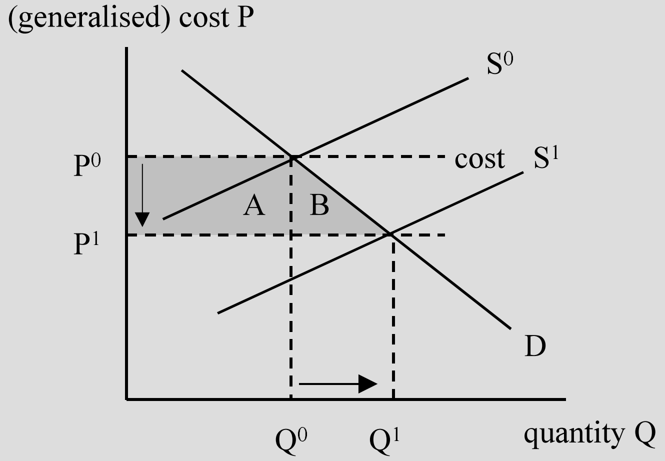


Figure 6.1: Time values (Euro) in EU countries per person per hour during working time when travelling by car (1995) (Nellthorp *et al.*, 1998).

Box 6.1: The rule-of-half equation

Suppose a highway capacity expansion results in a reduction in travel cost. Two categories of travellers benefit: (A) travellers who were already using the highway (existing users) and (B) new users, for whom the trip benefits outweigh the costs after the cost reduction. The figure below gives a schematic representation. The demand curve D intersects the marginal cost curve before (S^0) and after (S^1) the highway expansion; the generalised costs decrease from the price P^0 to P^1 and as a result the demand increases from Q^0 to Q^1.



The total benefits of the capacity expansion is represented in the grey surface below the demand curve and compries the benefits for existing users - surface of area A ($Q^0(P^0 - P^1)$) - and new users - surface of area B ($\frac{1}{2}(Q^1 - Q^0)(P^0 - P^1)$) -. Assuming a linear demand curve, new users receive on average half the benefits from the expansion of the already existing users. The total benefits for existing and new users together can be calculated using the rule-of-half formula, which was introduced in the London Transport Studies (Tressider *et al.*, 1968):

$$CS = Q^0(P^0 - P^1) + \frac{1}{2}(Q^1 - Q^0)(P^0 - P^1) = \frac{1}{2}(Q^1 + Q^0)(P^0 - P^1)$$

Thus the consumer surplus equals the product of half the sum of the travel demand before and after the highway capacity expansion and the change in the price as a result of the highway capacity expansion. In a transport network with alternative routes and modes the total benefits are derived by estimating the sum of consumer surpluses for each separate transport market where, as a result of a change in generalised costs, indirect price and demand changes occur.

When the travel demand is expressed in the number of trips by a specific mode and the price is written as generalised cost, the rule-of-half formula can also be written as in Williams, 1977:

$$CS = \frac{1}{2} \Sigma_{ijm} (\Sigma T_{ij}^{1nm} + \Sigma T_{ij}^{0nm})(c_{ij}^{0m} - c_{ij}^{1m})$$

Where T_{ij}^{nm} denotes the summation of trips from i to j for all person-type classes n using mode m; c_{ij} denotes the generalised cost of trip i to j using mode m.

Source: Johansson (1987), Williams (1977), Eijgenraam *et al.* (2000)

In the case of non-working time, there is no obvious market, and valuation is more complex. Applied methods explore an individual's willingness to pay to save time. Most European countries use a value for non-working time of roughly 10-40% of the working time value. The values differ from 2.4 to 5.3 Euro per hour (Nellthorp *et al.*, 1998).

Furthermore, from the overviews of current practice cost-benefit analysis it is concluded that environmental impacts are included in either monetary or physical terms. The more recent the methodology, the more environmental impacts are included and monetarily valued (Dings *et al.,* 1999).

Another issue is the incorporation of indirect (welfare) impacts of transport projects. Indirect impacts do not directly relate to the transport project but are the result of the direct impacts. Indirect effects can include a higher efficiency of production (macro-economic impacts) and distributional effects. Distributional effects occur when (a part) of the costs or benefits is allocated to non-users of a project. Distributional effects of transport infrastructure may also have impacts on a national scale, if costs or benefits of transport projects are allocated in other countries. Eijgenraam *et al.* (2000) states that indirect impacts should be timely included and sufficiently thorough in the project evaluation, despite difficulties in estimating these effects. There is no method or model available taking all theoretically relevant impacts into account. In the current practice of CBA, indirect impacts are usually excluded from the evaluation, or handled qualitatively only.

6.2.2 Potential accessibility, consumer surplus and compensating variation

Several authors have evaluated the relationship between the different forms of the spatial interaction models, utility and consumer surplus, e.g. Neuburger (1971), Williams (1976) and Williams & Senior (1978). The utility of accessibility of a location for a potential user can be derived by using the well-known multinomial logit (MNL) model. This model is shown to be linked to the concept of consumer surplus (Williams, 1976; Williams & Senior, 1978). Consumer surplus, the consumer's willingness to pay above the market price, is the most common way of evaluating economic benefits of (transport) projects. This measure is often called Marshallian consumer surplus (after (Marshall, 1920), although the original idea dates back from (Dupuit, 1844). The MNL specification of a calibrated indirect, or observed, utility function can be viewed as the demand curve for a particular mode-destination alternative k in which a change in the choice attributes. For example, a price increase results in a change in consumer surplus. The logsum (the denominator of the MNL-model) can be interpreted as a measure of consumer surplus, i.e. Jara-Díaz & Farah (1988) review consumer surplus measures for transport markets and note that the logsum expected maximum utility measures supports consumer surplus calculations.

The difference in consumer surplus (CS), which is more relevant for economic evaluations (in which an alternative is compared with a reference situation), can be computed as the difference in the logsums of two (accessibility) scenarios, i.e. the difference in expected maximum utility between a base condition (the 'before' situation) V^1 and a scenario reflecting a policy change (the 'after' situation), V^2

$$\Delta CS = \ln(\sum_k e^{V_k^2}) - \ln(\sum_k e^{V_k^1}) \qquad \text{(Equation 6.1)}$$

Equation 6.1 expresses consumer surplus as the difference in utility. A cost metric difference in (Marshallian) consumer surplus can be calculated by defining the travel cost coefficient β as the scale parameter of the extreme value distribution (Miller, 1999). In relation to the doubly constrained spatial interaction model (see Equation 4.20), Williams (1976) derived the following Marshallian consumer surplus for a variation in transport costs.

$$\Delta CS = \frac{1}{\beta}\left[\sum_{i=1}^{n} O_i \ln\left(\frac{a_i^0}{a_i^1}\right) + \sum_{j=1}^{n} D_j \ln\left(\frac{b_j^0}{b_j^1}\right)\right] \qquad \text{(Equation 6.2)}$$

Where O_i is the number of trips generated at each zone i to all destinations j, D_j the number of trips attracted at each destination j, and a_i and b_j are the balancing factors of the doubly constrained spatial interaction model (Equations 4.5 and 4.6). According to Williams & Senior (1978), each term in Equation 6.2 represents users' benefits or land rents, depending on whether the traveller is assumed to be a job seeker (with fixed residence) or home seeker (with fixed job location). More recently, Martínez (1995) argued that the first term (with balancing factor a_i) is associated with accessibility from the trip origin, or the benefits of making trips, and the second term (with factor b_j) is associated with the attractiveness of the trip destination, or the benefits of receiving trips. Martínez & Araya (2000) interpret Equation 6.2 as a measure for the *short-run* benefits from a transport project (comparing two situations), where land use is fixed. By relaxing Williams' assumption of fixed land use, a measure for the *long-run* transport users' benefits can be derived, where O_i and D_j change between two situations of being with and without a project. Consumer surplus is than formulated as follows (Martínez & Araya, 2000):

$$\Delta CS = \frac{1}{\beta}\left[\sum_{i=1}^{n} \frac{(O_i^0 + O_i^1)}{2} \ln\left(\frac{a_i^0}{a_i^1}\right) + \sum_{j=1}^{n} D_j \frac{(D_j^0 + D_j^1)}{2} \ln\left(\frac{b_j^0}{b_j^1}\right) + (T^0 - T^1)\right] \qquad \text{(Equation 6.3)}$$

Where the first term can be interpreted as the benefit of new travellers generated at the origin locations, the second term as the benefit of new travellers attracted at the destination locations, both measured by a "pseudo-rule-of-half", and the last term as the benefit associated by the total trip generation. The difference with the original rule-of-half formulation (see box 6.1) is that this pseudo-rule does not assume a linear approximation of the trip-demand function (Martínez & Araya, 2000). Furthermore, it is stated that the long-run benefits generated by a transport project will be correctly forecasted (using Equation 6.3) *only* if the transport demand model used properly forecasts the combined land-use transport equilibrium, including land-use transport feedback's.

An alternative approach to Marshallian consumer surplus is to derive consumer welfare as an evaluation measure. In this approach, the changes in utility are related to income changes by using theoretical research from economics studies. There are two common methods to measure the change in welfare: *equivalent variation* and *compensating variation.* These measures were originally introduced by Hicks in a series of articles (Hicks, 1939; Hicks, 1940; Hicks, 1943; Hicks, 1945). Both measures describe the change in income (or amount of money) that offsets negative or positive effects of a price change (or project) (e.g. Johansson, 1987):

- Equivalent variation (EV) gives the minimum amount of money that must be given to (or the maximum amount of money that can be taken from) a household to make it as well off as it would have been *after* a change (in price). Thus, EV is a measure of someone's welfare change compared to the 'after' situation.
- Compensating variation (CV) indicates the maximum amount of money that can be taken from (or the minimum amount of money that must be given to) a household while leaving it just as well off as it was *before* the change. Thus, CV is a measure of someone's welfare changes compared to the 'before' situation.

Small & Rosen (1981) show that an estimation of consumer welfare using compensating variation (CV) can be derived in discrete choice situations for the multinomial logit model as:

$$\Delta CV = -\left(\frac{1}{\lambda}\right)\left[\ln(\sum_{k=1} e^{V_k})\right]_{V^1}^{V^2} \qquad \text{(Equation 6.4)}$$

where ΔCV is the compensation variation, λ the marginal utility of income, V_k the mean indirect utility of choice k, V^1 the mean indirect utility of scenario 1 and V^2 the mean indirect utility of scenario 2. Equation 6.3 estimates the income transfer required to maintain the same utility level using the new costs as a base. λ, the marginal utility of income, is used as the scale parameter to transform utility changes into income changes.

Although compensating variation has been used to estimate the change in consumer welfare in many applications, the measure has only recently been applied to evaluate accessibility scenarios. Niemeier (1997) and Handy & Niemeier (1997) use ΔCV as an accessibility measure to estimate the value (utility) people attach to mode-destination accessibility for a trip to work and translate this into monetary terms using compensating variation (CV). The compensating variation of average mode-destination accessibility (car and public transport only) is estimated by constructing, first, a policy change in which the car-destination alternative is eliminated by the choice set and, second, a policy change in which the public transport destination alternative is removed. This is equivalent to the equation:

$$CV = \left[-\frac{1}{\lambda} \right] \left[\ln(1 - P_k) \right] \qquad \text{(Equation 6.5)}$$

where P_k denotes the probability that choice k in the base scenario is selected and λ is the marginal utility of income, expressed as the cost of the trip divided by the household income. As a result, the change in consumer welfare for individuals or groups of individuals can be estimated for accessibility changes as a result of change in the transport system (restrictions in car and public transport trips) or the locations of activities (limiting in destination choices). For example, Niemeier (op. cit.) estimates that the compensation required to make an individual indifferent to the elimination of a home-work trip by car in King County, Washington, is more than US$5; for a public transit trip this is less than US$1. The compensation for the elimination of King County's Central Business District as a workplace came to about US$1.50 per car trip and $0.5 per public transit.

This method of analysing the user benefits of transport projects differs from the traditional method, in which the concept of consumer surplus is examined by applying the rule-of-half equation (See Box 6.1). In this traditional approach the willingness to pay for time gains is examined to estimate the generalised cost function. If potential accessibility measures are used to examine consumer surplus, reduced travel time or cost is represented by improved accessibility to opportunities, which essentially is a transformed measure of time reduction on transport links. Several authors (e.g. Neuburger, 1971; Williams, 1976) have shown that mathematically, the rule-of-half method and the potential accessibility measure (Equation 6.2) yield more or less the same estimation of consumer surplus. According to Neuburger, the disadvantage of the rule-of-half method is the assumption that the benefits arising from improved accessibility lie midway between their possible maximum and minimum, i.e. a straight-line demand curve is assumed. By using the non-linear shape of the demand curve implicitly used in travel demand models, a more correct measure of consumer surplus can be derived.

The use of a utility-based accessibility measure in the measurement of consumer surplus (using Equation 6.2) has important benefits, compared to standard cost-benefit analysis:

- The benefits of improved accessibility can be analysed as a result of (a) an improved transport system and (b) changes in the physical location of land uses. In terms of the potential accessibility measure used here, there is no practical difference between the two methods of changing accessibility. The method will measure them both, whether they occur separately or together (Neuburger, 1971). In traditional cost-benefit analysis only the benefits of an improved transport system, resulting in a reduction of travel times and/or costs, are analysed. Thus benefits of accessibility changes due to changes in land uses are not taken into account;
- The potential accessibility measure incorporates a land-use component, i.e. the research area is split up in regions. Therefore, the user benefits of changes in accessibility can also

be located to regions. Thus, this measure of consumer surplus can be used to analyse equity aspects, i.e. it can be used to analyse which individuals or groups of individuals living in certain locations benefit from changes in accessibility. Equity aspects are usually not treated in current cost-benefit analysis of transport projects (e.g. Eijgenraam *et al.*, 2000).

- A more correct measure of consumer surplus can be derived, because a non-linear pseudo-rule-of-half is used;
- Consumer surplus can be estimated in relation to the balancing factors of the doubly constrained spatial interaction model, thus incorporating competition effects on the demand and supply side (see also Section 4.3.5).

A disadvantage of this approach is that the theoretically correct use of utility-based accessibility measures for measuring consumer surplus of a transport project requires a transport model which properly forecasts the combined land-use transport equilibrium, including land-use and transport feedback's. However, applying a land-use transport model to compute consumer surplus is beyond the scope of this study. This will be taken up as an issue for further research.

6.3 Accessibility and the production function approach

6.3.1 Introduction

The previous section was concerned with measuring consumer benefits using activity-based accessibility measures. Another approach for assessing the wider economic benefits of accessibility, the production function approach, is related to the impacts of infrastructure on the performance (in terms of GDP) of specific sectors of the economy. According to Rietveld & Bruinsma (1998), in this production function approach, the cost-benefit analysis method for analysing welfare effects is criticised because (a) the outcome may depend highly on travel-time savings of households, which do not have implications for GDP, and (b) strategic long-term macro economic benefits, which are only partially taken into account in a CBA.

6.3.2 Applications

Since the 1980s several studies have analysed the contribution of infrastructural improvements on productivity. In this approach, transport infrastructure is considered as a stock of a certain type of capital available to a region or country. See Rietveld & Bruinsma (1998), Sactra (1999) and Banister & Berechman (2000) for an overview of studies. The way infrastructure is dealt with strongly differs among studies. Detailed treatments of infrastructure are given by Blum (1982), Andersson *et al.*, 1989), Johansson (1993) and Forslund & Johansson (1995). Johansson (1993) and Forslund & Johansson (1995) do not directly include road infrastructure in the production function but instead include improved accessibility conditions. Johansson (1993) estimates several production functions for the manufacturing industry as a whole, and for subsectors of the manufacturing industry (engineering and forest-based industry) in Swedish municipalities. For the manufacturing industry as a whole: 11 feasible production functions were estimated. Four variables were found to be robust (i.e. they are statistically significant in several functions):

- the capacity of the road system, i.e. a ‘density’ index of the road system of municipalities taking capacity and driving speed into account;
- the capacity of the public transport system, i.e. an index taking the number of available seats, distance travelled and number of workplaces in municipalities into account;
- the regional accessibility, i.e. potential accessibility to the population;
- a variable describing ‘international freight accessibility’, i.e. a time–distance index to major ports via the road network.

In a later publication, Forslund & Johansson (1995) compare the economic impacts of national road investment programmes using the production function approach and a CBA including expected timesavings and reduced accident rates. Along with other factors, the production function includes the road system capacity and the variable describing ‘international freight accessibility’. The authors conclude that the production function approach and the CBA method partly overlap (i.e. the production function approach does not include all welfare benefits), but the two measures yield consistent results.

Recently, a study by Prud'homme & Lee (1999), of Paris and other French cities, suggest that transport infrastructure improvements (road and/or public transport) which successfully increase travel speed over the network as a whole would widen the labour market and in turn increase productivity, i.e. a 10% increase in travel speed, containing sprawl, would increase productivity by about 3%. In this study, productivity is a function of the ‘effective’ labour market size. The ‘effective’ labour market size is a function of (i) the size of the labour market, defined as the number of jobs within a certain travel time, (i) the geography of the area, or sprawl, defined as the average potential job-home distances for enterprises between all zones, (ii) the efficiency of the transport sector, defined as the average speed at which trips are made. Although the study provides interesting results, it raises a number of the questions. Firstly, average travel speed in a city can probably not be increased without increasing sprawl (in this case job-home travel distances) (e.g. see Mogridge, 1997). Secondly, the elasticities have been estimated using a relatively small sample of cities (22 French cities). As a result, the results may not, because of local conditions, be interpreted as a generic rule of thumb for analysing wider economic impacts of transport investments. Thirdly, the impact of improvements of the effective labour market size on productivity is probably not constant in time (i.e. diminishing returns can be expected), thus the derived elasticities can not just be used in forecasting impacts of transport investments on productivity changes.

Furthermore, a European study on the relationships between infrastructure, accessibility and economic development (in terms of GDP) was conducted within the framework of the EU project ‘Socio-Economic and Spatial Impacts of Transport Infrastructure Investments and Transport System Improvements’ (SASI) (Fürst et al., 1999; Fürst et al., 2000; Wegener et al., 2000b) For this project a simulation model was developed in which the socio-economic impacts of transport infrastructure investments and transport system improvements for 201 regions in Europe can be estimated. The model comprises several submodels forecasting developments in regional population, labour force, (un)employment, GDP, and accessibility for the European Union up to 2016. The production functions used estimate GDP for three industrial sectors (agriculture, manufacturing, services) for each region as a function of economic structure, labour force, endowment indicators (measuring the suitability or capacity of a region for economic activity, e.g. natural conditions, educational skills of the population) and accessibility indicators. The production function for each sector was calibrated using 1981 data from 193 regions using multiple non-linear regression techniques[1].

Fürst *et al.* (1999) analysed the relationships between activity-based accessibility measures and GDP per capita to select accessibility measures for inclusion in the production functions, based on their degree of explanation of GDP. More specifically, correlations were analysed (using bivariate regression analysis) between accessibility measures and GDP per capita for three economic sectors (agriculture, manufacturing, and services) using data from 201 European regions[2] for the years 1981, 1986, 1991 and 1996. The accessibility measures are estimated using raster-based GIS technology (see Spiekermann & Wegener, 1994; 1996; 1999 - see also Section 3.3). The following accessibility measures were analysed:

(1) Average travel time: average travel time for a fixed population (250,000 or 1,000,000) by road, rail, air and fastest mode;
(2) Daily accessibility: population which can be reached within five hours for one-way travel time by road, rail, air and fastest mode;
(3) Potential accessibility: population potential by road, rail, air, fastest mode and composite or logsum travel times for road and rail, and for road, rail and air (see Section 4.3.4). The potential accessibility is estimated using two different (negative exponential) impedance functions, i.e. using a impedance parameter (β) of 0.003 and 0.007;

Fürst concludes that the correlation between the accessibility measures and GDP per capita is much less than for the manufacturing and service sectors. For the manufacturing sector the correlation with road and rail accessibility or combinations (composite travel time) is relatively high (correlations between 0.2 and 0.5), whereas the correlation with air transport is low (correlations between 0.1 and 0.2). For the service sector, correlation is highest with accessibility by air transport and aggregations, including air transport. Interestingly, the differences between the different activity-based accessibility measures in explaining GDP per capita are not very large. Overall, the contour measures (daily accessibility and average travel time) have somewhat lower correlations than the potential accessibility measures. The potential accessibility measure with composite travel times has the highest correlation with GDP per capita. A potential accessibility measure with composite travel times for road and

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[1] The correlation (r^2) between estimated and observed GDP for the three sectoral models is considered relatively high: between 0.6 and 0.8 (Fürst et al, 2000).

[2] Some regions (outliers) were excluded from the analysis, i.e. regions in the former East Germany, Finland and Sweden.

rail was selected for inclusion in the production function for the manufacturing and agricultural sectors, and a potential accessibility measure with composite travel times for road, rail and air (using a steeper impedance function, $\beta = 0.007$) for the services sector.

Furthermore, Fürst analysed the relationships between GDP per capita by sector and the selected accessibility measures over time, i.e. for the period 1981-1996. Figure 6.2 and 6.3 show the relationships between GDP for the manufacturing and service sector over time, where accessibility and GDP are standardised for 1981 and 1996 to the European averages, i.e. relative changes are shown..

Figure 6.2 and Figure 6.3 show a considerable change in the position of the regions over time, and show the changes in accessibility to be much smaller (up to 10 percentage points) than the changes in GDP per capita.

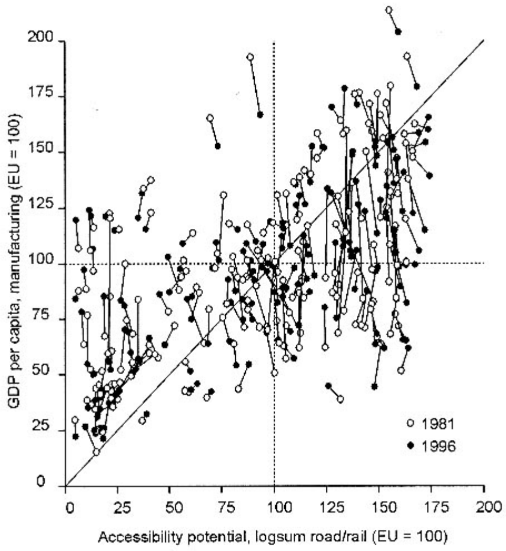

Figure 6.2: Relationship between potential accessibility and GDP per capita for the manufacturing sector in Europe (Fürst et al., 1999).

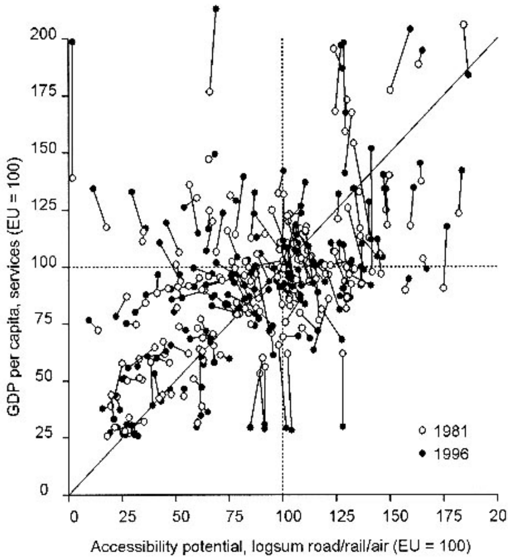

Figure 6.3: Relationship between potential accessibility and GDP per capita for the service sector in European regions (Fürst et al., 1999).

The SASI model is applied to several infrastructure scenarios for the 1996-2016 period, i.e. a do-nothing scenario and network policy scenarios containing assumptions on the overall development strategies for the Trans-European Networks (TEN). Figure 6.4 shows the relative changes in potential accessibility (using composite road/rail travel times) in the 1996-2016 assuming all road and rail infrastructure links of the TEN network to be implemented (scenario 10), compared to the do-nothing scenario (scenario 00). All European regions experience accessibility gains from TEN investments, but if the differences in percentage points are standardised on the European average, relative losses can be expected from TEN investments of roughly three to four percentage points in the core regions (The Netherlands, Belgium), whereas most of the peripheral regions, especially in the Southwest of Europe encounter the most positive effects. Figure 6.5 shows how the TEN investments translate into regional economic performance by considering percentage changes in GDP per capita, compared to the do-nothing scenario. The figure shows that most regions in the European core and northern European regions encounter losses in GDP from TEN investments, while most regions at the periphery receive considerable gains. As overall European GDP is put exogeniously in the model, very high accessibility gains of peripheral regions give these regions a comparative advantage that negatively affects regional economic development in less successful regions.

To the authors' knowledge, the SASI study is the only study which forecasts the impacts of infrastructure improvements on (regional) economic development, based on empirically derived productivity functions with *activity-based* accessibility measures as a variable. In the literature some models are described that forecast (regional) economic development incorporating *infrastructure-based* accessibility measures into the production function, e.g. the Dutch "Mobilec" model describes the relationships between the regional economy, infrastructure, travel costs, and other regional characteristics (Van de Vooren, 1998).

However, the SASI study not without methodological problems. Firstly, it is questionable if relationships between infrastructure, accessibility and economic development from the past (in the SASI study 1981-1996) may be directly extrapolated into the future. In general, there are diminishing returns to transport infrastructure investments (Sactra, 1999), i.e. additional accessibility gains of infrastructure improvements will not result in the same amount of productivity gains. Secondly, the question can be raised whether the assumption of a fixed (exogenous) overall European GDP development is plausible. As a result is this 'zero-sum game', strong accessibility developments in (peripheral) regions as a result of transport infrastructure improvement result in negatively affects regional economic developments in other regions. Although a 'two-way road' argument is, as Sactra (1999) notes, consistent with economic theory, i.e. improved accessibility between countries or regions may sometimes benefit one of them to the disbenefit of the other, this does not necessarily have to result in a zero-sum effect. Transport investments may in theory, besides locational impacts, also bring net economic gains, e.g. if they result in lower purchasing prices for customers or in "economies of scale". Ideally, in economic impact analysis of transport infrastructure one would want to include both distributional (locational) impacts as generative impacts as feedback loops.

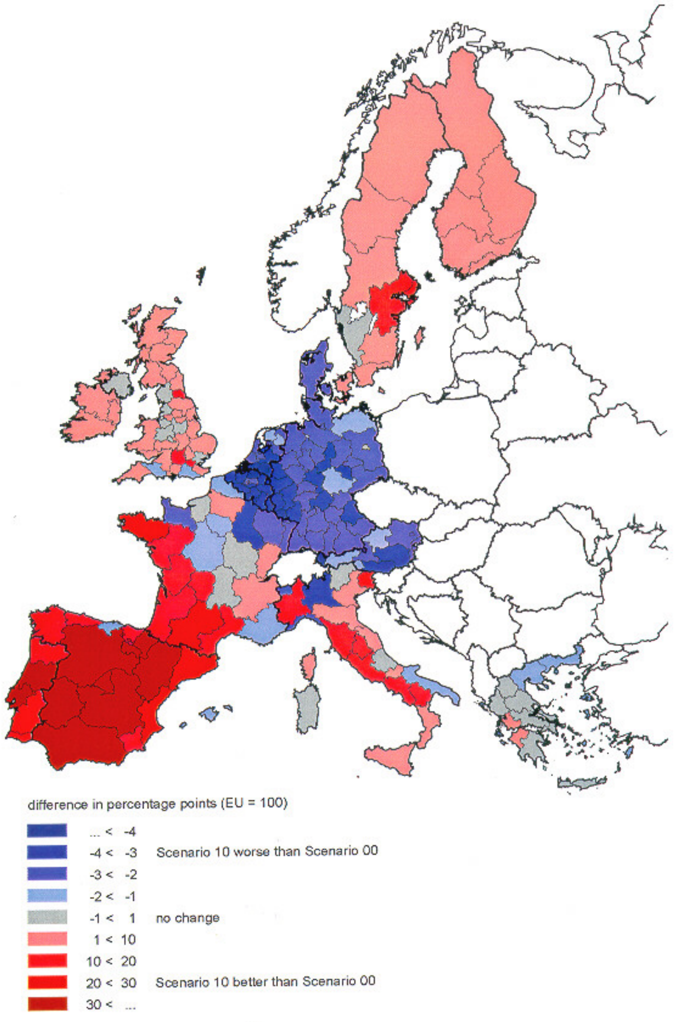

Figure 6.4: Changes in potential accessibility (using composite road/rail travel times) as a result of the planned TEN road and railway projects (Fürst *et al*., 2000).

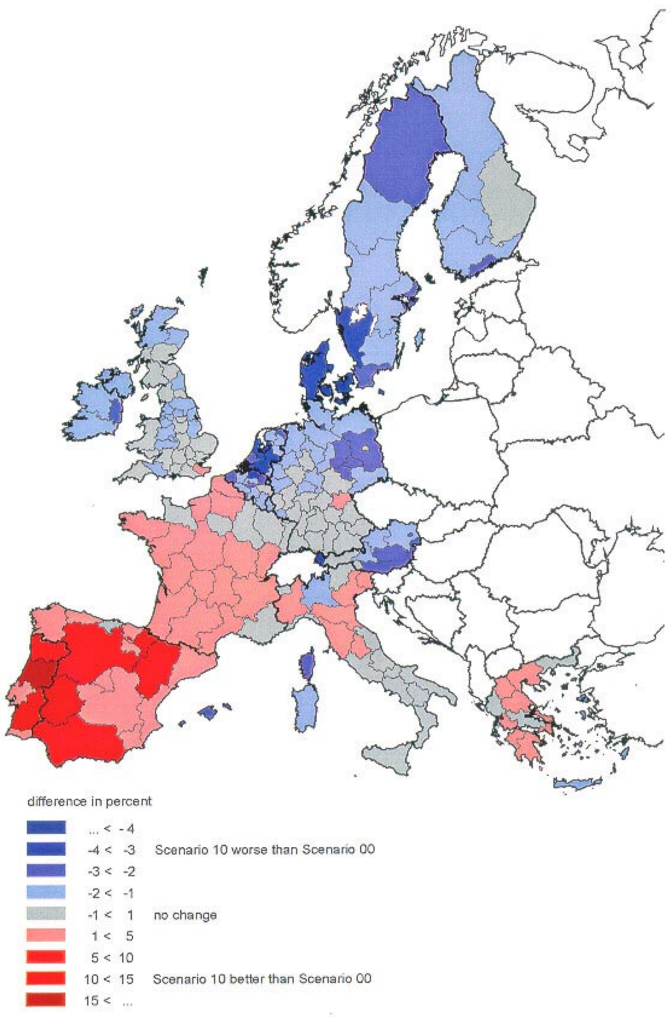

Figure 6.5: Changes in GDP per capita as a result of the planned TEN road and railway projects (Fürst *et al*., 2000).

6.3.3 Discussion

The link between infrastructure, accessibility and economic development has been debated over many years. See for recent overviews Rietveld & Bruinsma, 1998; SACTRA, 1999; Banister & Berechman, 2000; and ECMT, 2001. Economic theory indicates that transport infrastructure improvements could, in principle, improve economic performance, including increases in output resulting from lower costs of production, improvement of labour market catchment areas and hence on labour costs, unlocking' inaccessible sites for development, triggering growth which in turn stimulates further growth, contributes to productivity of private production factors. The empirical evidence on the size and nature of the impacts is limited, however, weak and disputed (Sactra, 1999). Infrastructure investments have some positive impacts on economic growth and private sectors productivity, but the magnitude and significance of estimated effects are far from being conclusive (Banister & Berechman, 2000). Furthermore, the impact on other production factors (labour, private capital) is subject to rather complex mechanisms with positive and negative feed-back loops, the net outcome of which is rather unknown (Rietveld & Bruinsma, 1998). Thus, the theoretical wider economic effects of transport investments can exist in reality, but none of them is guaranteed, and they are strongly dependent on specific local circumstances and conditions. Berechman (2001) concludes that transport projects can not be justified only by its contribution to productivity improvements or economic development, this would likely lead to adoption of inferior projects.

In literature, most empirical studies using the production function approach have estimated the effects of total public capital on economic growth and productivity. Much less studies have directly examined the impacts on transport infrastructure development on productivity and economic growth (e.g. see Banister & Berechman, 2000). Very little studies examined the impacts of activity-based accessibility measures on productivity and economic growth. Only the SASI study was found to forecasts the impacts of infrastructure improvements on (regional) economic development using activity-based accessibility measures as variable in the production function approach. Further research is necessary to determine how this approach can be used to examine the wider economic impacts of accessibility improvements.

6.4 Accessibility and employment

Another approach for analysing economic impacts of accessibility is to focus on employment. The employment effects of infrastructure are a special subject of interest in countries with high levels of structural unemployment where job creation is considered of prime interest. Infrastructure investments may have temporary and non-temporary employment effects on the demand side, i.e. employment from the construction phase and operations and maintenance. Furthermore, non-temporary employment effects on the supply side may occur via (a) substitution and complementarily relationships between labour, private capital and infrastructure and (b) differences in regional growth rates due to differences in advantages received from infrastructural improvements. Infrastructure investments usually have only temporary employment effects, which if included in economic evaluations, result in double counting of effects (Kandel & Poort, 2000). Non-temporary employment impacts of transport investments may be positive or negative. One the one hand, if transport developments result in increased labour productivity in some economic sectors in some locations, this may reduce employment as less workers would be needed to produce a given level of output. On the other hand, productivity gains in these sectors may result in lower output prices, thus consumers' disposable income rise and more money is spent on buying other products, thereby creating jobs in other sectors or regions (Banister & Berechman, 2000). Thus, the spatial dimension is often very relevant in analysing non-temporary employment impacts: transport infrastructure investments have spatially differentiated impacts on employment.

An example of a study on employment effects is from Bruinsma *et al.* (1997) and Rietveld & Bruinsma (1998), who investigated the relationship between highway construction, potential accessibility to employment and regional employment (40 regions) in the Netherlands for the 1970-1990 period. In this study, the changes of the potential accessibility measure only reflects the changes in infrastructure; the mass (employment) is kept constant. They conclude that there is no evidence that the construction of main-road infrastructure in the Netherlands and the resulting change in accessibility has a clear impact on overall regional employment. There is no simple mono-causal relationship between the development of accessibility and employment; the regions showing the highest employment growth do not show the highest growth in accessibility.

In general, employment effects are often an important issue in policy decisions of infrastructure projects, especially in periods or regions with chronic underemployment. However, employment effects are usually excluded from economic impact analysis because of large uncertainties. That is, employment effects are usually temporary and distributive (re-allocation of existing jobs between regions), which included would result in double counting of economic effects. Bruinsma & Rietveld (1998) conclude that employment effects are too narrow to be the sole basis for economic impact analysis of infrastructure and related accessibility changes. In other words, transport investments can not be justified by job creation only.

6.5 Accessibility and non-user benefits

6.5.1 Introduction

The consumer surplus approach in cost-benefit analysis of transport projects analyses user benefits. The non-user or non-traveller benefits for people (e.g. people living in the vicinity of transport infrastructure) are usually not included in economic evaluations of land-use and/or infrastructure projects. Non-user values can be split into (a) option values and (b) bequest values (Pearce & Turner, 1990).

Option value refers to goods or services that are used as a backup for another good or service, or that will be valuable in the future: e.g. public transport has an option value to those who would use it if the car broke down (Hansen & Beimborn, 1987). Furthermore, the existence of infrastructure may have an impact on the entrepreneurial perceptions of a region's accessibility and the willingness of an enterprise to invest or locate in the future, and on the hedonic price of property values and recreational sites, etc. (Lakshmanan *et al.*, 1997). Accessibility may also have an option value: people not only value a transport mode for the actual use in accessing destinations but probably also for accessing opportunities in the future. As an illustration, car owners who make little use of their cars have very high user costs per kilometre (fixed costs are currently about two-thirds of the total car costs in the Netherlands - Geurs & Van Wee, 1997) compared to alternative modes. An important reason people keep their car instead of using cheaper alternatives could be that the option value of potential access to opportunities is much higher for cars than for alternative modes, e.g. Geurs & Ritsema van Eck (2000) showed that the number of job opportunities which can be accessed within 45 minutes travel time by car in 1995 is – on average for the Netherlands - about 15 times greater by public transport.

Bequest values refers to goods and services for which individuals (users and non-users) would be willing to pay to assure that these services are available to *other people* – living now or in the future. Bequest values are motivated by some form of altruism. Firstly, people might value public transport for making their homes accessible to (non-car owning) visitors, thus benefit from the mode as a non-user. Secondly, a non-user might value a transport mode for reasons of altruism, e.g. public transport gives other people a basic level of access to social and economic opportunities. Thirdly, people might value the existence of alternative modes because this influences their benefits as users of another mode, i.e. car drivers might value public transport for reducing congestion on the road network. Thus, bequest values might involve user and non-user values. This is illustrated in Table 6.1, showing that non-user benefits may include an option value and a bequest value, and that bequest values may comprise both user and non-user benefits.

Table 6.1: Relationship between user and non-user benefits, option and bequest values

	option value	bequest value
user benefit		X
non-user benefit	X	X

The option value concept and its relationship with accessibility is further described in Sections 6.5.2 and 6.5.3. Sections 6.5.4 and 6.5.5 are devoted to methodologies for measuring non-user values.

6.5.2 The option value concept

The concept 'option value' was introduced by Weisbrod (1964) who argued that an individual who was unsure of whether he would visit, say, a national park would be willing to pay a sum in excess of his expected consumer surplus to ensure that the park would be available. Up to now, option values are frequently used in financial markets, for example, when the right to sell or buy in the future at a given price are bargained (Roson, 2000), and in the valuation of environmental resources, which may or may not be enjoyed in future, e.g. Johansson (1991), Johansson (1987), Pearce (1991) and Smith (1983).

According to Johansson (1987, 1991), there has been much discussion about the precise definition of option value. He distinguishes two different interpretations; the first interpretation links option value to the idea of a *risk premium* arising from uncertainty as to the future value of an option. Johansson relates this interpretation of option value to the concept of consumer surplus, i.e. option value is defined as the difference between the ‘option price’ and the ‘expected consumer surplus’. The ‘option price’ is the maximum sum of money the consumer is willing to pay for retaining the good, and the ‘expected consumer surplus’ (or the expected compensating variation) is obtained by multiplying the consumer’s surplus by the probability that the good cannot be consumed in the future. Thus, the expected consumer surplus of a good will underestimate the maximum price (option price) a consumer is willing to pay. This is because the option price (OP) measures both (a) the value of retaining an option to consume the good in future (OV) and (b) the expected value of actually consuming the good - the consumer surplus (CS), i.e.:

$$OP = CS + OV \qquad \text{(Equation 6.6)}$$

This view of the option value has been described by such authors as Bishop (1982), (Freeman, 1985) and (Plummer & Hartman, 1986).

A different concept of option value, called a ‘quasi-option value’, focuses on the intertemporal aspects and the *irreversibility* of any decision to close down an option and convert it to alternative uses. By delaying a decision to close down an option, one may obtain more information about the uncertain consequences, and this information has a value. This concept has been developed by Arrow & Fisher (1974) and (Henry, 1974) in the context of preservation of natural resources. See, for example, Hanemann (1989) for the relationship with Weisbrod’s option value interpretation.

6.5.3 Applications of the option value approach in transport

The concept of option values has received little consideration in theoretical and practical transport studies. Pearce (1991) gives an overview (of the few) American studies who separated option value from the overall willingness-to-pay concept of option price (i.e. only the option price is estimated) in estimating non-use values of environmental or ecological assets (e.g. groundwater quality, wilderness). He concludes that although the empirical literature is still in its infancy for the evaluation of environmental impacts of transport policies, it does suggest that non-use values are potentially important relative-to-use values.

In the context of evaluations of (subsidies of) infrastructure investments, a few authors use the option value concept. In this context, public transport is valued on the basis of the potential utilisation, rather than on its actual use. Recently, Roson (2000) argued that the existence of an option value for public transport might explain the willingness to pay, through public funds, for public transport services that are little used. He analysed the effects of different levels of subsidisation of public buses on urban transport in Bologna, Italy, using a model that maximises social welfare (consumer's and producer's surplus) and the net of external costs of accidents, road maintenance and emissions. The assessment of pricing policies in urban transport is concluded to critically depend on the interpretation of the subsidisation of public services, i.e. including subsidisation as an option value in the model to justify the potential use of public transport strongly affects the result.

Another approach is from Emery & McKenzie (1996), who analysed the subsidy to the Canadian Pacific Railway (CPR) Company's first transcontinental railway using a quasi-option value approach. This railway was subsidised by the Canadian government and was 'built ahead of demand' in the period, 1881-1885. The authors concluded that the subsidy was required to compensate the railway company for constructing the line at a less than optimal time from a private enterprise point of view.

6.5.4 Measurement of non-use values

In general, the willingness to pay for public goods may be measured (Johansson, 1991):

- directly by survey data;
- indirectly from market data.

In surveys, respondents are asked *directly* how much they are willing to pay for a change in the provision of a public good, or about the minimum compensation consumers require if the change is not carried out. According to Baarsma (2000), all stated preference methods are capable of measuring the total value of a good, including non-use values. For example, Wardman *et al*. (1997) conducted a Stated Preference study for estimating the monetary values (willingness to pay for improvements) of environmental quality and accessibility (expressed in amount of time spent travelling in a car or bus) of households and firms in Edinburgh, Scotland. A well-known method, which is used in economic valuation of non-use goods is Contingent Valuation, was introduced in the 1960s. This method attempts to estimate individual values for economic goods by asking people hypothetical questions about their willingness to pay for a change in the condition of some environmental resource (Mitchell & Carson, 1989). Contingent Valuation (CV) is probably the most popular method for the evaluation of environmental effects (especially in nature areas); several thousands of CV studies have been conducted. To a large extent, this popularity is caused by legislative developments in the United States (Baarsma, 2000). Although the method is very popular, it is also subject to criticism. A book edited by Hausman (1993), comprising conference papers by leading economists, raises several objections to the use of CV in valuing non-use goods. The most relevant points of critique are:

- CV does not properly measure the value of goods with a strong non-use component. These are goods for which the respondent has little experience and for which the context cannot be made to look like a realistic choice context (McFadden & Leonard, 1993);

- CV results are extremely sensitive to the survey design and interpretation. However, a clear basis for selecting among different survey designs does not exist because there is no clear link between the results of CV surveys and underlying preferences (Diamond & Hausman, 1993).

Willingness to pay can be estimated *indirectly* by using the property-value approach, i.e. the price of a unit of housing can be viewed as a function of a number of characteristics such as housing-structure variables, neighbourhood characteristics and accessibility variables. Implicit or hedonic prices for each attribute can be determined by examining home prices and attribute levels. However, according to Freeman-III (1993), revealed preference methods, like travel cost methods and the hedonic price method, are not capable of measuring non-use values, because non-use values are not reflected in market transactions. However, the non-user benefits of transport modes can be analysed using the hedonic price method. For example, a study in San Francisco showed that the non-user benefits to residents living close to transit rail stations of the Bay Area Rapid Transit (BART) (i.e. time savings and higher willingness to pay for properties) accounted for up to 50% of the observed property value premium (Lewis-Workman & Brod, 1997).

6.5.5 Measurement of non-user benefits of accessibility

There are very few examples of transport studies analysing non-user values of transportation. The studies available only consider the option value of public transport, measured by the level of subsidy. To the authors' knowledge, there are no studies analysing the option value of other modes (car and non-motorised modes); furthermore, the option value concept has not yet been applied to accessibility. However, accessibility may also have an option value: people not only value a transport mode for the actual destinations they access with that mode, but probably also value access to destinations which may be used in the future. Furthermore, some people might also value a housing location in a central urban area for its high accessibility level to different activities (e.g. shops, theatres, etc.), although they might not often actually participate in those activities.

There is probably not one methodology for estimating option values of transport modes or accessibility of locations. Hansen & Beimborn (1987) suggest that option value benefits (of public transit services) can also be measured by the random utility concept usually used for estimating user benefits. The main difference is that the probability that non-users will have to resort to another mode (e.g. when the car is not available or desirable) must be factored in. This probability can be an increasing function of public transport supply levels (Roson, 2000). If this method is applied, the option value of accessing a specific destination can be derived by multiplying the average user consumer surplus of that destination by the probability of a non-user's accessing the destination in future. Compensating variation may be used to derive monetary values for the option value of a mode-destination choice. Thus, non-user benefits are derived by estimating the amount of compensation a non-user would need to become indifferent to the elimination of a potential destination from his choice set. However, the value of compensation cannot be estimated directly from observed travel behaviour (revealed preference data), because these data do not provide insights in the number an individual benefits from (or is willing to pay for) accessing a potential destination in future. If the average user consumer surplus of accessing a location is used as a proxy for non-user benefit, the non-user benefits are probably overestimated. Thus, it does not seem realistic to derive option value benefits from observed travel behaviour and thus from user benefits.

Alternatively, (a) stated preference methods (contingent valuation) or (b) hedonic pricing methods could be used to value non-user benefits, including option values (see Section 6.5.4). However, both methods are not without methodological problems. Current practice of *stated preference studies* show that it is difficult to derive plausible estimations of the willingness-to-pay for the option-value goods or services in stated preference surveys, i.e. the respondent has little experience with the good or service and thus it is difficult to create a realistic choice context in the survey. *Hedonic pricing methods* could be used to analyse the willingness-to-pay for locations with different potential accessibility levels using a specific mode. Furthermore, the ‘option value’ benefits could, in theory, be specified as the difference between (a) activity-based accessibility (e.g. using a potential accessibility or contour measure), expressing the potential number of opportunities which can be accessed, and (b) the actual number of opportunities accessed (using travel behaviour data). However, it is uncertain if this approach is fruitful, as no studies are found analysing the relationships between option values, potential accessibility and hedonic pricing. A complication factor is the fact that, in practice, housing prices are not the result of a perfectly functioning market from an economic point of view. Housing supply does not perfectly match with housing demand, e.g. as a result of institutional and individual barriers. Thus, people’s preferences (including option values) are not fully reflected in location choices and home prices. However, an indication that option values of accessibility can help to explain home prises or rents is found in the hedonic pricing study by Kockelman (1997) (see also Section 5.3.1). The author found that in addition to travel behaviour attributes (e.g. travel time to work), potential accessibility to work is a highly statistically significant attribute in explaining home prices and rents.

To the author’s opinion, non-user values of transport modes and accessibility of housing locations can probably be the most easily qualitatively analysed by conducting Stated Preference studies. However, a plausible quantitative estimation of non-user values in economic evaluations of land-use infrastructural changes will probably be difficult to derive.

6.6 Conclusions

6.6.1 The role of accessibility in different approaches for analysing economic impacts

Increased accessibility as a result of a change in the transport system or land uses can have several economic impacts. In the literature, different approaches for analysing economic impacts of infrastructure and accessibility exist. Basically, three approaches can be identified, in which different types of accessibility measures may play a role:

- A social cost-benefit analysis (CBA) of transport projects;
- A production function approach with GDP as the main object;
- An approach focusing on employment effects.

These three approaches are partly complementary (e.g. consumer benefits and external costs are included in a CBA, but not in the production function), partly overlapping (e.g. benefits of business traffic and freight transport are included in the CBA and the production function) and partly conflicting (e.g. increased productivity may reduce employment).

In a *social cost-benefit analysis* (CBA) the main object of study is consumer surplus. Several authors have shown that utility-based accessibility measures can be used to estimate consumer surplus. By taking the natural logarithm of a potential accessibility measure (using a negative exponential distance decay function), essentially a measure of consumers' surplus (expressed in utility) is derived. These utilities can be translated into monetary values using the compensating variation concept. This approach has important benefits:

- The benefits of improved accessibility can be analysed as a result of (a) an improved transport system and (b) changes in the physical location of land uses. In traditional cost-benefit analysis only the benefits of an improved transport system, resulting in a reduction of travel times and/or costs, are analysed. Thus benefits of accessibility changes due to changes in land uses are not taken into account;
- Utility-based accessibility measure incorporate a land-use component, i.e. accessibility is analysed for regions or zones. Therefore, the user benefits of changes in accessibility can also be located to regions. So this measure of consumer surplus can be used to analyse equity aspects, i.e. it can be used to analyse which individuals or groups of individuals living at certain locations benefit from changes in accessibility.
- Consumer surplus can be estimated in relation to the balancing factors of the doubly constrained spatial interaction model, thus incorporating competition effects on the demand and supply side;
- A more correct measure of consumer surplus can be derived (compared to standard cost-benefit analysis), because a non-linear pseudo-rule-of-half is used.

The *production function approach* is sometimes used to assess the wider economic benefits of accessibility. This approach analyses the impacts of infrastructure on the performance (in terms of GDP) of specific sectors of the macro-economy. Only a few studies are found to incorporate activity-based accessibility measures into the production function model. This has the advantage of allowing one to use the production function model directly for the economic evaluation of infrastructure expansion schemes. However, the relationships between infrastructure improvements, accessibility and economic development are theoretically complex, and empirical evidence is still weak and disputed. As a result, the production function approach might over- or under-estimate the impact of accessibility improvements on economic development. Further research is necessary to determine how this approach can be used to examine the wider economic impacts of accessibility improvements.

Another approach which is sometimes taken is to analyse the *employment effects* of infrastructure projects. Employment effects are often considered important in the analysis of infrastructure projects, especially in periods or regions with chronic underemployment. However, employment effects of a typical transport project are generally considered to be only temporary and distributive (i.e. a re-allocation of existing jobs).

In conclusion, cost-benefit analysis can be considered the primary method for evaluation of the economic impacts of accessibility changes of land-use and transport projects or scenarios. The CBA-methodology is consistent with micro-economic theory, and in general, transport projects can be justified if they generate sufficient user benefits. However, further research is necessary to examine the value added of using utility-based accessibility measures in cost-benefit analysis of land-use and transport projects. Especially, the theoretically correct use of utility-based accessibility measures for measuring consumer surplus of a transport project requires a transport model which properly forecasts the combined land-use transport equilibrium, including land-use and transport feedback's.

Evaluation of wider economic impacts of accessibility changes using production function models is theoretically complex and results of existing studies are much debated. In general, transport projects can not be justified on the basis of economic growth only. Although some studies conclude that the production-potential approach and the CBA method yield consistent results, further research is necessary to determine how the production function approach can be used to examine broader economic effects not included in cost-benefit analysis without doubly counting positive effects.

Evaluation of employment impacts of transport projects is also subject of scientific debate. The general opinion is that the employment impact of a typical transport project is only temporary and distributive. Furthermore, transport investments can not be justified on the basis of positive employment effects only. To include employment effects in the economic evaluation in combination with CBA introduces the risk of double counting effects.

6.6.2 Accessibility and the evaluation of non-user values

In general, benefits from the land-use transport system occur to both users and non-users. User benefits of transport projects are commonly evaluated with the consumer-surplus approach. Non-user benefits of transport infrastructure may include an option value and bequest value. Option value refers to goods or services that non-users may benefit from having it available as a backup for another good or service, or having it available in the future. Accessibility may also have an option value: people not only value a transport mode for the actual use in accessing destinations, but probably also for accessing opportunities in the future. Bequest values refer to goods or services for which individuals are willing to pay to assure these services are available to other people. Accessibility may also have a bequest value: people may value public transport for making their homes accessible to (non-car owning) visitors.

In practice it will prove to be very difficult to include non-user values in economic evaluations of changes in accessibility. Non-user values cannot be derived directly from revealed preference data. More specifically, the option value of accessing a specific mode-destination choice cannot be derived with the consumer surplus approach, because the willingness to pay for a non-user cannot be estimated from observed travel behaviour. In theory, alternative (indirect) methods such as contingent valuation or hedonic pricing methods could be used to value non-user benefits, including option values. However, in practice it has shown to be difficult to derive plausible estimations of the willingness-to-pay for the option-value goods or services in stated preference surveys. In other words, the respondent has little experience with the good or service and thus it is difficult to create a realistic choice context in the survey. Using hedonic pricing methods, we may derive an indication of the option value of accessibility to opportunities as willingness-to-pay for locations with different potential accessibility levels to opportunities, and different actual accessibility indicators can be analysed. However, further research is necessary to determine the role of non-user values in willingness-to-pay for locations.

In conclusion, non-user values of transport modes and potential accessibility of locations can probably be qualitatively analysed by Stated Preference studies. However, a plausible quantitative estimation of non-user values in economic evaluations of land-use infrastructural changes will probably be difficult to derive.

7. Accessibility as a social indicator

7.1 Introduction

This section discusses the use of activity-based accessibility measures in the evaluation of the social implications of (alternative) land-use and transport policy plans or transport scenarios. Evaluations of the social impacts of transport scenarios can be categorised into three groups (see Geurs, 2000):

(a) The level of access to opportunities, e.g. jobs, schools, shops, hospitals;
(b) Equity issues of transport, i.e. differences in costs and benefits derived from the land-use transport system;
(c) The impacts of transport on (the functioning of) individuals or groups of individuals, e.g. transport-related health problems (caused by emissions, noise), traffic safety, social relationships, or impacts on specific groups, e.g. disadvantaged groups, people with disabilities, pedestrians, cyclists and the elderly.

This section focuses on the first two subjects (opportunity and equity) because of the relationship to accessibility. Namely, the land-use transport system, in general, gives people the opportunity to access goods, services and activities, which provides them with social and economic benefits. Furthermore, the level of accessibility to opportunities influences the locations where people choose to live, work, go to school and recreate. The level of access to opportunities also has economic implications for individuals, i.e. it may influence people’s standard of living, well being and welfare.

Recently, several authors have proposed integration of equity impacts in economic evaluations of transport projects. In standard social cost-benefit analysis of infrastructural projects, the net societal benefits of policy plans and projects are analysed; individuals’ gains and losses (transfers in economic terms) do not affect the aggregate result. However, the distribution of cost and benefits among people and firms are very important in the political decision-making process (Bruinsma & Rietveld, 2000). Moreover, including equity in economic evaluations has the advantage that efficiency and equity issues are separated, while otherwise they would be mixed. Since transfers cannot be ignored or excluded, it is better to include them explicitly in the analysis (Lee, 2000).

Table 7.1 shows a matrix of economic and other evaluation methods, and economic and social indicators. Economic evaluation methods (i.e. cost-benefit analysis, production function approach, employment – see Section 6.1) are seen to be used as social indicators if the distribution of costs and benefit regions and societal groups are analysed. Furthermore, social indicators can be used an input in the economic evaluation, i.e. traffic safety may be included in a cost-benefit analysis through valuation of the economic costs of traffic casualties.

Table 7.1: Economic evaluation methods, and economic and social indicators

indicator evaluation method	economic indicators	social indicators
economic evaluation methods	☐ consumer surplus; consumer welfare ☐ employment ☐ GDP	☐ equity aspects: distribution of economic costs and benefits among regions, societal groups
other evaluation methods		☐ access to opportunities ☐ health, traffic safety ☐ equity: differences in opportunities, health impacts

7.2 Opportunities

The spatial distribution of land-use activities and the level of service of the transport system (i.e. land-use transport system) determine the amount of access people have to all kinds of activities (e.g. employment, education, recreational areas, retail outlets, health services, social opportunities) and thus influence people's social and economic opportunities. Activity-based accessibility measures are very suitable to evaluate these social implications, expressing the number of opportunities within a person can reach from a given location. More specific, activity-based measures can be used to evaluate possible social impacts of changes in the land-use transport system, for example, as a result of policy measures (e.g. expansion of road or rail infrastructure) or other developments (e.g. urban sprawl). In the literature, some authors also argue that this type of accessibility indicator is a useful aid to planners and policy makers in the social evaluation of urban structure (e.g. Black &Conroy, 1977) or transport plans (e.g. Wachs & Kumagai, 1973).

7.3 Equity

7.3.1 The concept of equity

At present, there are no recognised and acceptable methods for analysing equity impacts of transport (Banister, 1998). There are several aspects related to equity, which will be shortly described here. In the economic literature, the term equity is normally used to refer to the fairness in the distribution of goods and services (or costs and benefits) among (groups of individuals) and to the corresponding injustice caused by substantial uncompensated losses (Lichfield *et al.*, 1975; Friedman, 1984). Two basic concepts are identified (e.g. see Khisty,1996; Litman, 1996):

- *Horizontal equity*, focusing on the fairness of cost and benefit allocation between individuals or groups with comparable needs, resources and abilities. Here, equity is interpreted as 'everybody gets what he or she pays for, and they pay for what they get'. An example of horizontal equity is the redistribution of road-pricing revenues to road investments or the provision of other benefits to the people who pay the taxes.

- *Vertical equity*, focusing on the allocation of costs and benefits between groups in society, e.g. stratified into income, social class or mobility needs and abilities. Here, equity means that the distribution of costs and benefits should reflect people's needs and abilities. Examples of policies related to vertical equity are progressive tax rates and special public transport services for disabled people.

Another dimension of horizontal and vertical equity is equity as the difference between equalisation of opportunities and outcomes (Friedman, 1984; Litman, 1996; Banister, 1998):

- *Equity of opportunity* focuses on the equal access to opportunities such as education and employment, regardless of people's need or financial contribution. Here, equity is interpreted to mean 'everybody deserves equity of opportunity', e.g. the society ensures that people who are disadvantaged should enjoy equal access to opportunities by improving or expanding public transport infrastructure.
- *Equity of the outcome*, focusing on the actual realisation of equality, e.g. the society ensures that disadvantaged people actually have access to opportunities. According to Banister (1998), this concept (contrast to equity of opportunity) includes income distribution, e.g. by subsidising specific users of public transport – elderly, students, etc.

Vertical equity can be further stratified along a spatial, social or economic dimension (Banister, 1998):

- *Spatial equity*, focusing on distribution of activities in space, e.g. because activities of a town are spread over an area, it is not possible for all parts of the town to have equal access to all facilities. In choosing where to locate, households and firms will trade-off the various attributes of the different locations. The concept of spatial equity can be related to notions of territorial justice (Bebbington & Bleddyn-Davies, 1980);
- *Social equity*, focusing on the different needs, abilities and requirements for access, depending on specific characteristics as age, gender, educational level, household structure, stage in the life cycle, disability or handicap. The concept of social equity relates to social justice (Miller, 1976);
- *Economic equity*, focusing on the different resources, levels of income or wealth of individuals. Not all individuals can compete equally because of 'economic' differences, e.g. some households cannot afford a car, and as a result their access to (economic and social) opportunities is reduced.

Table 7.2 summarises the matrix of the different dimensions of equity.

Table 7.2: Classification of equity concepts with examples of transport investments

Equity		Equity of opportunity	Equity of the Outcome
Horizontal		Minimum levels of public transport services Re-allocation of road pricing revenues to road infrastructure	Service distribution according to demand; market based public transport, no subsidies
Vertical	spatial equity	special public transport services for rural areas infrastructure investments in rural areas	travel subsidies for public transport services in rural areas
	social equity	special public transport services for disadvantaged people adapted vehicles	service distribution according to travel needs
	economic equity	public transport services for non-car owners	travel concessions, subsidies for students, elderly, disabled

Source: based on Banister (1998)

Note that the different dimensions are related, e.g. in the differing degrees of access to spatially distributed opportunities - spatial equity - can affect the real income of different groups - economic equity - (Breheny, 1978). Furthermore, decisions in transport often comprise several aspects of the matrix.

7.3.2 Equity aspects in economic evaluation

In standard cost-benefit analysis, a project can be justified if the total (monetary) benefits of all users exceed the total (monetary) costs. The starting points of CBA are formed by the 'Hicks-Kaldor criterion' and the concept of 'Potential Pareto Improvement' (e.g. see Gramlich, 1990). The Hicks-Kaldor criterion states that 'winners' of a project are able to compensate 'losers' through financial transfers. The combination of the project and the financial transfers may result in a potential pareto improvement, i.e. the welfare of at least one person increases, without reducing welfare for others. If a potential pareto improvement is achieved, thus total monetary benefits exceed total costs, the project can be justified from an economic point of view.

In standard economic cost-benefit analysis of infrastructural projects, costs and benefits are usually not differentiated by income groups (economic equity) or regions (spatial equity). In practical examples of CBA in Europe (e.g. see ITS, 1991; Dings et al., 1999), benefits and costs are computed for users and non-users (e.g. neighbouring people, authorities), although in Germany regional impacts are considered. In economic literature, several studies point out the relevance of incorporating equity impacts in economic evaluations of transport projects (e.g. Lakshmanan et al., 1997; Rietveld &Bruinsma, 1998). From an equity point of view, the standard CBA method has a number of disadvantages. Kandel & Poort (2000) give an overview:

- The *actual* financial compensation of 'losers' is not considered in a CBA, and, in practice, hardly takes place. Thus, in reality, a transport project always has 'winners' and 'losers';

- Actual financial or non-financial compensation will, in general, result in some efficiency, or dead-weight, losses. Actual compenstation will, according to Kandel & Poort, always result in economic distortions because (a) additional measures necessary to reduce the costs for surrounding inhabitants - e.g. measures to reduce of noise nuisance of a motorway or railway expansion - increases the overall costs of the project, and (b) redistributional measures will affect the economic behaviour of all participants. As a result, the amount of money taken from the 'winners' will be higher than the amount of money given to 'losers'. However, this does not mean that the net efficiency of a project, including financial and/pr non-financial compensation, will be negative.
- The monetary valuation of cost and benefits (of transport projects) differs between individuals, depending on individual characteristics such as preferences and incomes. For example, the monetary valuation of external effects of transport may differ between income groups. Thus, the benefits of clean air or reduced accident risks would be higher for high-income groups than low-income groups. In economic terms: the marginal utility of income differs between individuals. In theory, the aggregation of consumer surpluses requires the performance of interpersonal comparisons relative to preferences and marginal utility of income. This is the main reason why the rationale and use of consumer surplus is quite controversial in economic literature (Banister & Berechman, 2000). It is beyond the scope of this study to examine these and related issues. For approaches dealing with income and price effects in the computation of consumer surplus see Friedman (1984).

In a study on equity aspects in cost-benefit analysis of infrastructure projects, Kandel & Poort (2000) suggest to introduce the ‘Dalton criterion’ (Atkinson, 1970) in CBA. This principle has been applied outside the transport sector, for example, to evaluate alcohol and tobacco tax reform policies (Mayshar & Yitzhaki, 1995). The Dalton criterion states that financial compensation is socially desirable if (a) the money transfer is from a higher income group to a lower income group, *and* (b) the relative ranking order of the income groups does not change. In project evaluations, four situations can occur:

1. a project improves efficiency (the sum of costs and benefits is positive) and reduces inequality (the situation for most individuals improves): a Dalton improvement;
2. a project improves efficiency, but increases inequality: no Dalton improvement
3. a project reduces efficiency, but reduces inequality: no Dalton improvement;
4. a project reduces efficiency, and increases inequality: no Dalton improvement.

Figure 7.1 shows the Dalton criterion schematically. The figure shows the effects of transport projects (A and B) on income distribution analysing the relationship between rank-ordered income distribution (x-axis) and the cumulative income values (y-axis). Figure 7.1 illustrates the case where project A has the highest net benefits and both projects show a Dalton improvement: income inequality is reduced (the curve does not cross the x-axis) and efficiency increases (the cumulative income effect is higher than 0). However, project A has a stronger negative impact on the lowest and highest income groups than B (the curve descends). Thus, the difference between project A and B is not a Dalton improvement (the line crosses the x-axis). However, the difference between the net efficiency gains of project A and B is large enough to financially compensate the low-income groups for the negative impacts. Thus, project A is to be preferred.

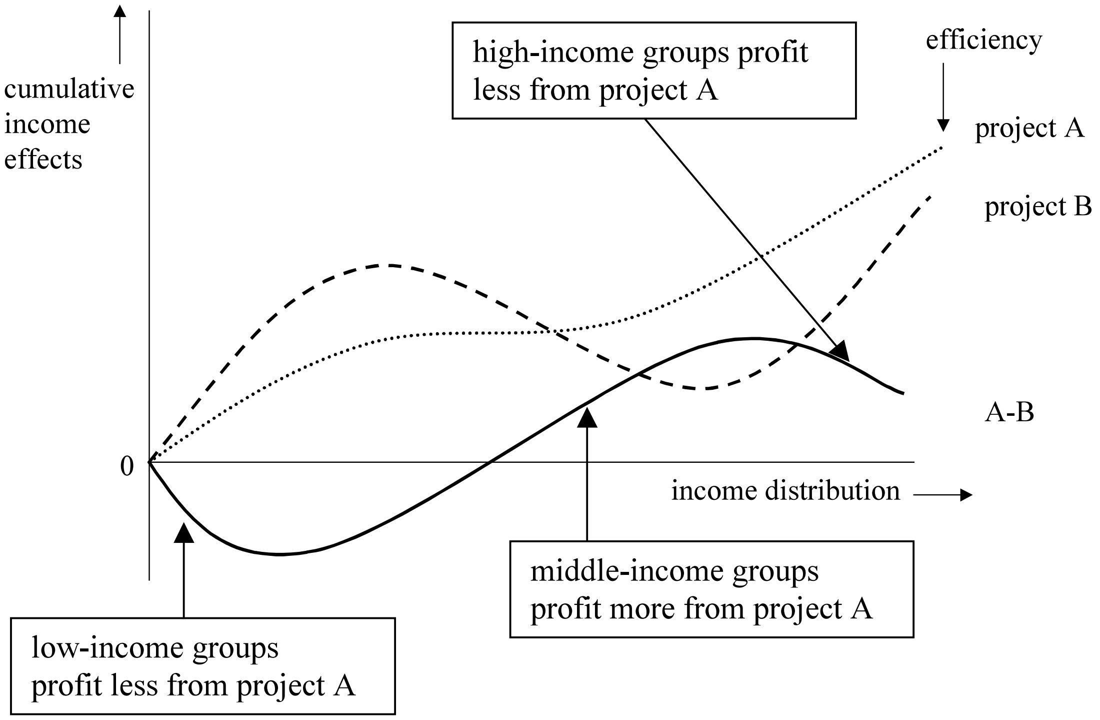

Figure 7.1: The Dalton criterion for evaluation economic equity (Kandel & Poort, 2000)

7.3.3 Equity in relation to activity-based accessibility measures

Potential accessibility measures can be a useful method for evaluating equity of opportunities, i.e. the effects of land-use and transport policy plans can be expressed in the difference in the potential number of opportunities, which can be reached by car, public transport or non-motorised modes. Furthermore, vertical equity of opportunities can be analysed by stratifying the population by region (= spatial equity), socio-demographic characteristics (e.g. age, educational level, gender, household structure) (= social equity) and income (= economic equity).

In the literature, several authors have analysed (vertical spatial, social and/or economic) equity of opportunities by using *potential accessibility measures*. For example, Wachs & Kumagai (1973) analysed potential accessibility to employment and health-care facilities in the Los Angeles County as a function of the spatial location of residence and socio-economic status (by occupational and income classification). Black & Conroy (1977) studied the potential accessibility to employment in Sydney for male and female workers, classified by captive public transport users (non-car owners), unsaturated households (not all household members own a car) and saturated households (all household members own a car) living in typical residential areas stratified by socio-economic composition. Domanski (1979) studied social and economic equity by analysing differences in accessibility as a function of socio-economic status (educational level, income). More recently, Shen (1998) studied employment accessibility of low-wage workers living in Boston's inner-city neighbourhoods, Zhang *et al.* (1998) studied the potential benefits of new rail transit system on job accessibility for different socio-economic groups, and Talen & Anselin (1998) assessed the potential accessibility to public playgrounds in Tulsa for children, as a function of residence and socio-economic characteristics (race, housing value).

Schürmann *et al.* (1997) and Fürst *et al.* (1999) illustrate several equity indicators to examine whether the Trans-European Network (TEN) investments reduce or increase existing disparities in regional accessibility in the European Union:

- statistical measures such as maximum, mean, minimum and standard deviations of regional accessibility values. These statistical measure can be used an indicators for the degree of homogeneity or polarisation;
- ratio's between the 5, 10 or 20 'best' and 'worst' regions;
- rank-size distributions of accessibility values of regions;
- A Lorenz distributions. A Lorenz distribution compares a rank-ordered cumulative distribution of indicator values of regions with a distribution in which all regions have the same indicator value. The area between the two cumulative distributions indicates the degree of polarisation or level of inequality (see Figure 7.2, where scenario A is less polarised than scenario B).

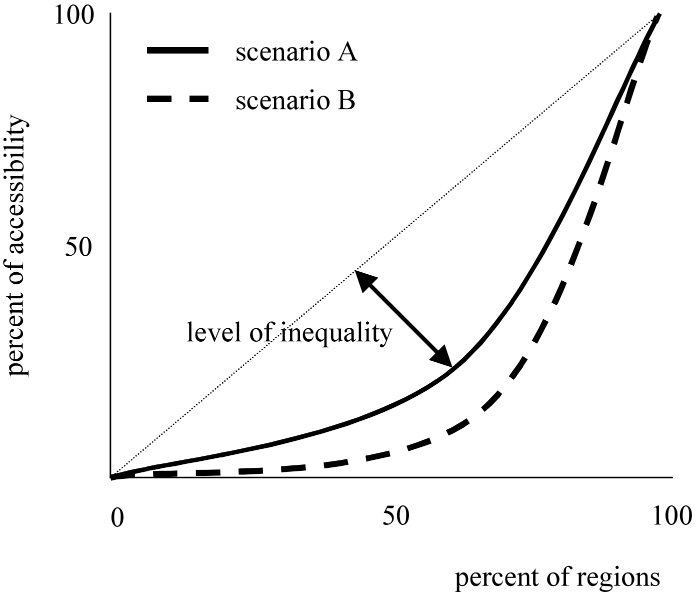

Figure 7.2: Lorenz curve of accessibility values for two scenarios

- A statistical measure, the GINI coefficient, can be used to calculate the ratio between the area between the two cumulative distributions and the triangle under the upward sloping line of the equal distribution. A GINI coefficient of zero indicates all regions have the same values, a coefficient close to 1 indicates that the regions are highly polarised. The equation for the GINI coefficient is:

$$G = 1 + 1/n - 2/(n^2 \overline{A}_i)\sum A_i \qquad \text{(Equation 7.1)}$$

Where A_i is the accessibility value sorted in decreasing order, $\overline{A}_i$ the average accessibility value of region i, and n the number of regions.

There are also several authors who analysed (vertical) equity impacts of transport by using *actual accessibility measures*. For example, Hodge (1986) described the (economic) equity of the distribution of transit revenues and expenditures and transit service levels by household income for Seattle. Câmara & Banister (1993) studied the spatial inequalities in the level of service of public transport as a function of residence location (core and peripheral areas) and population income for Latin American cities.

Note that in principle several potential accessibility measures (e.g. with or without distance decay and/or competition effects) can be used for the analysis of the spatial, social and economic equity of a given resource distribution. The choice of the indicator must be considered carefully because it implies a particular treatment of equity and also affects the conclusions about the existence of spatial mismatch and inequity (see Talen & Anselin, 1998). If the results of accessibility measures are to be aggregated to an average accessibility level (e.g. for a region or a group of individuals), utility-based measures, maximising consumer's surplus, will result in greater social equity than potential accessibility measures (see Section 4.4). The aggregation of individual's benefits implicitly assumes a normative evaluation of equity. This is explained below.

7.3.4 Normative evaluation of equity

An empirical approach can be taken for the evaluation of equity (For example, the analysis of accessibility impacts of land-use and transport policies for different groups in society). However, a normative approach can also be taken, i.e. what is just and unjust about the equity impacts? The empirical approach has been described above; the normative approach is described below.

There is no single way of evaluating equity, i.e. a fair number of equity, fairness and justice concepts may be applicable to transport problems (Hay, 1993). According to Khisty, there are at least three ways of distinguishing between just and unjust states of affairs: 'rights' (based on publicly acknowledged rules or established practices), 'deserts' or merits (based on a person's capabilities, moral virtue, productive capacity, etc.) and 'needs'. These three interpretations of justice may be in conflict, e.g. each person has "a right to something that he or she deserves" or "a right to something he or she needs" (Miller, 1976). Khisty (op. cit.) presents six theories of justice which are commonly used and understood by society or are documented in literature.

These theories attempt to answer certain questions about justice itself and can be used as an input in the decision-making process:

1. *Equal shares approach*: this is the most simple and easiest procedure for distributing net benefits equally among relevant social and economic groups. This approach is followed, for example, in democratic elections: one person, one vote.
2. *Utilitarian approach*: according to this approach, justice is done when utility is maximised, regardless of its distribution. The underlying idea is that differences in well-being are quantitative, not qualitative, and that a common measure can be derived that adequately trades off benefits and costs. This approach is taken in economic cost-benefit analysis. In a CBA, a policy which gave 5 Euro of benefit to a rich man and extracted 4 Euro from a poor person would yield a positive net benefit (MVA, 1991).
3. *Maximisation of average net benefits with a minimum floor benefit*: this approach ensures that the attempt to maximise the average benefit is constrained by a certain amount to ensure that certain individuals or groups receive a minimum benefit.
4. *Maximisation of average net benefits with a benefit range*: this approach ensures that the attempt to maximise the average benefit does not allow differences between the rich and the poor segments of society to exceed a certain amount.
5. *Egalitarism*: this approach states that all human beings are equal and should be treated equally in all respects. The objective is to level out any unevenness in the ‘distribution’ of well-being. Any policy resulting in more benefits to the less advanced would be regarded as egalitarian.
6. *Rawls’ theory of justice* (Rawls, 1971): this approach states that all social primary goods – liberty, opportunity, income and wealth, and the basis of self-respect – are to be distributed equally, unless an unequal distribution of any or all of these goods is to the advantage of the least favoured.

As a(n) (hypothetical) example of evaluating alternatives of a public transit project, Khisty shows that the use of a particular theory of justice results in different valuations of the distribution of net benefits to socio-economic groups and will thus give different conclusions.

In conclusion, there are several approaches to evaluating the normative aspects of equity. Diverse concepts of equity can be used which may result in quite different conclusions about the fairness of policies. If a potential accessibility measure is used to aggregate accessibility levels of individuals to an average accessibility level for a region or group of individual, an ‘equals share approach’ is implicitly taken: all individuals are equally weighted. If a utility-based accessibility approach is used, a utilitarian approach is taken: an accessibility improvement for a rich person may provide higher benefits than the same improvement for a poor person. Both approaches will result in different conclusions on the fairness of accessibility changes.

7.4 Conclusions

Activity-based measures may form a useful tool in examining the social impacts of land-use transport scenarios. Firstly, activity-based measures are an indicator of the degree the land-use transport system provides access to social and economic opportunities. Secondly, equity aspects of the land-use transport system can be analysed. Three dimensions of equity can be analysed:

- *spatial equity* can be analysed by estimating activity-based accessibility measures by region;
- *social equity* can be analysed by estimating activity-based accessibility measures for population groups stratified by socio-demographic characteristics (e.g. age, educational level, gender, household structure);
- *economic equity* can be analysed by estimating activity-based accessibility measures for income groups.

Analysing economic equity is related to economic evaluation of transpiration projects, where the distribution of costs and benefits is often an important issue. However, equity impacts are not considered in standard economic evaluations of transport projects. In CBA only the economic efficiency, the sum of total costs and benefits, of a project is computed. Recently, Kandel & Poort (2000) suggested introducing the 'Dalton criterion' in CBA, which shows the impact of transport investments on the income distribution of the population involved. In analysis of the equity impacts of accessibility scenarios, this principle can also be used. In addition, several statistical measures, such as standard deviation and Lorenz distributions can be used to illustrate equity impacts of accessibility scenarios.

In principle, several activity-based accessibility measures can be used for the analysis of the spatial, social and economic equity of a given resource distribution. However, the choice of a measure implies a particular treatment of equity and also affects the conclusions. Furthermore, the aggregation of individuals to an average accessibility level for a region and/or group of individuals has normative aspects. If an activity-based measure is used to derive an average accessibility levels, an "equals-share approach" is taken, i.e. all individuals are equally weighted. If a utility-based accessibility measure is used, a "utilitarian approach" is taken. Both approaches will lead to different aggregate results and thus "normative" conclusions on (changes in) social equity of accessibility.

8. Synthesis: evaluation of accessibility measures

8.1 Introduction

Accessibility is a concept that has taken on a variety of meanings and has been operationalised in several ways. Three perspectives on measuring accessibility can be identified:

(4) *Infrastructure-based accessibility measures* based on the observed or simulated performance of the transport system. This measure type is used in transport and infrastructure planning. The most commonly used measures are level of congestion and travel speed;

(5) *Activity-based accessibility measures* based on the distribution of activities in space and time. Several types of activity-based accessibility measures are in seen in urban planning and geographical studies, i.e. distance measures, contour measures, potential measures, the balancing factors of spatial interaction models, and space-time accessibility measures. The most commonly used measures are contour and potential accessibility measures.

(6) *Utility-based accessibility measures* based on the benefits people derive from access to the spatially distributed activities. This measure type is used in economic studies.

Furthermore, four components determining accessibility are identified: (1) a transport component, reflecting the effort to travel between an origin and destination location, (2) a land-use component, reflecting the spatial distribution of (supplied) activities at destinations and the demand for those activities (3) a temporal component, reflecting the time restrictions of individuals and destinations and (4) an individual component, reflecting the needs, abilities and opportunities of individuals.

Here, accessibility measures are, firstly, evaluated according to their (a) methodological soundness, i.e. the capacity for handling the four identified components of accessibility, (b) their interpretability, and (c) data need.

Secondly, the accessibility measures are evaluated according to their usability in evaluations of land-use and transport changes, and related economic and social impacts.

8.2 Methodological soundness

8.2.1 Transport component

All accessibility measures incorporate elements of the transport component. In general, the transport component consists of (a) the distance, travel time, travel costs and travel effort between an origin and a destination, (b) the perception and valuation of the impedance of a given origin-destination combination, i.e. the attractiveness of a destination is a function of the amount of travel time, cost and effort necessary to get there.

Infrastructure-based accessibility measures focus on one element of the transport component, e.g. average travel time, travel speed. Activity- and utility-based measures usually incorporates travel distance, travel time or costs as transport elements. The contour measure, one of the most commonly used activity-based accessibility measures, is the only activity-based measure which does not use an impedance function to weigh opportunities according to their travel time or cost away. This has the disadvantage that one incorrectly assumes that all opportunities are equally desirable, regardless of the time spent in travel or the type of opportunity accessed. Furthermore, the (arbitrarily) chosen maximum travel distance or time greatly affects the result.

8.2.2 Land-use component

In general, the land-use component of accessibility can be split up into two (interdependent) elements: (i) the spatial distribution of supplied destinations and their characteristics, e.g. the location of offices, schools and their attractiveness, capacity, etc. and (ii) the spatial distribution of the demand for activities and their characteristics, e.g. locations of dwellings and their inhabitants.

Although infrastructure-based accessibility measures are influenced by the land-use component (e.g. the spatial distribution of traffic is influenced by the spatial distribution of activities), they do not incorporate a land-use component. Activity- and utility-based measures explicitly incorporate a land-use component: a change of accessibility may be the result of land-use or transport changes. In practical applications of activity-based accessibility measures (contour measure, potential measure, and space-time measures) competition effects are usually not considered. That is, potential accessibility to destinations is estimated for each location, without considering capacity restriction of the supplied opportunity, e.g. jobs or hospital beds may be limited.

In literature, three approaches for handling competition effects in activity-based measures can be identified. Firstly, a number of authors developed accessibility measures incorporating competition effects taking the origin location as point of departure, e.g. Weibull’s accessibility measure estimates the average number of jobs within reach from a home location (origin), divided by the number of inhabitants with can be reached from the home location. A second approach is to take the destination location as starting point, e.g. Joseph & Bantock’s measure estimates the availability of general practitioners for inhabitants within the catchment area of the general practitioner (destination). A third approach, the balancing factors from Wilson’s doubly constrained interaction model, incorporates both competition effects on destinations and origins (see Table 8.1).

Table 8.1: Approaches for handling competition effects

origin location as point of departure	Weibull (1976), Knox (1978), Joseph & Philips (1984), Hagoort (1999)
destination location as point of departure	Breheny (1978), Joseph & Bantock (1985), Shen (1998), Ritsema & De Jong (1999)
competition on origin and destination locations are interdependent	Wilson (1971)

Depending on the study goal, one can choose an appropriate approach for handling competition effects. In analysing job accessibility, which is the object of this study, the accessibility measure should ideally incorporate both the competition of the demand (workers) on opportunities at destinations (jobs), and the competition of opportunities (employers) on the demand (workers) at origins. This is because in reality, in the case of a job vacancy, the employees within reach of the job compete for the vacant job, and the employer competes with other employers within reach of the employees. The balancing factor (a_i) of the doubly constrained spatial interaction model is the only accessibility measure found in literature which can handle these interdependent effects (by estimating the demand and supply potentials in an iterative procedure) and can thus be considered to be the most appropriate accessibility measure. Of course, the balancing factors are also appropriate for analysing other destinations where competition may occur on both origin and destination (e.g. schools, hospitals beds).

In analysing accessibility to destinations where only competition effects occur on the destination (e.g. nature areas), or capacity limitations of supplied opportunities are the subject of interest (e.g. recreational facilities or hospitals), Joseph & Bantock's measure is an appropriate accessibility measure.

8.2.3 Temporal component

The temporal component of accessibility involves (i) the availability of activities at different times of the day or weeks, seasons, years, etc. and (ii) the times in which individuals participate in specific activities.

The space-time accessibility approach is the only approach focusing on the time component of activities. Space-time activity measures indicate the possible space-time paths of individuals or households between locations, given household activities to be performed and time-constraints. Infrastructure-based, other activity-based measures and utility-based measures handle the time component only implicitly, i.e. travel time and costs may vary in time (e.g. between peak hours and off-peak hours).

A problem with including the temporal component is that individuals' time budgets are not available from (standard) revealed preference data. Thus, additional data must be collected resulting in applications which are often restricted to a relatively small region and a small subset of the population because of the large data requirements. This makes the measures difficult to apply on the national level.

8.2.4 Individual component

The characteristics of individuals play an important role in determining the level of access to social and economic opportunities. Three groupings of characteristics are identified: needs (e.g. age, household situation), abilities (e.g. physical abilities, car ownership) and opportunities (available income, travel budget).

In general, the space-time and utility-based approach focus on determining accessibility on an individual or household level. Space-time measures determine possible space-time paths of individuals between locations, given activities to be performed and individual time-constraints. Utility-bases measures assess the welfare or benefits accruing to individuals. Standard activity-based measures (contour measure, potential accessibility measures) do not account for the characteristics of the individuals for whom the accessibility is being estimated; all individuals in the same location have the same level of accessibility, despite their characteristics (e.g. skills, perceptions). For example, if residents of an area are closely situated to a large number of job opportunities, but they do not have the skills or education to qualify for the job, they still have a low job accessibility level.

In practical accessibility studies, the different approaches handle the individual component similarly. Utility-based measures are, because of practical reasons, estimated for homogeneous socio-economic population groups, and activity-based measures are often disaggregated according to socio-economic characteristics, e.g. job accessibility is estimated for the population stratified by educational level.

If accessibility is estimated for individuals or subgroups, the question arises how to aggregate the results to a regional or national value. Standard activity-based measures may lead to unsatisfactory conclusions when accessibility levels for subgroups are aggregated to derive aggregate values of accessibility. Namely, the influence of a small increase in the accessibility of highly populated areas (e.g. the allocation of 100 additional jobs in an area with 100,000 inhabitants) on the accessibility measure is larger than a large increase in the accessibility of low populated areas (e.g. allocation of 100 additional jobs in an area with 1000 people). In contrast, when utility-based accessibility measures are used, the improvement of accessibility for individuals living in low-accessibility areas results in a higher level of consumer surplus than the improvement of accessibility for individuals living in areas with an already high level of accessibility to opportunities.

8.3 Interpretability of the measures

The most simple activity-based measures are the most easy to interpret, i.e. distance and contour measures can be considered “common-sense” measures showing the travel distance or time to one destination, or the total number of destinations which can be accessed within a certain travel time. The potential accessibility measure is somewhat less easily interpreted, i.e. the number of opportunities within reach are weighted according to the distance away from the origin. However, the interpretability can be improved by showing the separate influence of land-use changes (the amount and spatial distribution of activities) and transport changes (changes in travel times) on changes in the accessibility measure. More theoretically and methodologically sound accessibility measures (i.e. accessibility measures including competition effects, space-time measures, utility-based measures) are even more difficult to interpret.

8.4 Data need

All activity-based accessibility measures, except space-time measures, seem to have modest data requirements and can, in principle, be calculated using existing data from land-use and transport models. The most simple activity-based measures (distance and contour measures) require the least amount of data, whereas the more complex space-time accessibility measures require large amounts of data because of the disaggregate level of estimation. The application of space-time accessibility measures in a theoretically satisfying manner requires additional data collection, i.e. time budgets are not available from standard revealed preference travel data. As a result, applications of space-time accessibility measures have been, up to now, often restricted to a relatively small region and a small subset of the population. This makes the accessibility measures difficult to apply on the national level (which is the aim of this study).

8.5 Usability in economic evaluations

Accessibility changes as a result of changes in the transport system or land uses can have different economic impacts. In the literature, different approaches for analysing economic impacts of infrastructure and accessibility exist. Basically, three approaches can be identified, in which different accessibility measures may play a role:

- A social cost-benefit analysis (CBA) of transport projects;
- A production function approach with GDP as the main object;
- An approach focusing on employment effects.

Accessibility can be related to the concept of consumer surplus and consumer welfare from the micro-economic welfare theory. In particular, random utility theory can be used to model travel behaviour and the benefits of different users of a transport system. In this case, accessibility is expressed as the net benefit that people achieve from accessing opportunities. Consumers’ surplus can be interpreted as the difference between two accessibility scenarios (e.g. one base situation and one reflecting a policy change) using a utility-based accessibility measure. The changes in utility can be converted to monetary units using the compensating variation from economic theory. This approach has important benefits:

- The economic benefits of improved accessibility can be analysed as a result of (a) changes of the transport system and (b) changes in the physical location of land uses. In traditional cost-benefit analysis only the benefits of an improved transport system, resulting in a change of travel times and/or costs, are analysed. Thus benefits of accessibility changes due to changes in land uses are not taken into account.
- The potential accessibility measure incorporates a land-use component, i.e. the research area is split up in regions. Therefore the user benefits of changes in accessibility can also be allocated to regions. Thus this measure of consumer surplus can be used to analyse equity aspects; in other words, it can be used to analyse which individuals or groups of individuals living in certain locations benefit from changes in accessibility;
- A more correct measure of consumer surplus can be derived (compared to standard cost-benefit analysis), because a non-linear (pseudo-)rule-of-half formulation is assumed;
- Consumer surplus can be estimated in relation to the balancing factors of the doubly constrained spatial interaction model, thus incorporating competition effects on the demand and supply side.

A disadvantage of this approach is that the theoretically correct use of utility-based accessibility measures for measuring consumer surplus of a transport project requires a transport model which properly forecasts the combined land-use transport equilibrium, including land-use and transport feedback's. Unfortunately, this is beyond the scope of this study.

To the authors' knowledge, no studies have been found where *non-user* benefits of accessibility were examined. Non-user benefits may include option value and bequest value, i.e. people might not only value opportunities they actually access, but also opportunities which may be accessed in future (option value), and opportunities which are available to others (bequest value). Non-user benefits may also be examined with utility-based measures, but the 'willingness-to-pay' of non-users for a mode-destination choice cannot be derived by revealed preference data; these must be derived from stated-preference data or indirect methods (e.g. hedonic pricing methods).

In the production function and employment approaches contour measures and potential accessibility measures may be used as input for the analysis. These measures can be used as an indicator of the market area of firms and companies, which is considered a determinant for regional economic production. A recently conducted study on the relationships between infrastructural improvements, accessibility and regional economic production on the European level (Fürst *et al*., 1999; 2000) found potential accessibility measures (using composite travel times of different modes) to have the highest correlation with GDP per capita. However, the relationships between infrastructure improvements, accessibility and economic development

are theoretically complex, and empirical evidence is still weak and disputed. As a result, the production function approach might over- or under-estimate the impact of accessibility improvements on economic development. Further research is necessary to determine how this approach can be used to examine the wider economic impacts of accessibility improvements.
In conclusion, cost-benefit analysis can be considered the primary method for evaluation of the economic impacts of accessibility changes of land-use and transport projects or scenarios. The CBA-methodology is consistent with micro-economic theory, and in general, transport projects can be justified if they generate sufficient user benefits. However, further research is necessary to examine the value added of using utility-based accessibility measures in cost-benefit analysis of land-use and transport projects.

8.6 Usability in social evaluations

Activity-based measures may form a useful tool in social evaluations. Firstly, (changes in) the level of access to opportunities can be analysed i.e. the effects of land-use and transport policy plans can be expressed as the difference in the potential number of opportunities which can be reached by car, public transport or non-motorised modes. Secondly, the distribution of access to opportunities (equity aspects) among societal groups and regions can be analysed. Three dimensions of equity can be analysed using activity-based accessibility measures, i.e. *spatial equity* can be analysed by estimating the accessibility measures by region; *social equity* can be analysed by estimating the accessibility measure for population groups stratified by socio-demographic characteristics (e.g. age, educational level, gender, household structure); *economic equity* can be analysed by estimating the accessibility measure for income groups. Note that a social evaluation of economic equity here is not equivalent to an economic evaluation; i.e. in a social evaluation, the differences in levels of access to certain opportunities are estimated, not the monetary valuation of individuals of accessing opportunities.

In principle, several activity-based accessibility measures can be used for the analysis of the spatial, social and economic equity of a given resource distribution. However, the choice of a measure implies a particular treatment of equity and also affects the conclusions. Furthermore, the aggregation of individuals to an average accessibility level for a region and/or group of individuals has normative aspects. If an activity-based measure is used to derive an average accessibility levels, an “equals-share approach” is taken, i.e. all individuals are equally weighted. If a utility-based accessibility measure is used, a “utilitarian approach” is taken, assuming that the 'losers' of a project can be compensated by the 'winners', assuming the marginal utility of money to be constant between individuals. For example, a 1% accessibility increase for high-income groups at the cost of a 1% decrease for low-income groups yields positive net benefits. Both approaches will lead to different aggregate results and thus “normative” conclusions on (changes in) social equity of accessibility.

8.7 Conclusions

This report reviewed accessibility measures for the purpose of developing and applying accessibility measures as an indicator for the social and economic consequences of alternative land-use transport systems. Thus, accessibility should relate to role of the land-use transport system in society, i.e. to give people the opportunity to participate in activities at different places. Activity- and utility-based measures are the most appropriate for this purpose, because they are sensitive to both land-use changes (i.e. changes in the amount and spatial distribution of activities) and transport changes (i.e. changes in the amount of time, cost and effort to reach a destination from an origin).

The main conclusions from the literature review are as follows:

- There seems to be trade-off between the 'common-sense' interpretability and methodological soundness of the measure, i.e. measures with a better theoretical basis (utility and space-time based measures), and measures which are methodologically improved to account for competition around opportunities but less easy to interpret.

- Infrastructure-based accessibility measures do not incorporate a land-use component; the spatial distribution of activities is not included in the measure. In contrast, activity- and utility-based measures are responsive to both land-use and transport changes. The literature study clearly shows that there is no first-best activity-based accessibility measure. Each accessibility measure has its theoretical and practical advantages and disadvantages. As a result, the choice of an accessibility measure for analysing the impacts of a land-use or infrastructure project, plan or scenario depends on the study object:
    - ❑ For the purpose of analysing accessibility to destinations where no competition effects occur or competition effects are not a subject of interest, the potential accessibility measure can be considered an appropriate and practical accessibility measure;
    - ❑ Joseph & Bantocks' measure is appropriate for analysing accessibility to destinations where competition effects only occur on destination locations (e.g. nature areas), or capacity limitations of supplied opportunities are the subject of interest (e.g. in the analysis of recreational facilities or health care facilities);
    - ❑ The inverse balancing factor is an appropriate measure for analysing job accessibility, where competition effects both occur on destination locations (jobs) and origin locations (working population). The (inverse) balancing factors are computed in an iterative procedure to handle these interdependent competition effects.

  Space-time based accessibility measures analyse accessibility from the demand side (on an individual level) and are not found to incorporate competition effects. Utility-based measures can, in theory, be computed by using the balancing factors of the doubly constrained spatial interaction model as a basis, thus incorporating competition effects.

- Temporal aspects of accessibility are explicitly handled in accessibility measures based on space-time theory, i.e. individuals' time budgets are used as constraints in the analysis.

Other accessibility measures and individual component handle the time component only implicitly.

- Individuals' characteristics play an important role in determining the level of access to social and economic opportunities. Space-time based accessibility measures and utility-based measures are disaggregate approaches focusing on individuals' accessibility. In contrast, geographical accessibility measures (e.g. contour and potential accessibility measures) analyse accessibility at a location, where all individuals in the same location have the same accessibility. However, in practical applications of accessibility measures, the contrast is often not so large. That is, accessibility is analysed for different population groups, depending on selected socio-economic characteristics.

- All accessibility measures can be estimated using standard revealed preference data or existing land-use and transport models, except space-time measures. Note that the plausibility of the result also depends on the theoretical basis and practical limitations of the land-use and transport models used.

- Activity-and utility-based measures can be a useful method for evaluating the social consequences of accessibility scenarios (in terms of spatial, social and economic equity), if the measures estimate accessibility for the population stratified by region, socio-demographic and socio-economic characteristics. Only utility-based measures can be used as a basis for the economic evaluation of user-benefits for accessibility scenarios.

Table 8.2 summarises the literature review.

Table 8.2: Characterisation of accessibility measures

	components					data need	interpretability	usability for evaluation		
	transport	land use		temporal	individual			land use and transport changes	economic changes	social changes
		demand	supply							
infrastructure-based measures	+	-	-	+/-	-	+	+	+/-	+/-	-
activity-based measures										
• contour measures	+	+/-	-	+/-	+/-	+	+	+/-	-	+
• potential accessibility	+	+	-	+/-	+/-	+	+/-	+	-	+
• Joseph & Bantock	+	+	+	+/-	+/-	+	+/-	+	-	+
• inverse balancing factor	+	+	+	+/-	+/-	+	+/-	+	-	+
• space-time based measures	+	+	-	+	+	-	-	+	-	+
utility-based measures	+	+	+/-	+/-	+	+	-	+	+	+

+ = positive, +/- = some positive elements, some negative, 0= neutral, - = negative

In summary, *infrastructure-based accessibility measures*, such as average speed on the road network, are relatively easy to interpret, but are not very capable of evaluating accessibility impacts of land-use transport scenarios. That is, these measures are only sensitive to transport changes; land-use changes are not considered. *Activity-based accessibility measures* are effective measures for analysing accessibility impacts of land-use transport scenarios. The choice of an activity-based accessibility measure for analysing the impacts of a land-use or infrastructure project, plan or scenario depends on the study object. The (inverse) balancing factor is methodologically sound measure for analysing job accessibility, satisfactory incorporating the different components of accessibility (i.e. the transport, land use, temporal and individual components), including competition effects. Furthermore, the inverse balancing factors may be used as input for a *utility-based accessibility measure*, estimates the utility (or benefits) people accruing to accessibility. The resulting utility measure may be used as a basis for analysing the economic impacts of accessibility scenarios. *Space-time accessibility measures* are theoretically very capable of analysing the accessibility impacts of land-use transportation scenarios, i.e. accessibility is analysed at the individual or household level, incorporating time-constraints. However, in current practice, the space-time approach can not yet be applied to forecast accessibility impacts on the national level due to the large (additional) data requirements.

Part II: Case studies

9. Introduction to the case studies

9.1 Introduction

Part II of this report, Case studies, describes the application of accessibility measures for (the base year) 1995 and two land-use scenarios for the Netherlands for the 1995-2020 period. The aim of the case studies is to analyse the capability of selected accessibility measures for the evaluation of accessibility impacts of land-use and transport changes and related social and economic impacts.

Several accessibility measures are selected for application, based on theoretical aspects, interpretability, data need and evaluation capability (see Section 10.2): contour measures, a potential accessibility measure, two measures incorporating competition effects, i.e. Joseph & Bantock's accessibility measure and the (inverse) balancing factors of the doubly-constrained spatial interaction model, and a utility-based accessibility measure.

In the case studies, the accessibility measures are applied to two modes (car and public transport) and to one destination (jobs). This study object is chosen because of its policy relevance and data and time restrictions. Car and public transport are important modes for job accessibility, they currently account for about 65% of home-to-work trips and 90% of the home-to-work passenger kilometres in the Netherlands (CBS, 2000). Note that analysing car and public transport accessibility implies that the study focuses on regional home-to-work accessibility. Only one destination (jobs) is chosen, because the study focuses on comparing the results of different accessibility measures, contrast to applying one accessibility measure to all possible destinations. Jobs are chosen as destination because of theoretical and methodological aspects (i.e. competition effects occur), policy relevance and data availability (i.e. existing land-use scenarios can be used). An application of activity-based accessibility measures for other destinations (nature areas, retail facilities) is reported elsewhere (Geurs & Ritsema van Eck, in prep).

Several land-use transport scenarios have been developed by the RIVM in the context of the evaluation of the Dutch 'Fifth Memorandum on Spatial Planning' (VROM, 2001). These scenarios contain land-use developments and changes in the supply and use of road and rail infrastructure within the context of long-term economic developments from the Netherlands Bureau for Economic Policy Analysis (CPB, 1997). In this report, the following two land-use scenarios are analysed (see Section 10.4):

- A 'Trend scenario'. This scenario contains (a) land-use policies described in the Update of the Fourth National Policy Document on Spatial Planning Plan Extra (VROM, 1997) regarding new housing locations in the Netherlands for the period up to 2015, (b) the continuation of historic trends (1980-1995 period) in the spatial distribution of housing for the 2015-2020 period, and (c) transport infrastructure policies up to 2010 (V&W, 1999).

The Trend Scenario is constructed with the Land Use Scanner (Schotten *et al.*, 1997), and is described in Goetgeluk *et al*. (2000);

- A ‘Tolerant scenario’ in which consumers’ housing preferences are assumed to determine the spatial distribution of housing and related employment developments. This scenario is based on the housing market model Socrates (Heida & Poulus, 2000), and is described by Crommentuijn *et al.* (2001).

The accessibility measures applied in the case studies use land-use data and travel times as input. The land-use data for 1995 and the Trend and Tolerant scenarios are derived from the land-use models (as described above) on the level of 1308 regions or zones. The land-use models output data (number of inhabitants by age group, households, employment by economic sector) have served as input for the Dutch National Model System (NMS) to estimate average travel times between origins and destinations by car and public transport for 1995 and 2020 (see Section 10.4).

9.2 Structure of Part II of the report

The rest of Part II is divided into five sections. Section 10 describes the methodology behind application of the accessibility measures and the construction of two land-use transport scenarios. Section 11 describes the application of several accessibility measures for 1995, Section 12 for the Trend scenario and Section 13 for the Tolerant land-use scenario. Finally, Section 13 presents the conclusions of Part II.

10. Methodology and scenario construction

10.1 Introduction

This section describes the methodology behind the application of the accessibility measures and the construction of the land-use transport scenarios. The case studies are based on existing land-use and transport scenarios, i.e. the Trend scenario, developed by Goetgeluk *et al.* (2000) and the Tolerant scenario, developed by Crommentuijn *et al*. (2001).

Section 10.2 describes the selection of accessibility measures, and the selection and estimation of impedance functions. Section 10.3 describes Trend and Tolerant land-use scenarios, the land-use models used and resulting land-use patterns, while in Section 10.4 the construction of the transport scenarios and transport model used is outlined. Section 10.5 describes the methodology for estimating the separate influences of land-use changes and transport changes on the accessibility measure. Finally, Section 10.6 presents an overview of estimated accessibility measures.

10.2 Application of accessibility measures

10.2.1 Selection of accessibility measures

The literature study described in Part I of this report reviewed accessibility measures according to (a) theoretical and methodological aspects, i.e. the incorporation of the different components of accessibility into the measure, (b) interpretability (or communicability), (c) data needs, and (d) the use to which the evaluation of land-use and transport changes, and related social and economic impacts, can be put (see Section 8). Here, these criteria are used to select accessibility measures for case studies, so as to analyse job accessibility in the Netherlands.

The following accessibility measures are selected for application:

1. A contour measure, describing the total number of destinations within a maximum travel time (see Section 4.3.3 for a description). This measure is selected because of the easy interpretability of the measure. A maximum travel time of 45 and 60 minutes is assumed . in the case studies. Travel times of 45 to 60 minutes are usually considered to be the maximum accepted home-to-work travel times in the Netherlands (e.g. Gerritse, 1997), i.e. in roughly 85% of all home-to-work trips by car in the Netherlands, the travel time is shorter than 45 minutes and in 95% it is shorter than 60 minutes (see also Section 10.2.3);
2. A potential accessibility measure (see Section 4.3.4 for a description). This measure estimates the number of destinations within reach using a impedance function for travel distance, time or costs. This measure is selected because it overcomes some of the methodological problems of the contour measure (see Section 4.3.3);
3. The accessibility measure developed by Joseph & Bantock (1982) (see Section 4.5.2). This measure uses a potential accessibility measure corrected for competition effects on

destinations (here: jobs). This measure is selected because of the incorporation of competition effects;

4. The inverse of balancing factor, a_j, of the doubly-constrained spatial interaction model (see Section 4.3.5); this incorporates competition effects on the destinations (here: jobs) and on the origins (here: working population). This measure is also selected because of the incorporation of competition effects;
5. A utility-based accessibility measure (see Section 4.4). This measure estimates the utility inhabitants of a location derived from potential accessibility to destinations, using a impedance function for travel cost. This measure is selected because of the foundation in welfare economics.

10.2.2 Selection of impedance functions

The choice of the impedance function can strongly influence the result of an accessibility measure (see also Section 3.2.2). Therefore, the relationships between impedance functions and actual travel behaviour need to be analysed. In this study, several forms of impedance functions were estimated using the 1995 Dutch National Travel Survey from Statistics Netherlands (CBS, 1996). The 1995 Travel Survey contains almost 700,000 trips with information on other variables like trip length, trip time, trip purpose and mode used.

Several forms of impedance functions are used in accessibility studies. Here, the following functions are analysed:

- A negative power or reciprocal function: $F(d_{ij}) = d^{-\alpha}$
- A negative exponential function: $F(d_{ij}) = e^{-\beta d}$
- A modified version of the normal or Gaussian function: $F(d_{ij}) = 100*e^{-d2/u}$
- A modified loglogistic function: $F(d_{ij}) = 1+e^{a+b*\ln d}$

The impedance functions are estimated for the trip likelihood for all modes and trip purposes together. The trip likelihood is derived from the cumulative distribution of trips according to travel time. Figure 7.1 shows the observed trip likelihood[3], and the estimated impedance functions. The loglogistic function shows the highest correlation with observed travel behaviour, followed by the negative exponential function. The negative power function and the Gaussian function have the lowest correlation. The negative power function decays too rapidly at short distances (trips less than 10 minutes travel time); the Gaussian function decays too slowly at short distances and too rapidly at longer distances (more than 20 minutes travel time).

In conclusion, the loglogistic function is found to have the highest correlation using the travel data from the Dutch National Travel Survey. Hilbers & Verroen (1993) also drew this conclusion based on 1990 travel data from the Dutch National Travel Survey. So in this report, loglogistic distance decay functions are estimated for the application of the potential

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[3] Note that the observed trip likelihood is not a smooth line; this has to do with the format of the travel time data from the National Travel Survey.

accessibility measure, Joseph and Bantock's measure and the doubly constrained model. Negative exponential functions are estimated for the utility-based accessibility measure, i.e. the equation of the utility-based measure only allows an exponential function. The results are described in the next section.

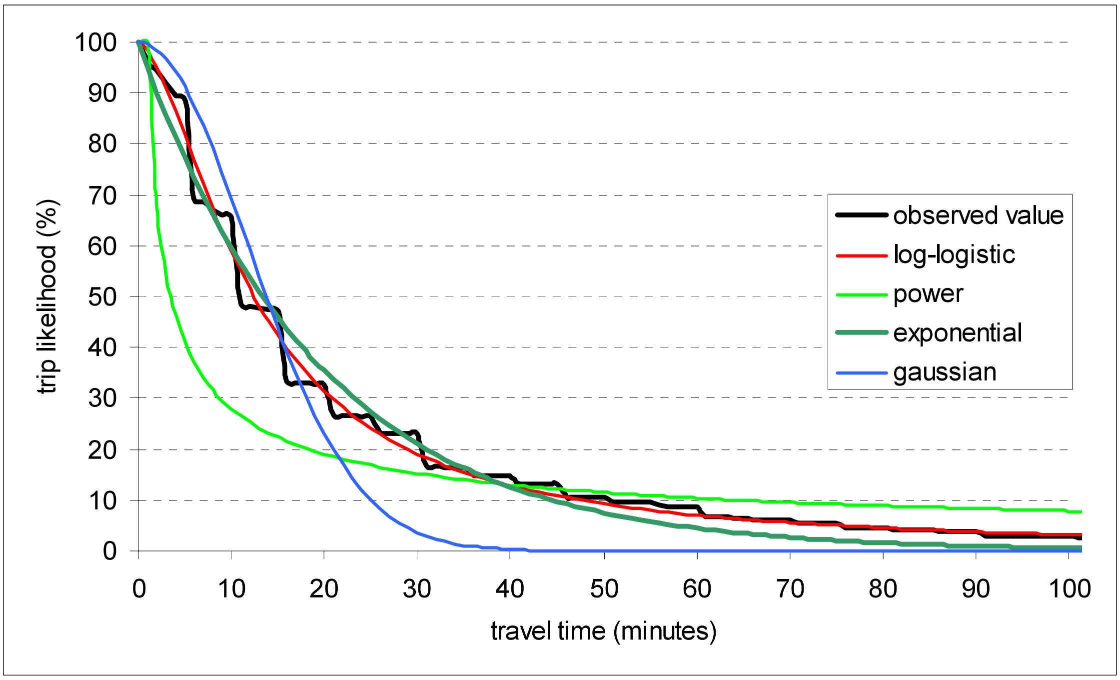

Figure 10.1: Impedance functions (all modes and all trip purposes taken together), 1995.

Note that in this study the impedance functions estimated for 1995 are also used for 2020. Thus it is implicitly assumed that the form of the impedance function is constant in time. However, in reality, travel impedance is probably not constant; for example, due to socio-economic developments like increased income and changes in preferences and attitudes. Furthermore, empirically derived impedance functions may not be valid in a scenario context where radical land-use and/or infrastructural changes are assumed.

10.2.3 Estimated impedance functions by mode, trip purpose and educational level

The perception and valuation of the 'travel resistance' (time, costs and effort) between an origin and destination influences the attractiveness of that location, i.e. when the travel resistance to access a certain destination is high (compared to other destinations), this destination will be considered less attractive, and people are less likely to visit the destination. In general, the perception and valuation of travel resistance differ among transport modes, trip purpose, characteristics of the individual (e.g. income, educational level) and the destination (e.g. diversity of shops at the destination) (see also Section 3.2.2). Thus, in general, (a certain level of) differentiation of impedance functions according to these characteristics will improve the result of the accessibility measure.

With the use of the Dutch National Travel Survey, impedance functions can be estimated by mode (i.e. car driver, car passenger, bus/tram/subway, train, motorcycle, moped, walking, bicycle), trip purpose (i.e. work and business; social, recreational and medical trips) and household characteristics (e.g. gender, age, income and educational level).

In this study, impedance functions are estimated for each mode (car, public transport) separately. As a result, the impedance functions are based on different trip markets, i.e. different users, a different number of trips (the number of car trips in the Travel Survey being about four times higher than for public transport) and different origin–destination patterns (e.g. public transport is mainly used for longer trips, whereas cars are used for shorter trips). As a result, the accessibility measures applied in the case studies can not be used to compare the absolute level of accessibility by car and public transport, whereas the (relative) regional distribution of accessibility can indeed be compared.

Figure 10.2 shows the differences between the estimated (loglogistic) impedance functions for car and public transport trips for several purposes (i.e. work, recreation, shopping and social trips). Figure 10.3 shows the (loglogistic) impedance functions for home-to-work trips for three educational levels, i.e. low (no education, primary education), medium (lower vocational to education) and high (higher vocational education, university).

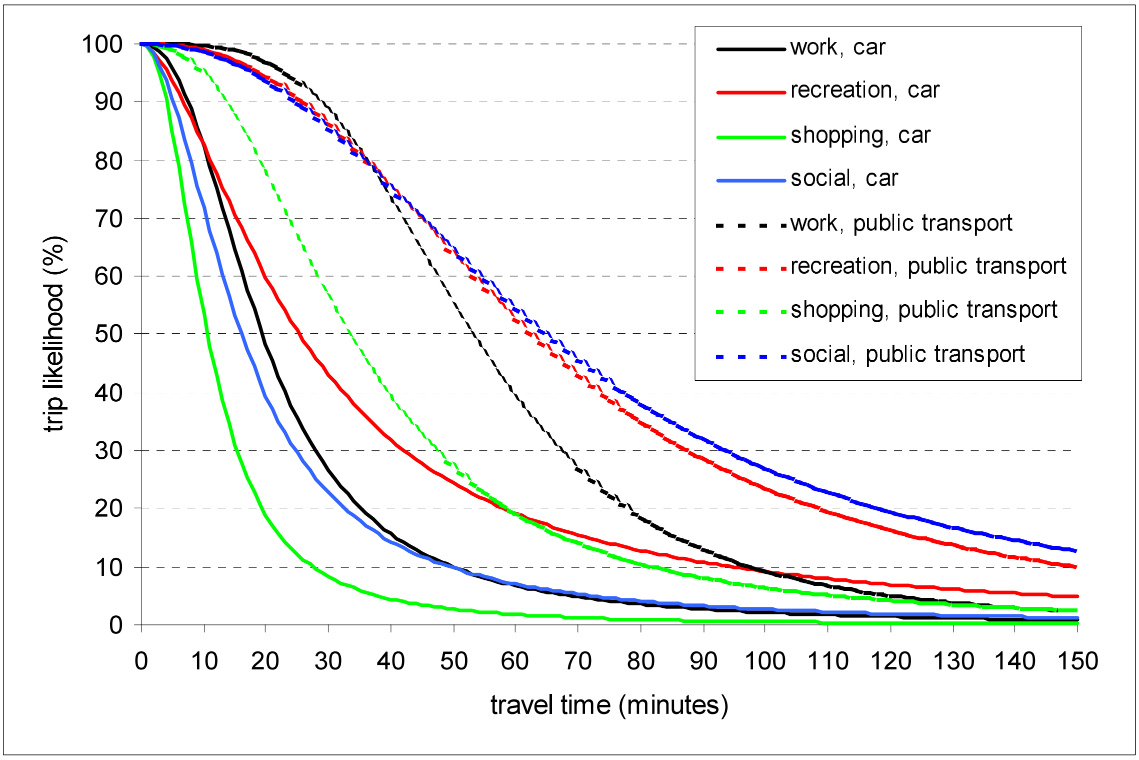

Figure 10.2: Loglogistic impedance functions according to mode and trip purpose, 1995.

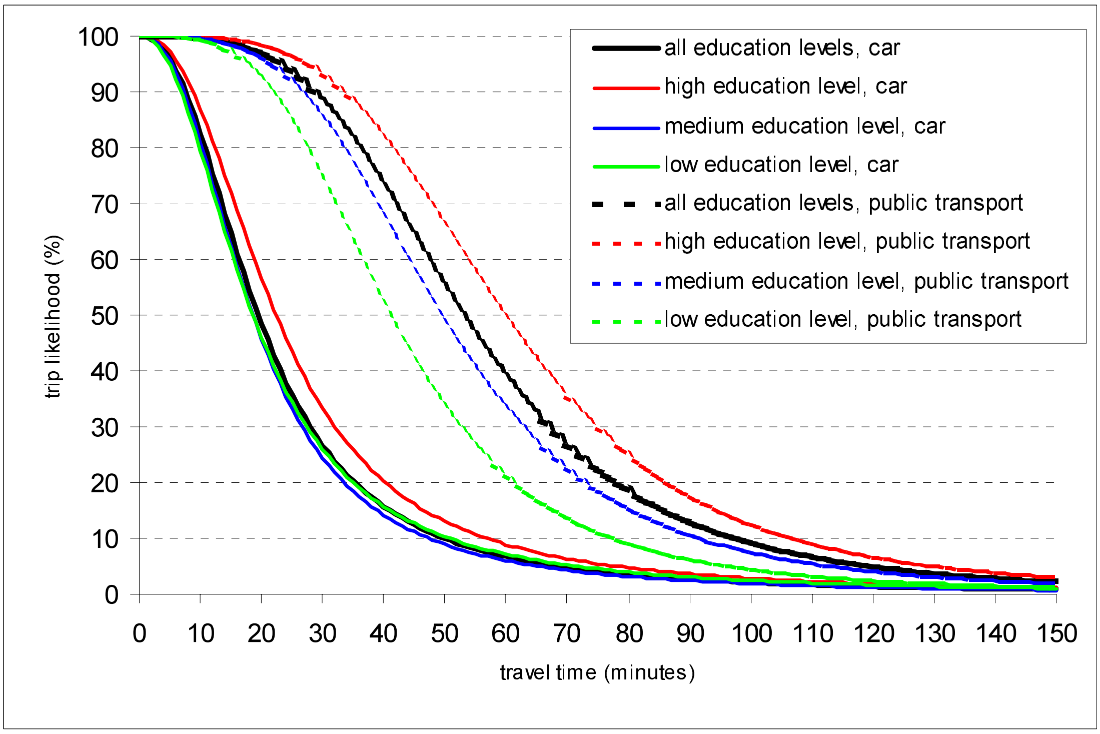

Figure 10.3: Loglogistic impedance function by mode and educational level, 1995.

Figure 10.2 shows that the decay of the impedance function differs highly between trip purpose and travel mode. Shopping trips show the strongest decay whereas recreational and social trips show the weakest decay, both for car and public transport. The distance decay for car trips for all trip purposes is stronger than for public transport trips, implying that the attractiveness of a location for public transport is much less dependent on the travel time to that location than for transport by car. Public transport is typically used for relatively long home-to-work trips. As an illustration, the average home-to-work distance by car in the Netherlands in 1995 was about 20 km, compared to roughly 40 km by public transport (CBS, 1996). Figure 10.2 shows, for example, that 75% of all home-to-work trips by car is shorter than 30 minutes travel time, compared to 5% by public transport; 10% of all home-to-work trips by car take longer than 50 minutes, compared to 50% trips by public transport.

Figure 10.3 shows that the differences in the travel time decay between educational levels are much greater for public transport trips than for car trips. The decay is the lowest for highly educated workers using public transport (which accounted for about 5% of all home-to-work trips in 1995). For instance, about one-half of these trips takes longer than one hour.

The valuation of travel resistance also differs among income groups. In this study, impedance functions are estimated for three income groups (based on the Dutch National Travel Survey), i.e. a low-income level (net income of less than 13,600 Euro per year), a medium-income level (between 13,600 and 22,700 Euro per year) and a high-income level (more than 22,700 Euro per year). Here, only negative exponential impedance functions are estimated, because this function is used in the utility-based accessibility measure. As the utility-based accessibility measures uses travel costs and not travel time as impedance, travel costs must also be derived.

Ideally, the use of generalised costs in the accessibility measure is preferable, including travel distance, travel time, and other costs (see Section 3.2.2). However, in this study only travel times are used as costs, done by multiplying the travel times (from the National Travel Survey) by a time value. As a result, the estimated negative exponential functions based on the travel times from the Travel Survey can be easily transformed to travel costs. HCG (1998) gives time values for the Netherlands for 1997 by mode (car, train and bus/tram), gross household income for 4 income groups: 1- less than 16,300 Euro; 2 - 16,300 to 27,200 Euro; 3 - 27,200 to 40,800 Euro, and 4 - more than 40,800 Euro) and travel purpose (home-to-work, business and other). Unfortunately, the income definition differs between the HCG study and the National Travel Survey, i.e. the HCG study uses gross household income whereas the Travel Survey uses net individual income. Here, it is assumed that the values of time from the lowest and highest income groups from the HCG study can be used for the low and high income groups from the travel survey, and the average time value of the two middle income groups (16,300 to 40,800 Euro) for the medium income group. The time values used are shown in Table 10.1.

Table 10.1: Values of time for the Netherlands (Euro per hour, 1997 values)

	Car	Public transport
Average	14.5	14.6
Low income (less than 16,300 Euro gross household income)	11.2	10.2
Medium income (16,300 to 40,800 Euro)	11.5	12.4
High income (more than 40,800 Euro)	19.9	21.3

Source: HCG (1998)

Figure 10.4 shows the resulting negative exponential impedance functions for home-to-work trips by car and public transport by three income levels.

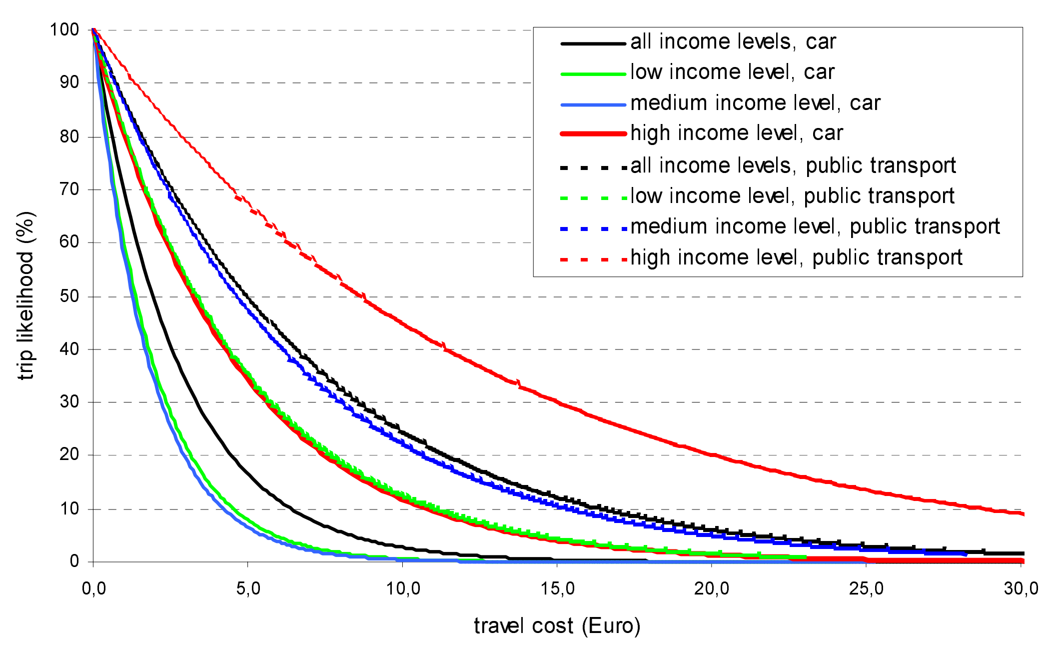

Figure 10.4: Negative exponential impedance functions by mode and income level.

Figure 10.4 show the differences between the low and medium income groups to be small, and between high and medium income groups to be relatively large. This is mainly due to the relatively high time value for high-income workers. High-income workers using public transport (accounting for less than 4% of all home-to-work trips) have a very slow decay, i.e. more than 50% of these trips have a travel (time) cost of more than 7.5 Euro.

10.3 Land-use scenario construction

10.3.1 Introduction

In this study, the selected accessibility measures are applied to two existing land-use transport scenarios: a Trend scenario and a Tolerant scenario. Several land-use transport scenarios have been developed by the RIVM in the context of evaluating the Dutch 'Fifth Memorandum on Spatial Planning' (VROM, 2001), using Geographical Information Systems and land-use models. The methodology for the Trend scenario and models used is described in detail by Goetgeluk *et al.* (2000) and for the Tolerant scenario by Crommentuijn *et al.*(2001).

This section describes in brief the land-use models used (Section 8.4.2), the characteristics of the two land-use scenarios and the main assumptions made in the scenario construction (Section 8.4.3). The results of the two land-use scenarios are described in Section 8.4.4 (describing the development of the working population) and Section 8.4.5 (describing the development of jobs).

10.3.2 Land-use models

Trend scenario

To derive land-use forecasts for the Trend scenario, two land-use models were used: the Land Use Scanner (Schotten et al., in prep.; Schotten et al., 1997) for allocating regional population developments to the local level and the Opera model (Louter, 1997) for forecasting employment developments.

The Land Use Scanner is a GIS-based simulation model for the Netherlands providing an integration framework for databases and sectoral policy proposals (e.g. housing policies) by confronting these inputs in a spatial-analytical context. The model is driven by forecasts at a national or regional level (40 regions) in terms of variables such as population, production (by economic sector) and infrastructure developments. These developments determine regional land-use demands by land-use type (e.g. residential, industrial, infrastructure, agriculture and nature areas). The land-use demands are based on present land-use patterns, and suitability and attractiveness of grids for certain types of land use allocated to a 500 x 500-m grid level. The attractiveness of grids for housing is based on a regression analysis of location factors for residential construction for the 1980-1995 period, including accessibility to work locations and nature areas, proximity to other residential areas and proximity to road and rail infrastructure (see Wagtendonk & Rietveld, 2000; Schotten et al., in prep.). The result is a forecast of the relative proportion of land to be used for each land use for each grid. Finally, residential land uses (on a 500 x 500-m grid) are translated into forecasts of the housing stock (single- and multiple-family dwelling houses), number of inhabitants (by age) and the number of households.

The Opera model is a shift-and-share model forecasting economic development per municipality and 4-digit postal codes for 7 economic sectors and 44 subsectors. Firstly, the share in the national economic development (by sector) is derived for each municipality. Secondly, the difference (the shift) between the actual economic development and the expected economic development for the 1973-1992 period is estimated for each economic development (by sector) in the basis of a regression analysis of location factors for each economic sector, including population developments (here: derived from the Land Use Scanner). Thirdly, the economic development for each municipality is translated into developments by postal codes, based on a regression analysis of explanatory factors for the period 1991-1996, including the density of housing and employment, the relative share of employment and the proximity to road and rail infrastructure.

Tolerant scenario

The Tolerant scenario is constructed using the Socrates housing market simulation model (Heida & Poulus, 2000) to estimate population developments and the OPERA model to estimate employment developments.

The Socrates model is a housing-market simulation model estimating housing demand and supply on a regional housing market, as well as the confrontation between demand and supply. The model uses regional housing demands (40 (COROP) regions) as a basis for the estimation of housing developments on the local level (on the level of 4-digit postal codes, comprising almost 3940 areas). The housing demand is split up by 72 household types[4], categorised by five characteristics, including income and educational level. Developments of the housing demand are determined by demographic developments (e.g. birth rate, migration) and economic developments (e.g. household income). Housing supply is split into 25 housing types[5]. Developments of the housing supply are determined by new housing developments, demolition, housing transformation (e.g. joining houses) and neighbourhood transformation (e.g. increasing or decreasing housing densities may change the neighbourhood type).

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[4] Households are categorised by household type (singles, couples living together), age (30 years or less, 30-65 years, older than 65 years), educational level (low/medium and high), income (four classes: less than 13,600 Euro, between 13,600 and 22,700 Euro, between 22,700 and 36,300 Euro, more than 36,300 Euro) and demand type (starter, mover).

[5] Housing supply is categorised by dwelling type (single or multiple), property type (owner-occupied or rental), size (2 classes), price (3 classes) and five neighbourhood types, i.e. ‘Central Urban’, ‘Peripheral Urban’, ‘Green Urban’, ‘Rural Village’ and ‘Peripheral Rural’.

Furthermore, the attractiveness of an area as a housing location is determined by urban attractiveness[6] and attractiveness of the landscape[7]. The models' output comprises (for each 4-digit postal code) the number of households by household type (age, educational level and income group) and housing type, and the number of inhabitants according to age for the 1998-2020 period.

The Opera model is also used for the Tolerant scenario to forecast employment developments using the population forecasts from the Socrates model as input.

10.3.3 Land-use scenarios

This section characterises the Trend and Tolerant scenarios in brief and describes the assumptions made specifically for the computation of the land-use data used as input for the accessibility analysis.

In principle, two approaches can be taken when simulating population developments: a 'supply-oriented' and a 'demand-oriented' approach. In a 'supply-oriented' approach housing supply is driven by (restrictive) land-use policies. This approach is more-or-less taken in the Trend scenario, where planned housing locations up to 2010 are realised. The Trend scenario can be seen as the continuation of current land-use trends, assuming the realisation of planned housing locations for the 1995-2010 period, as formulated in the Update of the National Policy Document on Spatial Planning (VROM, 1997), and where the housing demand for the period 2010-2020 is allocated according to historical trends (1980-1995). The scenario is presented as a reference scenario for evaluating the impacts of new land-use policies, as formulated in the Fifth Memorandum on Spatial Planning (VROM, 2001).

Alternatively, a 'demand-oriented' approach can be taken, where housing supply is determined by household preferences. This approach is taken in the Tolerant scenario, where the planned housing locations for the 1995-2010 period are realised only if the plans are in an advanced stage and/or meet consumer preferences.

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[6] Heida & Poulus (2000) derive the attractiveness of neighbourhoods from surveys from Statistics Netherlands, in which the neighbourhood satisfaction of households is determined by postal code-based surveys. Peripheral Urban areas have the highest satisfaction level, Central Urban, Peripheral Urban and Green Urban neighbourhoods have a (roughly equal) lower satisfaction level.

[7] The attractiveness of the landscape is determined by the distance from home locations to recreational areas and recreational attractiveness, which is based on survey results (see Crommentuijn *et al.,* in prep.).

Land-use data for the Trend scenario

For computing the accessibility measures for the Trend scenario, the output of the Land Use Scanner and the Opera model for the Trend scenario is used in two ways. Firstly, the number of inhabitants by age group and the number of jobs by sector are used as input for the transport model (i.e. the National Model System - see Section 10.5) to estimate the average travel times between origins and destinations. For this purpose, the output of the Land Use Scanner (500 by 500-m grid cells) and Opera (4-digit postal codes) is first aggregated to the level of 1308 zones of the National Model System. Secondly, the working population[8] and the number of jobs (on the level of 1308 zones) are used as input for the accessibility calculations.

The Land Use Scanner does not forecast population developments by educational or income level, in contrast to the Socrates model. Thus the accessibility computations for the Trend scenario can not disaggregated by socio-economic groups.

Land-use data for the Tolerant scenario

The relevant output from the Socrates model (the number of households by type and inhabitants by age) on the level of 4-digit postal codes is also aggregated to the level of 1308 zones to serve as input for the National Model System and the accessibility calculations.

To analyse the effect of incorporating the match between workers' educational level and job requirements in the estimation of accessibility, the working population and employment are split up by educational level. The educational level of the working population for the 1995-2020 period is derived as follows. Firstly, the share of low to medium- and high-educated households (for each zone) for 1998 from the Socrates model are used to estimate the number of workers by educational level for 1995. Secondly, the development of the educational level of the working population for the Tolerant scenario for the 1995-2020 period is derived from the development of the household educational level given by the Socrates model.

The educational requirements of jobs can not be directly derived from existing data from Statistics Netherlands[9]. Here, the data are derived as follows. Firstly, the average educational requirement of jobs for each working location for 1995 is derived from the Dutch National Travel Survey for 1995. The 1995 travel survey gives the destination (working) location (on the municipality level) for about 90,000 home-to-work trips for of the Dutch population, which can be split by workers' education level. These figures are used to estimate the share of low-, middle- and high-education jobs for 650 municipalities taken as the average for the (1308) zones located within the municipal boundaries. Multiplied by the total number of jobs per zone for 1995 gives the number of jobs by education requirement. Note that this method does not

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[8] The working population is defined as the number of employed persons between 15 and 64 years working 12 hours or more per week. The working population for the Trend and Tolerant scenario (on the level of 1308 zones) was derived by the Hague Consulting Group from the number of inhabitants by age groups, corrected for unemployment.

[9] In the Netherlands, two data sources from Statistics Netherlands are available to derive the education level from workers, i.e. the Working Population Survey (EBB) or the National Travel Survey (OVG). Here, the OVG is used because of the consistancy with the other data used (i.e. the OVG is also used to estimate the distance decay functions) and the larger sample size of the survey.

account for the current mismatch in workers education level and the educational requirements of jobs, e.g. a high-educated worker having a job with medium or low educational requirements. Secondly, the development in the educational requirements of jobs for the Tolerant scenario for the 1995-2020 period is taken at the level of 40 (COROP) regions from the CPB (1997). Thus, all zones within the boundary of a region are assumed to have the same development.

To analyse the effect of incomes on job accessibility, accessibility is also analysed by income groups. For practical reasons, this is only done for the utility-based accessibility measure. Three income groups are used on the basis of the Socrates model: low (less than 13,600 Euro net yearly household income), medium (13,600 to 36,300 Euro) and high (more than 36,300 Euro). The Socrates model gives households by income level on the level of 4-digit postal codes for the period 1998-2020. To derive the number of inhabitants by income level for the base year 1995, it is assumed that the share of inhabitants by income level equals the 1998 figures for households from the Socrates model. Furthermore, the development of incomes for the Tolerant scenario for the 1995-2020 period are taken directly from the Socrates model.

In this report, the Trend and the Tolerant scenario are developed within the context of long-term economic developments from the Netherlands Bureau for Economic Policy Analysis (CPB, 1997). This Bureau (CPB in Dutch) developed three long-term economic scenarios, i.e. 'Divided Europe', 'European Co-ordination' and 'Global Competition'. In this study, the Tolerant and Trend scenarios are estimated within the economic context of the European Co-ordination scenario, in which economic growth is moderate, household growth is moderate and population growth is high. However, for the Tolerant scenario, a partial update of CPB scenarios is used. As a result, the total number of jobs, working population and inhabitants slightly differ from the Trend scenario for 2020. Table 10.2 shows the number of jobs (by educational level), inhabitants (by income level) and the working population (by educational level) for the Trend and Tolerant scenarios for 1995 and 2020.

Table 10.2: Jobs, inhabitants and working population for the Trend and Tolerant scenarios, 1995 and 2020

	1995	2020 Trend scenario		2020 Tolerant scenario	
	Total (million)	Total (million)	Index 1995-2020	Total (million)	Index 1995-2020
Number of jobs	5.9	7.5	128	7.8	133
low to medium educational level	4.2 (72%)	n.a.	n.a.	5.5 (71%)	131
high educational level	1.7 (28%)	n.a.	n.a.	2.3 (29%)	138
Working population	6.0	7.8	129	7.7	128
low to medium educational level	4.5 (74%)	n.a.	n.a.	4.9 (64%)	111
high educational level	1.5 (26%)	n.a.	n.a.	2.8 (36%)	177
Number of inhabitants	15.4	17.8	115	17.9	116
low income (0-13,600 Euro)	5.0 (32%)	n.a.	n.a.	2.5 (14%)	50
medium income (13,600-36,300 Euro)	8.8 (56%)	n.a.	n.a.	10.5 (59%)	120
high income (> 36,300 Euro)	1.6 (10%)	n.a.	n.a.	4.9 (26%)	297

n.a. = non-applicable

The table shows that for 1995 the number of jobs almost equals the working population, whereas for the Trend scenario the number of jobs is somewhat less, and for the Tolerant scenario somewhat more. However, for the accessibility computations the development of the educational and income level is more important. The table shows that the educational skills of the working populations grow much quicker than the educational requirements of jobs. As a result, job competition for highly educated workers will increase sharply, i.e. the number of highly educated workers increases by more than 75% and the number of jobs by about 40%. On the other hand, competition for jobs with a low to medium educational level will be much lower: in 1995 there was a surplus of low- to medium-educated-workers but in 2020 this has become a shortage.

Furthermore, the table shows the substantial income development for the period 1995 to 2020, i.e. the number of inhabitants with a low income level decreases by about 50%, whereas the number of inhabitants with a high income level increases by about factor 3.

10.3.4 Spatial development of the working population

Trend scenario

Figure 10.5 shows the spatial distribution of the working population (number of employed people per hectare) in the Netherlands in 1995. The figure shows the western part of the Netherlands as the most urbanised area (highest number of working persons per hectare). This highly urbanised area is also called the ‘Randstad’ and is roughly marked as the (horseshoe-shaped) region comprising (the four largest Dutch cities) Rotterdam, The Hague, Amsterdam and Utrecht (see Figure 10.6). Other relatively urbanised areas are found more to the east (roughly the area around the cities of Arnhem and Nijmegen) and the southeast (the region comprising Breda, Den Bosch, Eindhoven and Helmond, also called the ‘Brabantstad’ area – see Figure 10.6).

Figure 10.6 shows the spatial distribution of the working population for 2020 according to the Trend scenario; Figure 10.7 shows the development for the 1995-2020 period. The figures show the continuation of land-use policies and historical urbanisation trends for 2020. The land-use policies (VROM, 1997) are relatively successful in focusing on building in and near existing towns (in relatively high housing densities) and metropolitan areas. As a result of restrictive policies, central and suburban areas of large and middle-sized towns show a population increase whereas peripheral areas show a modest increase or stabilisation of the population. Furthermore, Figure 10.7 also shows new housing locations near existing towns, e.g. the housing location (called the Leidsche Rijn) comprising more than 50,000 inhabitants west of Utrecht. The Trend scenario shows the continuation of urbanisation trends which have been present in the past decades in the Netherlands (see, for example, WRR, 1998), moderated by national land-use policies. Firstly, the continuation of the population shifts from the Randstad area to the middle and eastern parts of the Netherlands (a process of national deconcentration of activities). Secondly, the continuation of the population growth in suburban and rural areas (a process of regional suburbanisation). For a more elaborate description of the Trend scenario see Goetgeluk *et al.* (2000).

Tolerant scenario

Figure 10.8 shows the spatial distribution of the working population for 2020 according to the Tolerant scenario; Figure 10.9 shows the development for the 1995-2020 period. The figures show the development of the working population if consumers' housing preferences are assumed to determine housing developments in the Netherlands. The Tolerant scenario shows a clear shift from the Randstad Area (especially from the three largest towns -Amsterdam, Rotterdam and The Hague) to the middle and eastern part of the Netherlands where more land is available for relatively low-density housing locations in or near attractive landscapes (e.g. nature areas, woodlands and national parks). Figure 10.10 shows the differences between the Tolerant and the Trend scenarios. This figure clearly shows that the population shift from central and suburban areas of large and middle-sized towns inside and outside the Randstad Area to suburban and peripheral rural areas. Compared to the Trend scenario, population growth is more equally distributed in space due to a lack of restrictive land-use policies. Furthermore, Figure 10.10 shows that planned housing locations, as assumed in the Trend scenario (e.g. locations to the west and south of Utrecht, near Almere), are not fully developed in the Tolerant scenario.

In summary, the Tolerant scenario can be described as a scenario with a high level of national deconcentration (i.e. a substantial population shift from the Randstad to the middle and eastern parts of the Netherlands) and regional suburbanisation (i.e. a shift from towns to surrounding municipalities). For a more elaborate description of the Tolerant scenario see Crommentuijn *et al*. (2001).

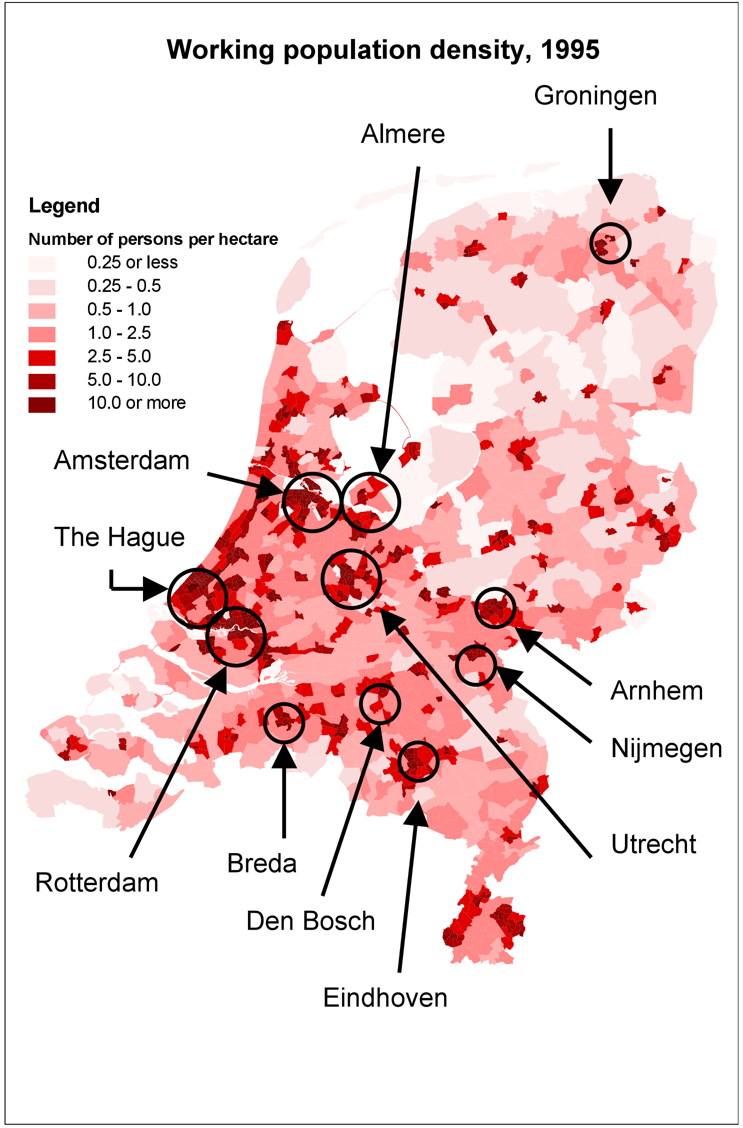

Figure 10.5: Working population density, 1995.

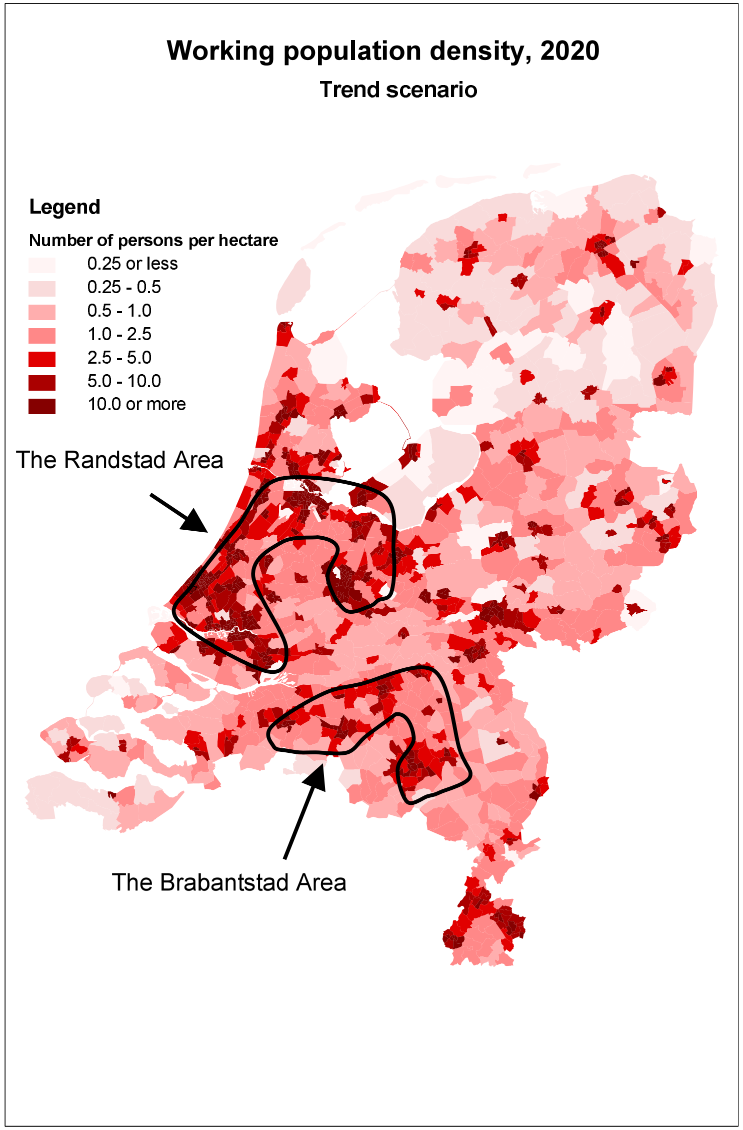

Figure 10.6: Working population density, Trend scenario 2020.

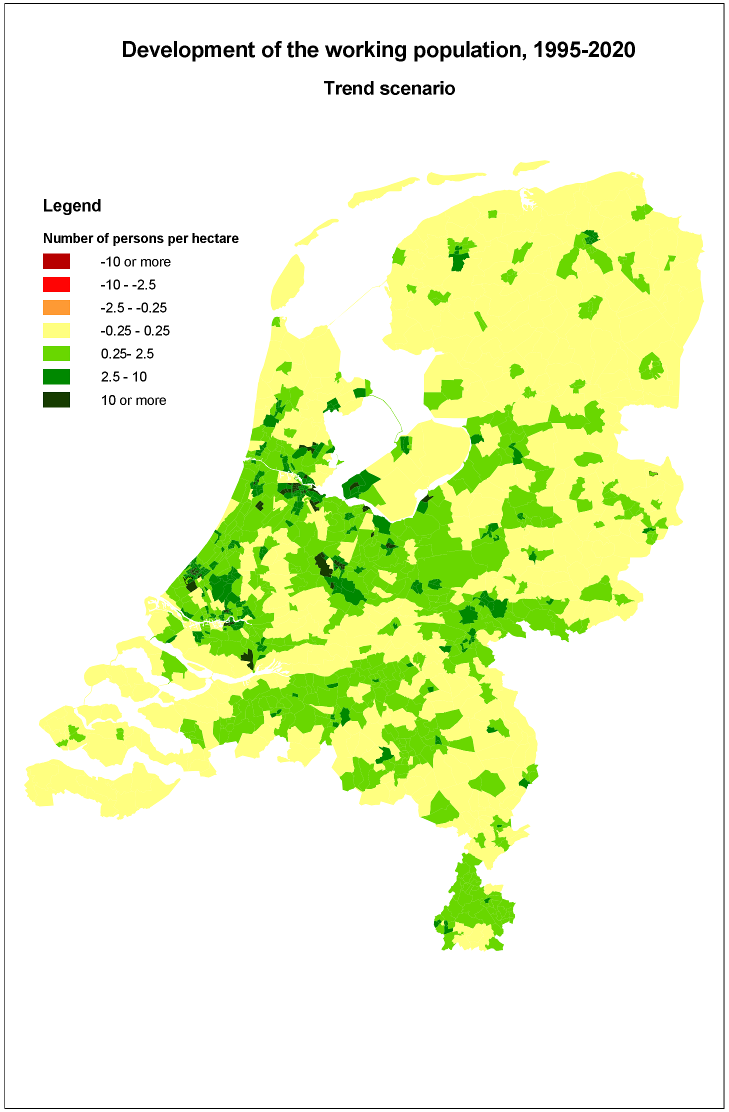

Figure 10.7: Development of the working population density, Trend scenario 1995- 2020

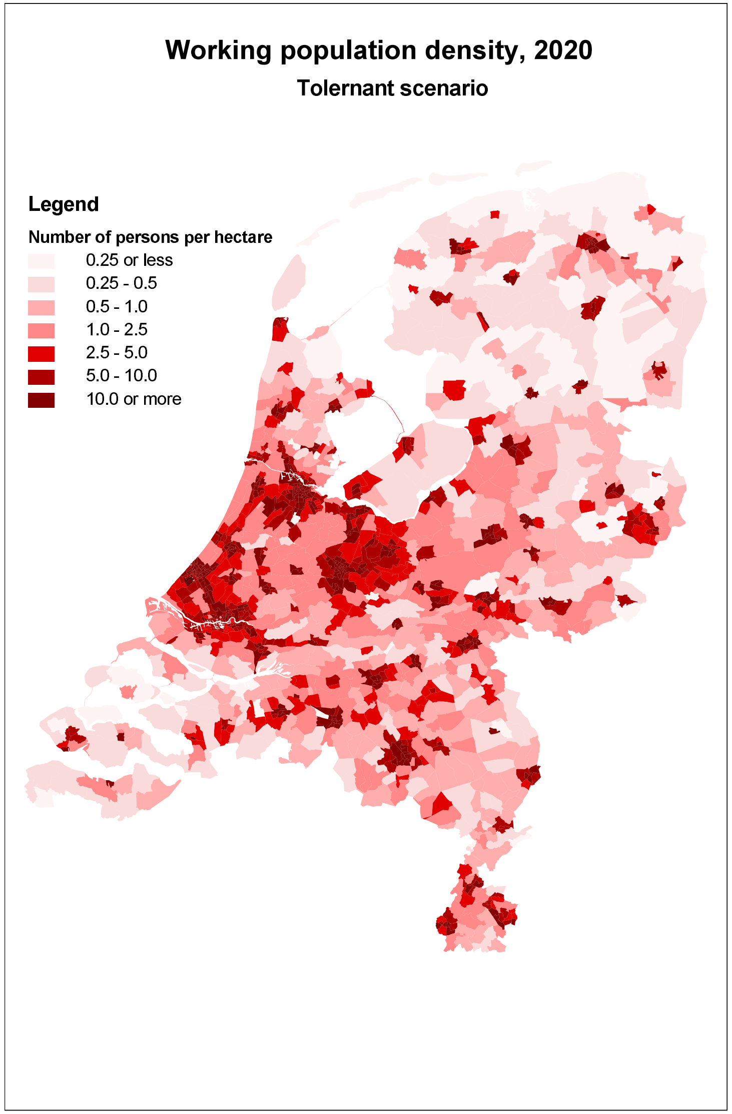

Figure 10.8: Working population density, Tolerant scenario 2020

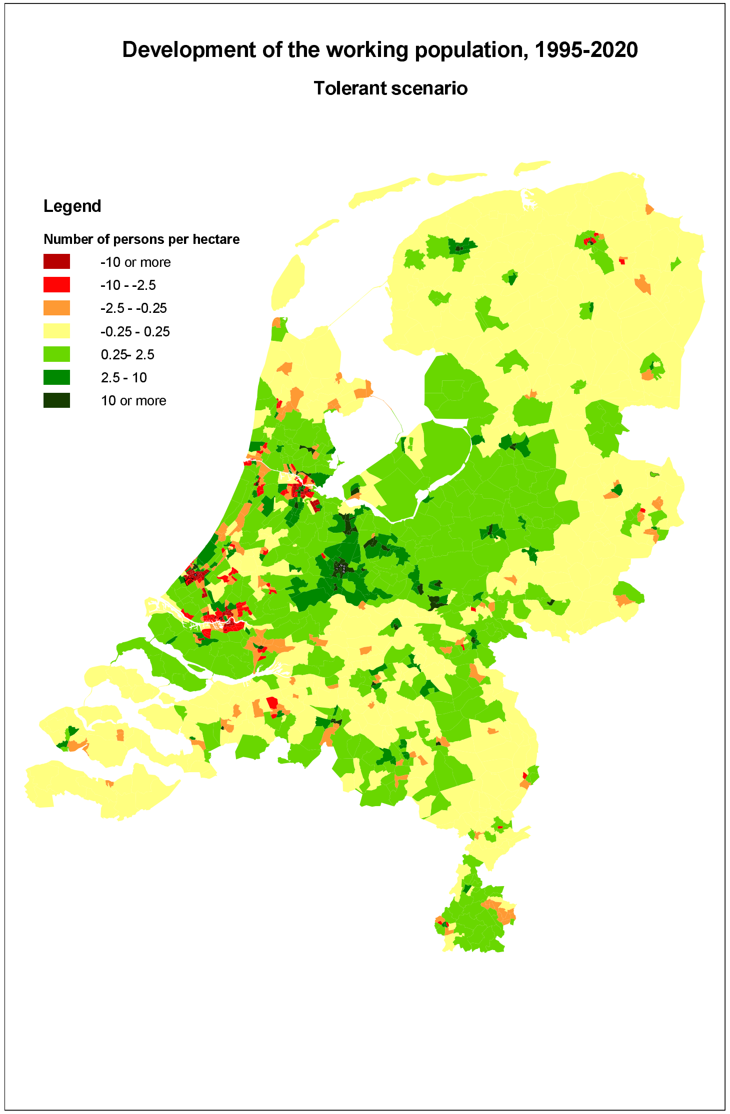

Figure 10.9: Development of the working population density, Tolerant scenario 1995- 2020.

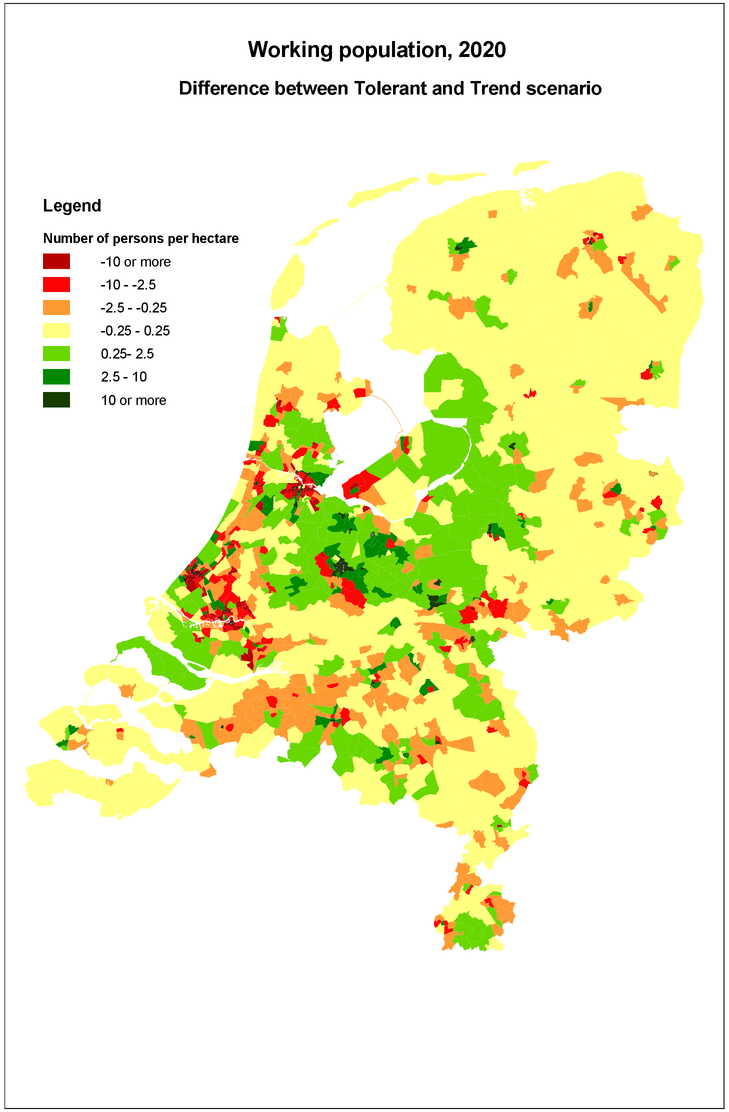

Figure 10.10: Difference between the working population density in the Tolerant and Trend scenarios, 2020.

10.3.5 Spatial development of jobs

Trend scenario

Figure 10.11 show the density of jobs (number of jobs per hectare) in 1995. The figure clearly shows the highly urbanised Randstad Area. Other relatively urbanised areas are found more to the east (roughly the area around Arnhem and Nijmegen) and the southeast (the Brabantstad Area). Compared to the working population (Figure 10.5), employment is more concentrated in and around cities.

Figure 10.12 shows the spatial distribution of jobs according to the Trend scenario in 2020. Figure 10.13 shows the development of job density for the 1995-2020 period. Both figures show a gradual increase in job density, especially in the suburban areas, which were already relatively highly urbanised in 1995 (e.g. in the western part of the Netherlands). Inner cities show a relatively stable (Amsterdam) or decreasing number of jobs (Rotterdam, Utrecht, The Hague). The largest employment growth is concentrated in suburban areas of the Randstad (e.g. the area between The Hague and Rotterdam, southwest of Amsterdam). This process of spatial deconcentration of employment is caused mainly by lack of space, congestion and high land-use costs for offices in cities. In conclusion, the Trend scenario continues the process of spatial deconcentration of employment in the Netherlands. For a more elaborate description of the Trend scenario, please refer to Goetgeluk *et al.* (2000).

Tolerant scenario

Figure 10.14 shows the spatial distribution of jobs in the Tolerant scenario in 2020; Figure 10.15 show the development of the job density in the 1995-2020 period. The Tolerant scenario shows a higher level of national deconcentration and regional suburbanisation of employment than the Trend scenario. This Tolerant scenario also shows a clear employment shift from the largest cities (Amsterdam, The Hague and Rotterdam) to the urban (Utrecht) and suburban areas of the central (central-eastern) part of the Netherlands. This is mainly as a result of the population shift. Figure 10.16 shows the difference in the development of density between the Tolerant and the Trend scenarios. This figure shows even more clearly the shift of jobs from the Randstad to the central and central-eastern parts of the Netherlands.

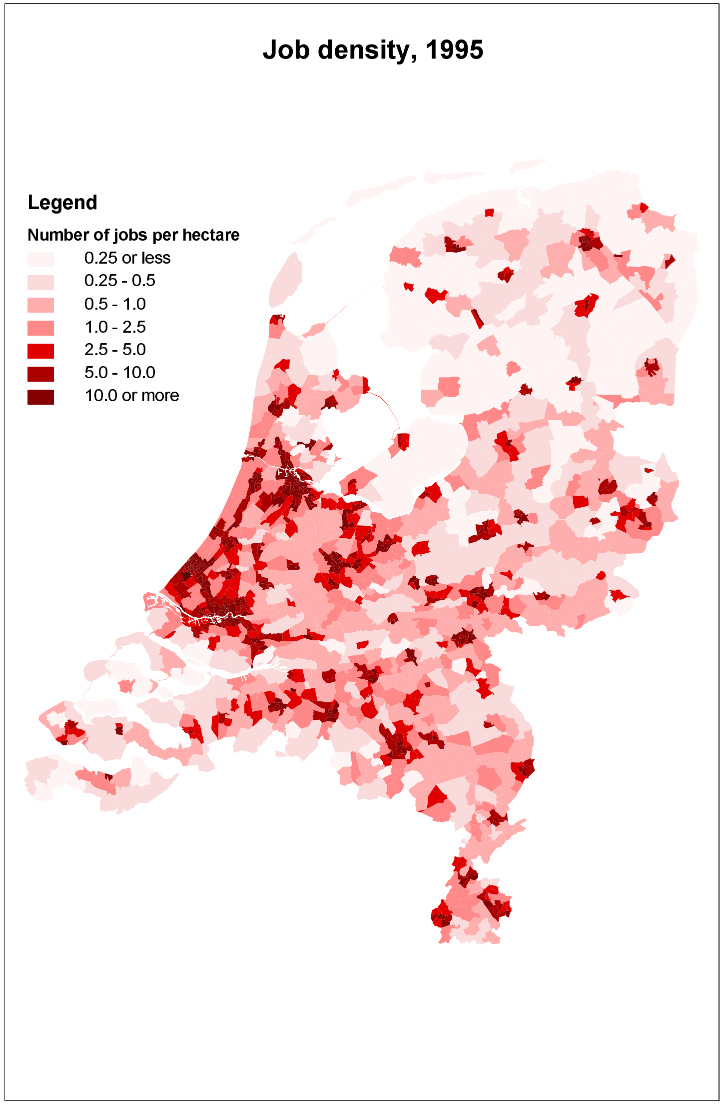

Figure 10.11: Job density, 1995.

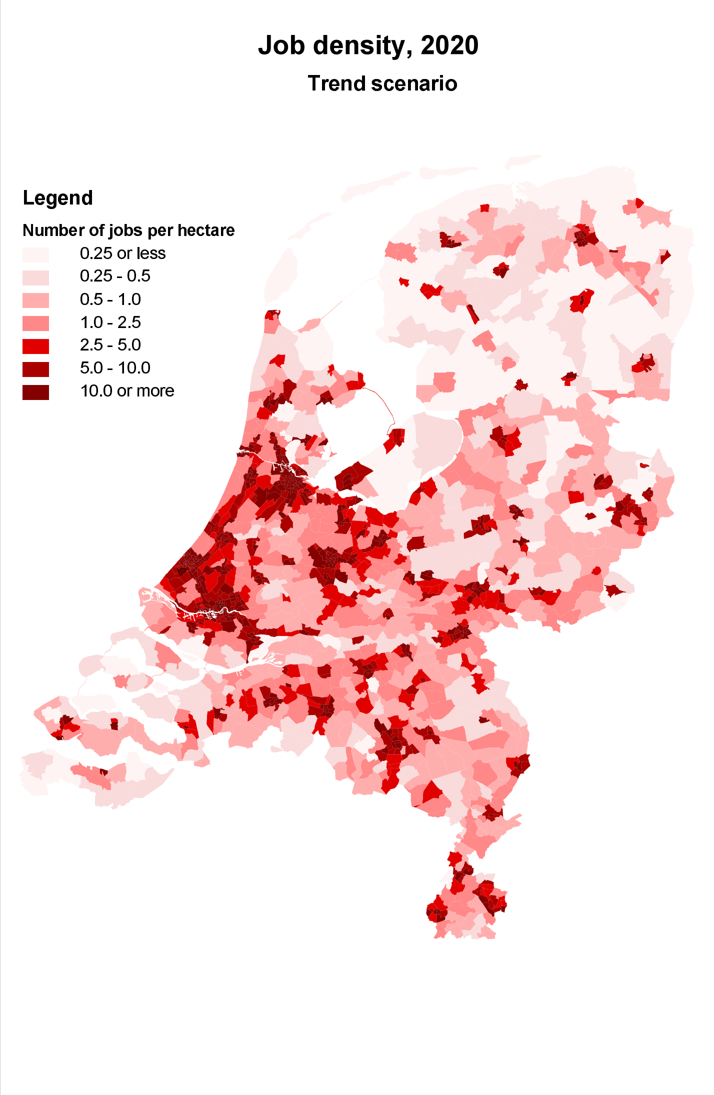

Figure 10.12: Job density, Trend Scenario, 2020 .

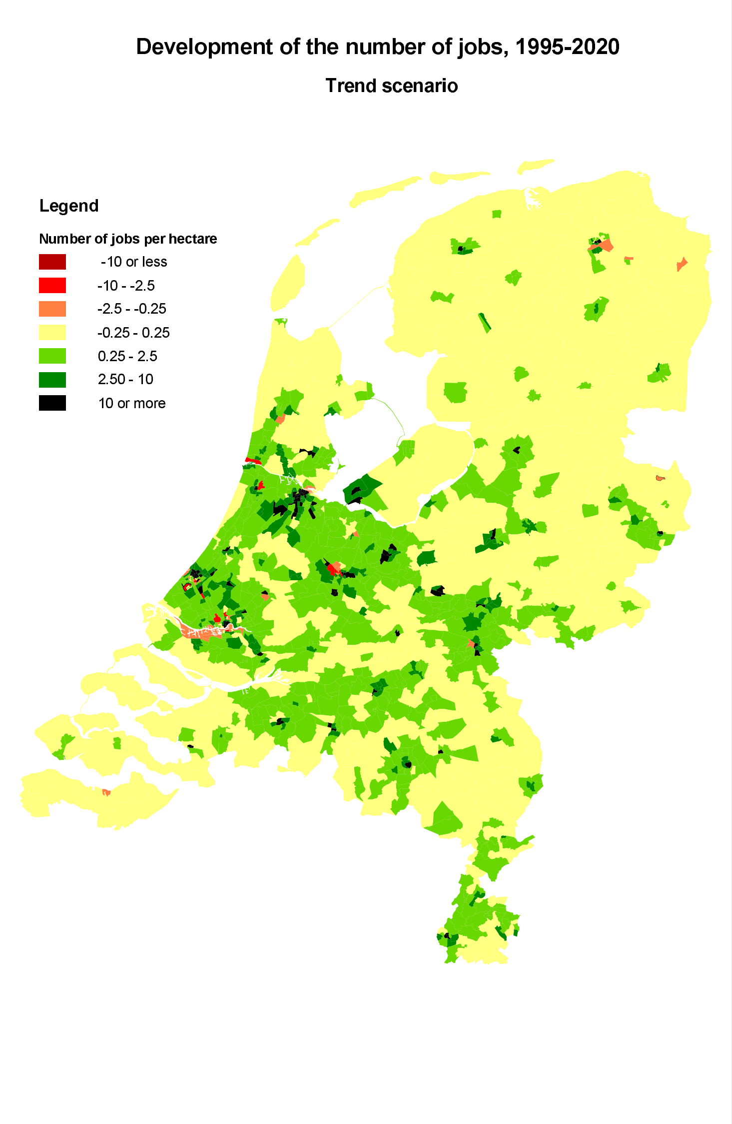

Figure 10.13: Development of job density, Trend scenario 1995- 2020.

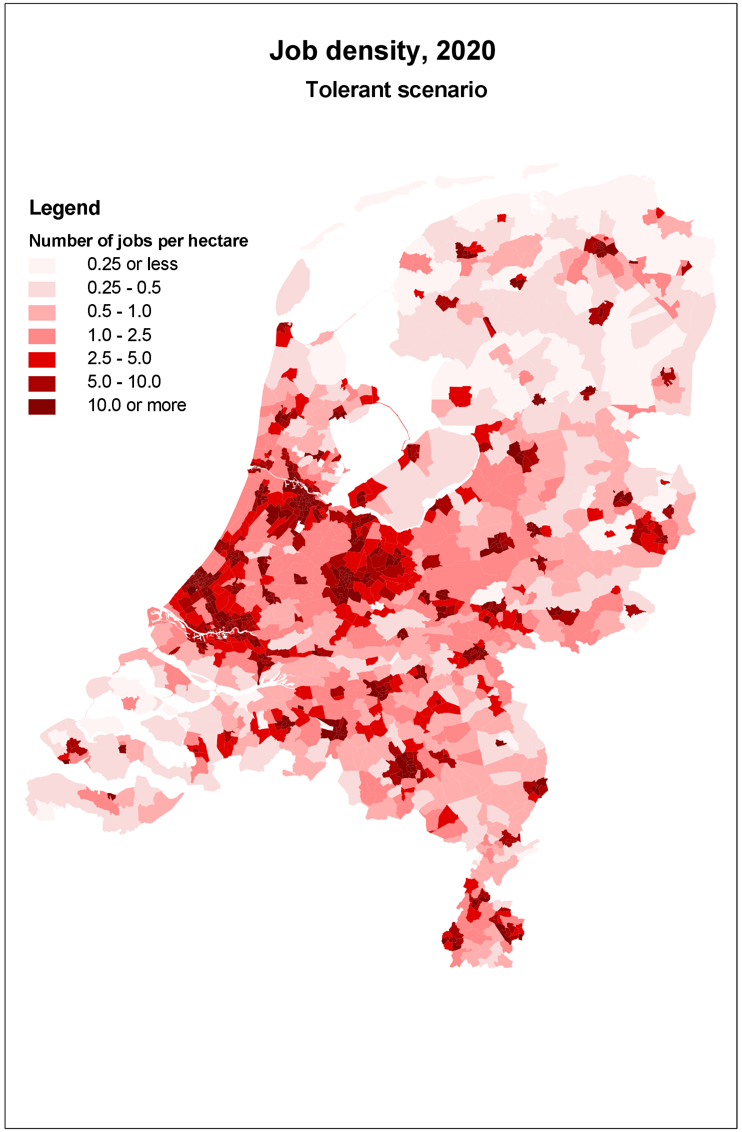

Figure 10.14: Job density, Tolerant scenario 2020.

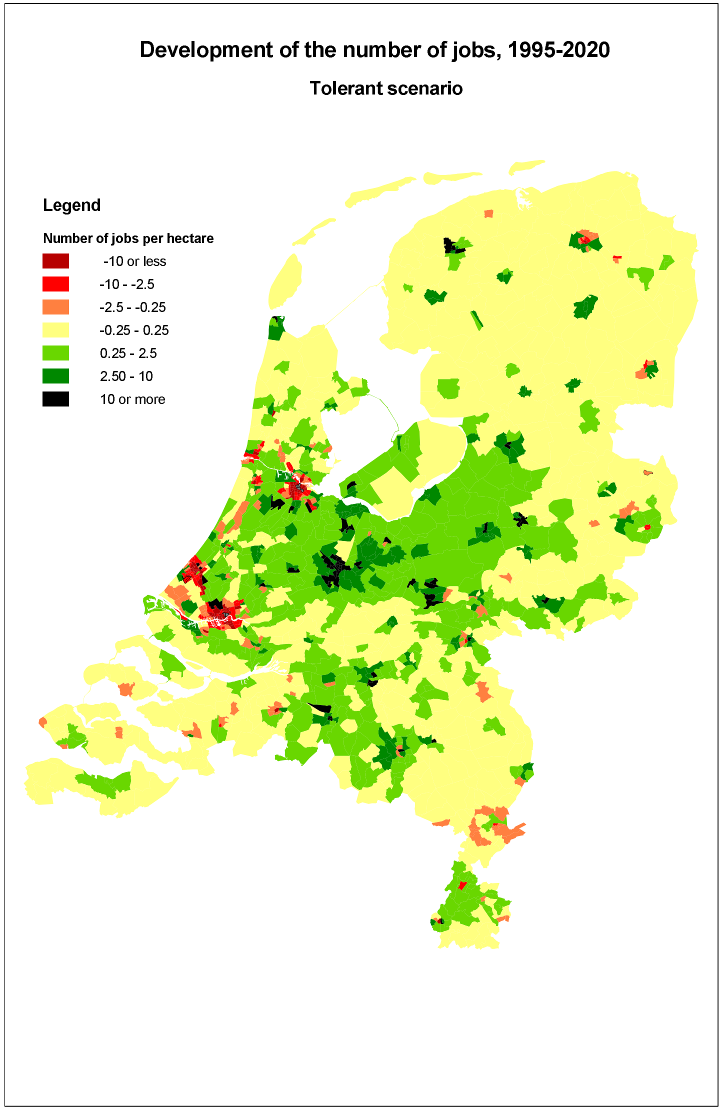

Figure 10.15: Development of job density, Tolerant scenario 1995- 2020.

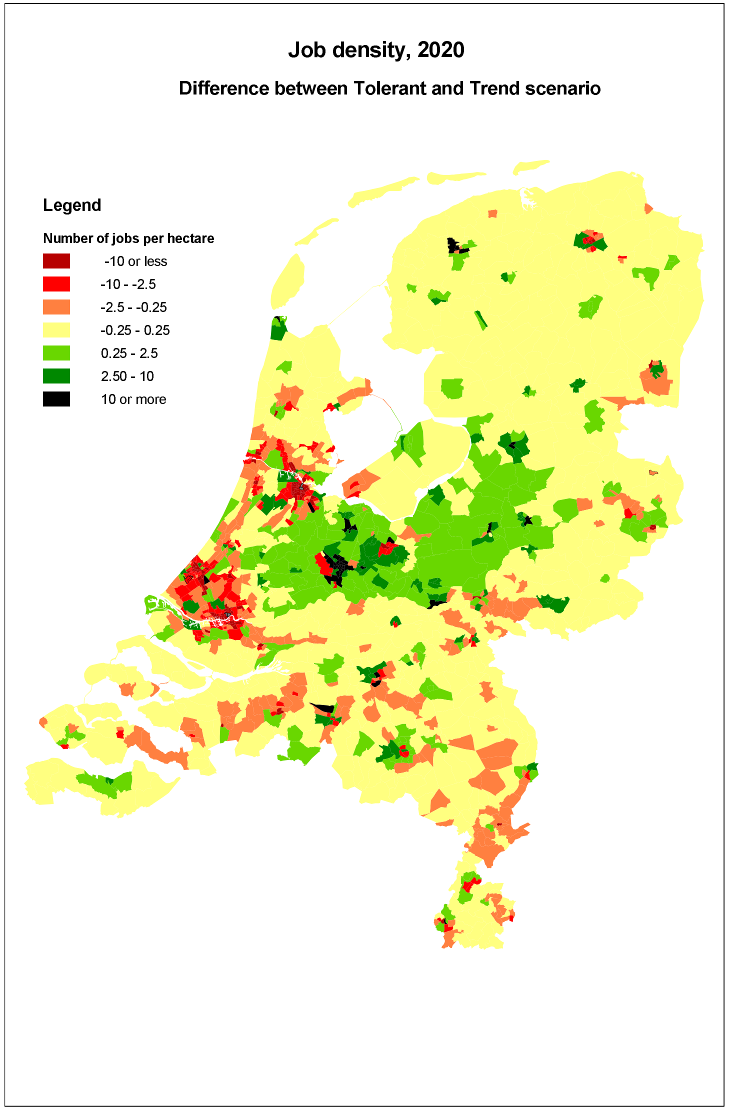

Figure 10.16: Difference between job density in the Tolerant and Trend Scenario, 2020.

10.4 Transport scenario construction

10.4.1 The Dutch National Model System for Transport

The output of the land-use models (Land Use Scanner, Socrates, Opera – see Section 10.4) has served as input for the Dutch National Model System for transport (NMS) (Gunn, 1994; HCG, 1997) to derive the travel times and costs between origins and destinations for the Trend and Tolerant scenarios. The NMS is the main model in the Netherlands to forecast passenger travel and analyse the impacts of transport policies on the national level and is in use since the 1985 (Gunn, 1994).

The NMS is developed as a system of models forecasting long-term developments in travel by all land-based travel modes for the Netherlands according to developments in socio-economic variables (e.g. development in employment, household income), socio-demographic variables (e.g. composition and development of the population) and variables describing the (quality) of infrastructure supply, e.g. travel times, travel costs (e.g. fuel prices, train tickets) and availability of the road network.

The model forecasts passenger travel by mode (car, public transport, walking and bicycling) and purpose (e.g. work, business, school, shopping) and within and between regions or zones. The model uses a spatial distribution of land-use data at the level of 1308 (sub)zones (municipalities or aggregates of 4-digit postal codes). Furthermore, the model forecasts road traffic levels and congestion levels on the main road network and travel demand on the rail network.

Land-use data taken from land-use models (here: the Land Use Scanner, Socrates and Opera - see Section 10.4) - the number of inhabitants by age, the number of workers by gender and the number of households by employment (by economic sector) - are exogenous on the level of subzones. Relevant output of the model is formed by average travel times between all origins and destinations (on the level of 1308 zones) per mode. The following data are used for 1995 and 2020 for the case studies:

- average peak-hour car travel times (including the effect of congestion)
- average free-flow car travel times.
- average (24-hour) public transport travel times. These are average ‘door-to-door’ travel times, including waiting times, transfer times and travel times by access and egress modes.

10.4.2 Transport scenario

To forecast passenger travel with the NMS, assumptions must be made regarding (i) the development of new and existing road and rail infrastructure and (ii) other transport policies, e.g. pricing policies. In the case studies, the Trend and Tolerant scenarios use the same transport infrastructure scenario, comprising modest infrastructure developments. This transport scenario, also called ‘reference scenario’ has been developed by the Transport

Research Centre (AVV) of the Ministry of Transport, Public Works and Water management for the evaluation of National Transport Policy Plan. See for an elaborate description AVV (2000) and Geurs & Ritsema van Eck (2000).

The assumed road and rail infrastructure developments comprise capacity expansions of existing road and rail infrastructure, and the construction of new road infrastructure. Infrastructure plans up to 2010 are assumed to be implemented according to the Transport Infrastructure Plan 2000-2004 (V&W, 1999) The infrastructure projects roughly comprise (a) projects which already have being ordered for realisation up to the year 2010, e.g. the realisation of the high-speed rail links from Amsterdam Schiphol Airport to Frankfurt, Germany and Antwerp, Belgium and (b) project plans in a far advanced stage which are to be realised before the year 2020. Figure 10.17 illustrates the locations (in red) of infrastructure expansions and capacity improvements on the main motorway network for the 1995-2020 period.

Figure 10.17: National road infrastructure expansion scheme for the 1995-2020 period according to the 1999 Transport Infrastructure Plan (adapted from AVV, 2000).

Other relevant transport policies assumed in the Trend and Tolerant scenarios are (a) the lowering of the maximum speed levels for road traffic in residential areas to 30 km per hour,

(b) improvement of the road capacity of the main motorway network by 4% with traffic control measures, and (c) public transport improvements resulting in improvements of average public transport trip travel times by 5 to 10%.

10.5 Methodology for analysing the contribution of land-use and transport changes to the development of accessibility

As already descibed in Section 3, an accessibility change may be the result of a change in the:

(a) land-use component, i.e. changes in the amount and/or spatial distribution of opportunities (here: employment);
(b) transport component, i.e. travel time changes, for example, as a result of increased delays and congestion or infrastructure expansion;
(c) temporal component, e.g. development of peak hour and off-peak hour travel times;
(d) individual component, i.e. changes in socio-economic composition of the population.

With the data available, the contribution of land-use changes, transport changes or both, to the development of accessibility can be analysed as follows. The contribution of the different factors - or components - to the development of accessibility can by analysed by estimating different accessibility maps (using one of the selected accessibility measures) by varying the land-use and transport data for the different years (here: 1995 and 2020). These components can estimated by varying the land-use and travel time data for 1995 and 2020 inter-independently.

- ☐ Overall change: Land-use Component + Travel Time Component + Interaction Component
- ☐ Land-use Component: 2020 land-use and 1995 travel time data (‘Emp20Tra95’) – 1995 employment and travel time data (‘Emp95Tra95’)
- ☐ Transport Component: 1995 land-use and 2020 travel time data (‘Emp95Tra20’) – 1995 employment and travel time data (‘Emp95Tra95’)
- ☐ Interaction Component: 2020 land-use and travel time data (‘Emp20Tra20’) – Emp20Tra95 – Emp95Tra20 + Emp95Tra95

The *Land-use component* consists of the changes in the accessibility caused by changes of the size and spatial distribution of employment, the *Transport component* consists of the changes of the accessibility caused by changes of the travel times. The *Interaction component* contains the changes of the accessibility that are caused by the combination of both changes in the size and spatial distribution of employment and changes in the travel times. This can best be visualised if the impedance function is ignored and the number of jobs within, say, 45 minutes are simply counted. We can then construct a “circle” around each location, which represents the perimeter of the area people can reach within 45 minutes travel time. The number of jobs within this circle in 1995 is then the accessibility of 1995. The Land-use component is the increase or decrease of the number of jobs within this circle between 1995 and 2020. Changes in congestion, infrastructure and so on will cause the 45-minute travel time circle to change between 1995 and 2020. There will usually be represented by a “ring” between the two circles.

The number of jobs in this ring in 1995 is the *Transport component*. And finally, the increase or decrease in the number of jobs in this ring between 1995 and 2020 is the *Interaction component*. The use of an impedance function makes it more difficult to illustrate exactly which change is part of which component, but the general principle remains the same.

Furthermore, the *Transport component* can be split into a *Congestion component*, reflecting changes in delays and congestion, and an *Infrastructure component*, reflecting changes in infrastructure supply, e.g. capacity expansions of road infrastructure, changes in the maximum travel speed. Using "free flow" and "congested" travel time matrices for 1995 and 2020, these components can be separated as follows:

- ☐ Transport Component = Infrastructure Component + Congestion Component
- ☐ Infrastructure Component = 1995 land-use data and 2020 free-flow travel times ('Emp95Tra20ff') – 1995 land-use data and free flow travel times ('Emp95Tra95ff')
- ☐ Congestion Component = Em95Tra20 – Emp95Tra20ff – Emp95Tra95 + Emp95Tra95ff

Theoretically, there is also an Interaction component between the Infrastructure and Congestion components. This Interaction component will contain all changes of the accessibility that are caused by a combination of changes in infrastructure and maximum speeds on the one hand, and changes in the level and location of congestion on the other. The available data does not allow the computation of this component: in order to do so, travel time data would be needed on the basis of 1995 infrastructure, but with the congestion levels of 2020, or the other way around. This is probably not a logical possibility. Here, the interaction between infrastructure and congestion is included in the Congestion Component.

Note that the temporal component could, with the data avialable from the NMS, also be analysed by computing the accessibility maps for peak hour and off-peak hour travel times for the different years. However, the temporal component is not examined here. The individual component is analysed for the Tolerant scenario by computing accessibility measures for different socio-economic groups.

10.6 Overview of applied accessibility measures

In the case studies, five accessibility measures are applied to analyse car and public transport accessibility for 1995 and 2020. Combined with the available land-use data for the Trend and Tolerant scenarios, several hundreds of accessibility maps can potentially be computed. For practical reasons, the total number of accessibility maps has to be reduced. Table 10.3 gives an overview of estimated accessibility measures. This table shows that the contour measures and Joseph and Bantock's measure are only estimated for the total number of jobs. The potential measure and inverse-balancing factors are also estimated for two educational levels, and the utility-based measure is also estimated for three income groups. Section 11 describes the results of the accessibility computations for 1995, Section 12 for the Trend scenario and Section 13 for the Tolerant scenario.

Table 10.3: Overview of applied accessibility measures.

		1995		Trend scenario		Tolerant scenario	
		car	public transport	car	public transport	car	public transport
Contour measure, 45 minutes	total	X	X	X	X	X	X
	low/medium education level						
	high education level						
	average, weighted by education level						
	low income						
	medium income						
	high income						
	average, weighted by income level						
Contour measure, 60 minutes	total	X	X	X	X	X	X
	low/medium education level						
	high education level						
	average, weighted by education level						
	low income						
	medium income						
	high income						
	average, weighted by income level						
Potential measure	total	X	X	X	X	X	X
	low/medium education level	X	X	X	X	X	X
	high education level	X	X	X	X	X	X
	average, weighted by education level	X	X	X	X	X	X
	low income						
	medium income						
	high income						
	average, weighted by income level						
Joseph & Bantock's measure	total	X	X	X	X	X	X
	low/medium education level						
	high education level						
	average, weighted by education level						
	low income						
	medium income						
	high income						
	average, weighted by income level						
Balancing factor	total	X	X	X	X	X	X
	low/medium education level	X	X	X	X	X	X
	high education level	X	X	X	X	X	X
	average, weighted by education level	X	X	X	X	X	X
	low income						
	medium income						
	high income						
	average, weighted by income level	X	X	X	X	X	X
Utility-based measure	total						
	low/medium education level						
	high education level						
	average, weighted by education level						
	low income	X	X	X	X	X	X
	medium income	X	X	X	X	X	X
	high income	X	X	X	X	X	X
	average, weighted by income level	X	X	X	X	X	X

11. Case study 1: Accessibility analysis for 1995

11.1 Introduction

This section describes the results of the first case study: the application of selected accessibility measures for 1995 (the base year). Section 11.2 describes the aggregated results of the accessibility measures at national level. Section 11.3 describes the regional distribution of the selected accessibility measures for the car users mode and Section 11.4 for public transport.

11.2 Results on the national level

Tables 11.1 and 11.2 show the aggregated results of the selected accessibility measures at national level for 1995. Table 11.1 shows the aggregated results of the accessibility measures as the average of all regions (the 1308 zones of the National Model System). Table 11.2 shows the results of the accessibility measures as the average per person per region. The results of the contour, potential and Joseph & Bantock's measures, and the balancing factor, yield the average for the number of working people per region; the results of the utility-based measure yield the average for the number of inhabitants per region. The potential accessibility measure and balancing factor are also split by education level, and the utility-based measure by income level.

Table 11.1: Average job accessibility per zone by car and public transport for 1995.

	car	public transport
Contour measure, 45 minutes	687,904	61,159
Contour measure, 60 minutes	1,210,805	138,154
Potential accessibility measure	366,390	278,689
Joseph & Bantock's measure	0.97	0.19
Balancing factor	338,594	230,572
Utility-based measure	78.8	198.8

Table 11.2: Job accessibility by car and public transport for 1995, average per worker or inhabitant

		Car	Public transport
Contour measure, 45 minutes [a)]		702,680	61,661
Contour measure, 60 minutes [a)]		1,243,420	141,049
Potential accessibility measure [a)]	total	372,763	287,808
	low/intermediate education level	235,440	154,309
	high education level	150,747	134,547
	average, weighted by education level	209,914	144,376
Joseph & Bantock [a)]		1.14	0.19
Balancing factor jobs [a)]	total	343,793	237,710
	low/intermediate education level	223,849	131,316
	high education level	126,485	95,356
	average, weighted by education level	195,821	118,318
Utility-based measure [b)]	total	79.0	199.5
	low income (0-13,600 Euro)	44.2	109.4
	medium income (13,600-30,600 Euro)	70.1	155.9
	high income (> 30,600 Euro)	162.0	291.0
	average, weighted by income level	71.6	155.4

[a)] average per worker
[b)] average per inhabitant

The ***contour measure*** expresses the average number of jobs which can be reached within 45 or 60 minutes travel time by car and public transport from a zone of origin. Table 11.1 shows that the number of jobs which can be reached by car within a maximum of 60 minutes travel time is about 75% higher than within 45 minutes; the number of jobs within by public transport comes to more than doubles (factor of 2.25). This illustrates that a relatively large number of jobs are further away than 45 minutes by public transport. Moreover, the contour measures shows that job accessibility by car is much better than by public transport. The average number of jobs in the Netherlands which can be reached by car within 45 minutes in 1995 is more than 11 times as with public transport, for 60 minutes this is almost nine times as much, the result of (i) higher average travel times and (ii) job locations unfavourable for public transport. This makes average home-to-work travel times by public transport much higher than by car, e.g. average public transport travel times (including access and egress travel times) between all origins and destinations of the National Model System (1308 zones) for 1995 are roughly twice as high as peak hour travel times by car. The spatial distribution of jobs also negatively influences job accessibility by public transport. As an illustration, Boks & Louter (1998) show that more than 80% of total Dutch employment in 1996 was found at locations which are not well accessible by rail.

Furthermore, the average accessibility level per person (Table 11.2) is somewhat higher (1-3%) than the average per region (Table 11.1). This reflects the fact that relatively more people (about 8%) live in (urban) regions with a more than average number of jobs within reach.

The results of the ***potential accessibility measure*** differ strongly from the contour measure. The average number of jobs which can be reached by car (unweighted average) is about half the total number of jobs within 45 minutes travel time (i.e. the contour measure); by public transport factor of roughly 4.5 higher. The difference is explained by the combination of (a) the maximum travel distance used in the contour measure and (b) the impedance functions used in the potential accessibility measure (see Figure 10.1). The distance decay of home-to-work trips by car is relatively strong: 50% of the trips have a travel time shorter than 20 minutes; roughly 85% are shorter than 45 minutes. In using an impedance function the total number of jobs within reach by car is highly reduced. Home-to-work trips by public transport are much less sensitive to travel time: almost 60% of these trips take longer than 45 minutes (see also Section 10.2). Thus, using an impedance function (thus including jobs relatively far away) highly increases the total number of jobs within reach by public transport.

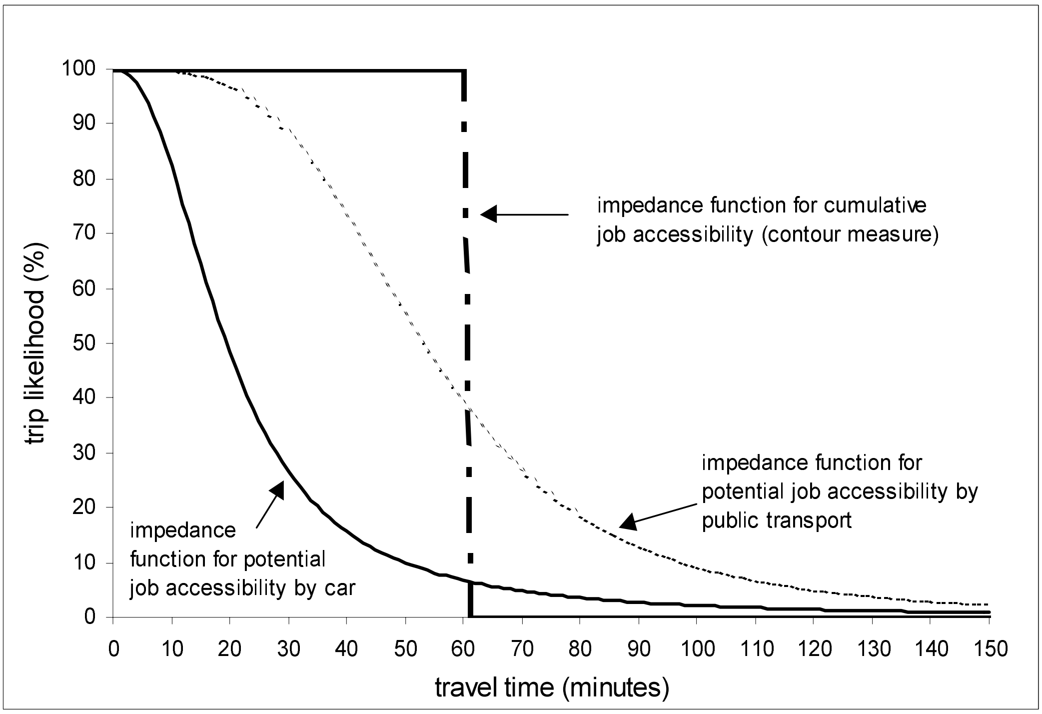

Figure 11.1: Impedance functions used for the contour measure (60 minutes) and potential accessibility measure.

Note that in this case study, the estimated accessibility measures (except the contour measure) can not be used directly to compare car and public transport accessibility. This is because the impedance functions used are estimated for each mode separately and the estimated impedance functions strongly differ between car and public transport users (see also Section 10.2). Those interested in the differences between car and public transport accessibility, can analyse them by (a) using the estimated parameters of the impedance function for the car mode to estimate potential accessibility by public transport, or (b) estimating impedance functions for the total car and public transport trips (see also Section 11.4).

Furthermore, Table 11.2 shows that the potential job accessibility is strongly reduced if the occupational match (using two education levels) is accounted for. This is the result of two factors: (a) the potential number of jobs which can be reached differs (in 1995 72% of the jobs requires a low or intermediate educational level; 28% a high education level) and (b) the impedance function, which differs for people with different educational levels (see Section 10.2). The number of jobs an average person (weighted by educational level) can reach by car or public transport is about 50% lower than the average job accessibility level if no educational level is assumed.

Joseph and Bantocks' measure shows the ratio between the number of jobs which reach the working population and are within reach of this population. Thus a value of 1 indicates that job accessibility and accessibility to the working population are balanced, e.g. 100 jobs per 100 workers. On the national level, the measure shows that job accessibility by car is relatively well-balanced, whereas public transport accessibility is not well-balanced, on average only one job is within reach of five workers. Thus, competition on jobs is much greater among public transport users than among car users. This measure illustrates that public transport users have fewer potential jobs within reach (because of the relatively high travel times) and these have to be shared with potentially more people, i.e. areas with a high job accessibility level using public transport are located near railway stations situated in highly populated areas (thus a high number of potential competitors).

Note that because Joseph & Bantocks' measure is expressed as an index, the results of the measure can not be directly compared with the contour or potential accessibility measures.

Furthermore, it should be noted that the job competition in this measure (also valid for the balancing factor) is only estimated among the potential car users *or* potential public transport users. Implicitly it is assumed that every working person is a potential car or public transport user. In reality, car and public transport users compete for jobs among each other and with users of other modes (walking, cycling). In theory, this effect could be taken into account by aggregating the potential accessibility across all modes using the fastest mode or the logsum cost (see Section 3.3.4). In both cases, the car mode will be dominant.

The ***inverse balancing factor*** of the doubly-constrained spatial interaction model gives a significant lower average job accessibility level (per region and per person) than the potential accessibility measure: car accessibility is about 8% lower, public transport accessibility 17% lower. This is the result of the competition of the working population on jobs: on average, regions with high job accessibility level (city centres) are well accessible to employees. The competition for jobs among public transport users is larger than among car users. This result is consistent with Joseph and Bantocks' measure: high public transport accessibility levels are the downtown areas of cities (near railway stations), with a relatively high number of potential competitors.

The competition for jobs is greater for highly educated workers, especially for those using public transport, than for low- or intermediate-educated workers. That is, compared to the basic potential accessibility measure the balancing factor for people with a high educational level is about 20% lower for the car mode and 30% lower for the public transport mode; for people with a low or intermediate education level this is 5 to 15%, respectively.

The ***utility-based accessibility measure*** is strongly influenced by the income level of inhabitants: the utility people in the highest income groups derive from accessibility to jobs is about 2.5 (car mode) to 3.5 (public transport mode) as much as people in the lowest income group. As a result, the average utility computed for the entire population is much different than when computed for the different income groups. The utility-based measure strongly depends on (a) differences in value-of time between income groups, i.e. in this study the high-income group has factor about factor 2 to 2.5 higher value-of-time than the low-income group, and (b) differences in sensitivity to travel cost (as expressed in the negative exponential impedance function - see Section 10.2.2). As a result, the utility-based measure highly depends on the assumed classification of inhabitants by income level.

11.3 Regional distribution of job accessibility by car

This section describes the regional distribution job accessibility by car for each accessibility measure selected.

Contour measure
Figure 11.2 shows the spatial distribution of job accessibility by car for 1995, using a contour measure with 45 minutes as maximum travel time. The figure basically shows three regions (illustrated in Figure 11.3): (1) the densely-populated Randstad Area (the areas in and between the four largest cities - Amsterdam, Rotterdam, The Hague and Utrecht), where job accessibility by car is the highest, (2) a central region (roughly the area to the east of Utrecht and Rotterdam, and west of the cities Apeldoorn and Eindhoven) where job accessibility is moderate, and (3) peripheral areas in the sparsely populated northeastern, southern and southwestern parts of the Netherlands, where job accessibility is the lowest.

The contour measure with 60 minutes as maximum travel time (Figure 11.3) shows a smoother picture; differences between urban and rural areas largely disappear. For example, Randstad Area job accessibility by car is relatively high, whereas with 45 minutes as a maximum travel time (Figure 11.2) the sparsely populated area in the centre of the Randstad (i.e. also called the ‘Green Hart’) has a significant lower level of job accessibility.

Potential accessibility measure
The spatial distribution of the potential accessibility measure (Figure 11.4) has relatively higher accessibility levels in the central urban areas and lower in surrounding suburban regions – compared to the contour measure with 45 minutes as maximum travel time. This reflects the relative importance of jobs at shorter distances according to the potential measure. Furthermore, the potential measure also clearly shows the Randstad Area with the highest accessibility levels, the central region and the peripheral regions.

Joseph and Bantock's measure

As a result of the incorporation of the spatial distribution of the working population into the measure, Joseph and Bantock's measure (Figure 11.5) is clearly more spatially differentiated than the contour and potential accessibility measure. The accessibility measure shows a relative job surplus (more than 1.4 jobs per working person) in central urban areas, where relatively large concentrations of jobs are found (resulting in a relatively low level of job competition). Job accessibility in surrounding (suburban) areas is lower (around or less than one job per working person) due to the relatively large labour force in and near these areas (resulting in a relatively high level of job competition). Peripheral areas show a relative job shortage (0.8 or fewer jobs per worker).

Inverse balancing factor

Figure 11.6 shows job accessibility by car according to the (inverse) balancing factor, which incorporates the interdependent competition for jobs and among the labour force. At a glance, the spatial distribution of job accessibility according to the balancing factor for 1995 looks similar to the potential accessibility measure (Figure 11.4). This illustrates that the spatial distribution of the potential accessibility to jobs (for the working population) does not highly differ from distribution of potential accessibility to the labour force (for employers). However, there are relatively large regional differences in the effect of competition on jobs and the labour force on the potential accessibility measure. The (absolute) differences between the balancing factor and the potential accessibility measure are shown in Figure 11.7. This figure shows that in the highly urbanised Randstad Area, the balancing factor is much lower than the potential accessibility measure, a result of competition effects. In other words, the labour force in the Randstad Area is relatively large compared to the potential number of jobs, especially in suburban areas of Amsterdam, Rotterdam and The Hague, where the balancing factor is 20-25% lower than the potential measure.

The central region east of the Randstad Area also has a relative labour force surplus (but lower than in the Randstad); thus the balancing factor is slightly lower (by about 1-15%). In peripheral areas (northeastern, southern and southwestern parts of the Netherlands), the balancing factor is 10-100% higher than the potential accessibility measure due to the relatively small labour force within reach. The differences between the balancing factor and the potential measure can also be illustrated by analysing a cross-section of the Netherlands. As an illustration, a cross-section comprises the area from the southwestern to the northeastern areas of the Netherlands, including zones from the rural area around Middelburg (southwest) to the suburban and inner city of Rotterdam, Utrecht, Zwolle and the rural area around Emmen (northeast). Figure 11.8 shows the zones included in the cross-section; Figure 11.9 shows the result.

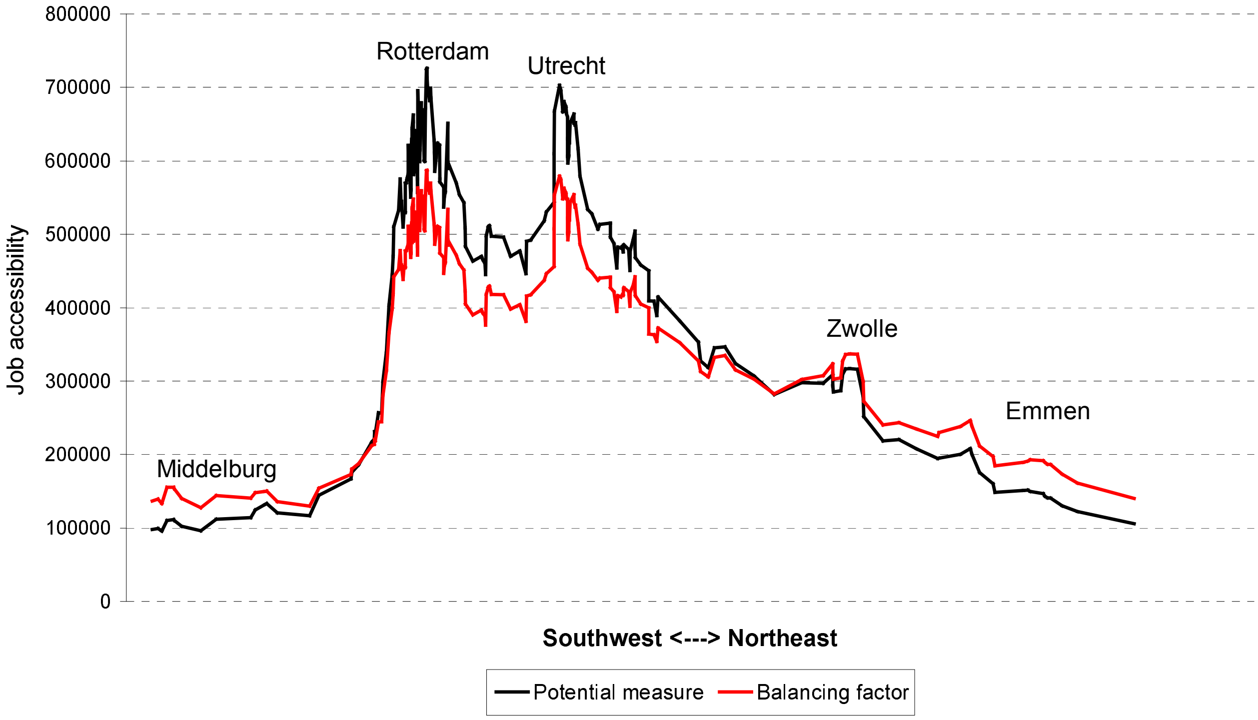

Figure 11.9: Cross-section of the potential measure and balancing factor, 1995.

Figure 11.9 shows the balancing factor to result in higher accessibility levels than the potential accessibility measure for peripheral areas (i.e. the areas in and around Middelburg and Emmen) and lower for suburban and urban regions of the highly urbanised Randstad area (i.e. the areas in and around Rotterdam and Utrecht).

Figure 11.9 essentially illustrates the relationship between job competition and potential accessibility to the working population according to the balancing factor: job competition being highest in central urban areas, where the working population is large, and lowest in peripheral areas where the working population is small. This relationship is illustrated in Figure 11.10, showing a scatter diagram of the percentage difference between the balancing factor and the potential job accessibility, and potential accessibility to the working population for all (1308) zones. The figure shows the balancing factor to be greater than the potential measure, when potential accessibility to the working populations for a given zone is small (a relative job surplus). When the accessibility for the working population increases, job accessibility according to the balancing factor decreases as a result of job competition increases.

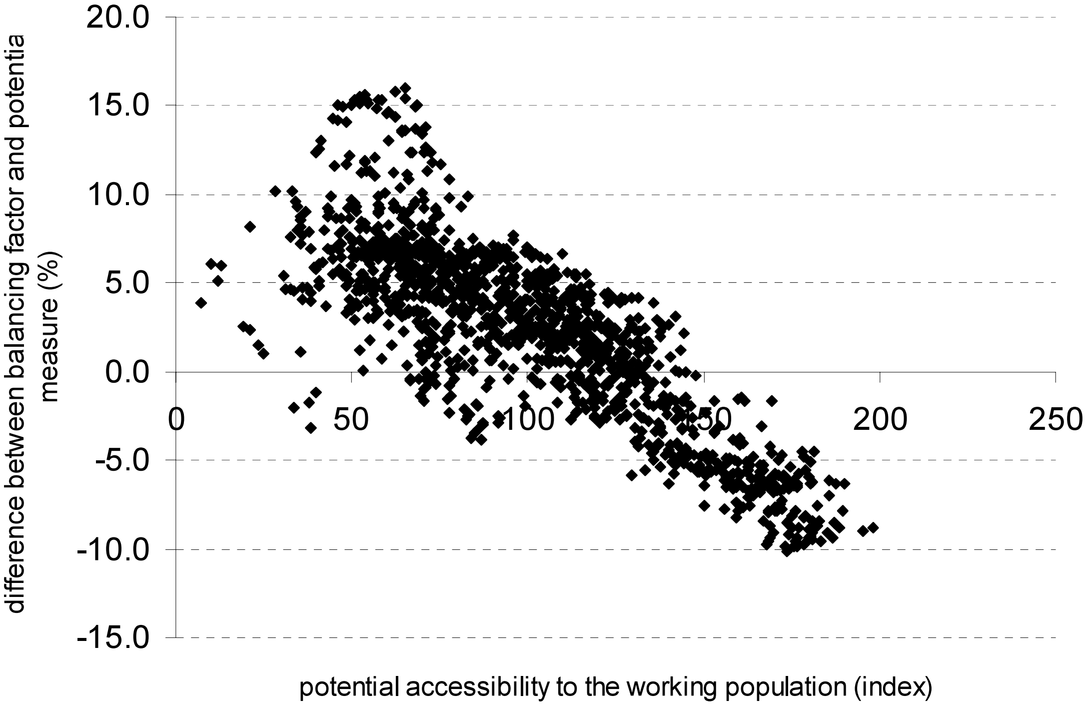

Figure 11.10: Relationship between the level of job competition and potential accessibility for the working population.

The spatial differentiation of job accessibility according to the inverse balancing factor is somewhat larger if the educational match is accounted for. Figure 11.11 shows the weighted-average job accessibility of low- and intermediate educated and high-educated workers per zone. As already described in the previous section, job accessibility sharply decreases (by roughly a factor of 2) if one accounts for a (potential) match between the workers education level and job-level requirements. As an illustration, Figure 11.12 shows job accessibility for low- and intermediate-educated workers and Figure 11.13 for highly educated workers. Job accessibility for both highly educated workers and low-and intermediate-educated workers is highest in and around the four largest cities in the Randstad Area. Job accessibility for highly educated workers is more concentrated in the Randstad Area and the central part of the Netherlands; job accessibility for low- and intermediate-educated workers is more spread out eastward, north-eastward (towards the city of Groningen) and southeastward (the Brabantstad Area). Job accessibility for the low- and intermediate-educated workers (comprising more than 70% of the labour force) dominates the weighted-average job accessibility level (Figure 11.11). Job accessibility weighted by educational level is, compared to Figure 11.6, relatively higher in central region of the Netherlands and more spread out to the east and southeast.

Utility-based accessibility measure

Figure 11.14 shows the regional differentiation of the utility-based accessibility measure. The spatial distribution is similar to the potential accessibility measure. However, the bandwidth of utility values is much smaller than for the potential accessibility measure (utility values are found within a range of about 45 to 84 and potential values within a range of about 18,500 to 865,000). This is the result of the functional form of the measure, i.e. the measure takes the natural logarithm of a potential accessibility measure using travel cost as impedance (and using a negative exponential impedance function), multiplied by a cost-sensitivity parameter. Figure 11.15 shows the non-linear relationship between potential job accessibility by car and utility for 1995.

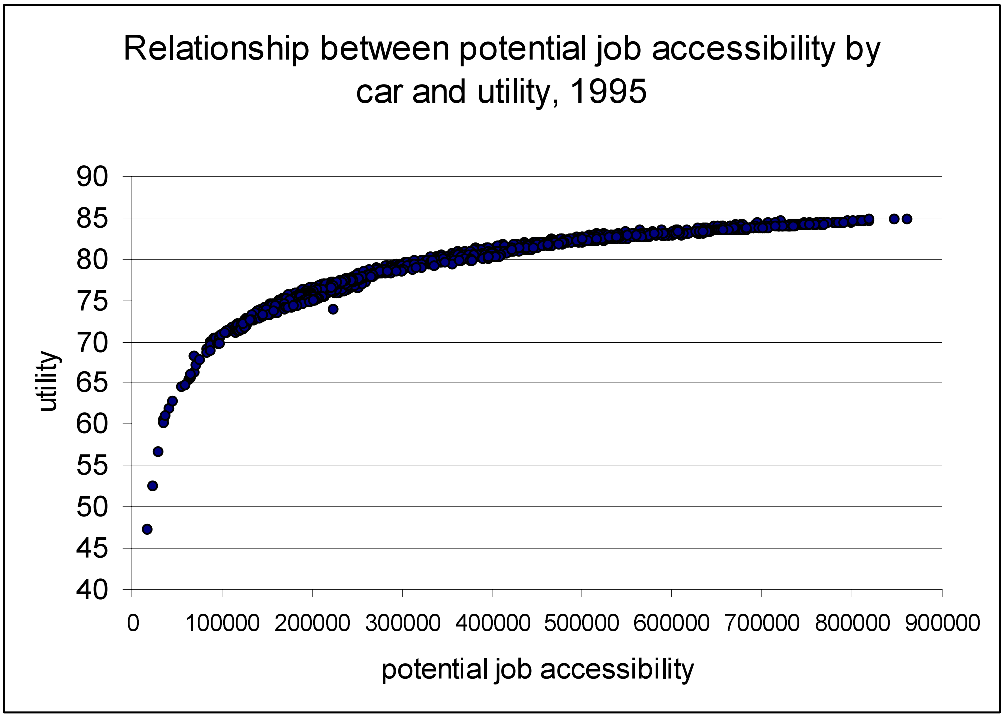

Figure 11.15: Relationship between potential job accessibility by car and utility for 1995.

Figure 11.15 shows that sharp changes in potential job accessibility at locations with a relatively high accessibility level (e.g. central urban areas) result in a relatively small change in utility, whereas a relative small change in job accessibility at locations with a low accessibility level (e.g. peripheral areas) result in a relative strong utility change. Figure 11.14 does not account for the different sensitivity to travel costs between socio-economic groups, i.e. an average cost-sensitivity parameter is used. The spatial distribution of utility is very different if the utility-based accessibility measure is estimated separately for different household income groups (less than 13,600 Euro, 13,600-30,600 Euro; more than 30,600 Euro (50,000 Dutch guilders) and then aggregated to a weighted average utility value (Figure 11.16). Figure 11.15 shows that utility is relatively low in central urban areas of large and middle-sized cities and relatively high in surrounding suburban areas. Clearly, the spatial distribution of socio-economic groups (with different cost sensitivities) dominates the result. That is, central urban areas have a relatively low utility level as a result of low average household incomes (with a lower time value and higher cost sensitivity) despite the high number of jobs within reach by car. Utility is the highest in areas with a relatively high average household income combined with a relatively high to moderate potential job accessibility level, e.g. suburban areas between the large and middle-sized cities in the Randstad Area.

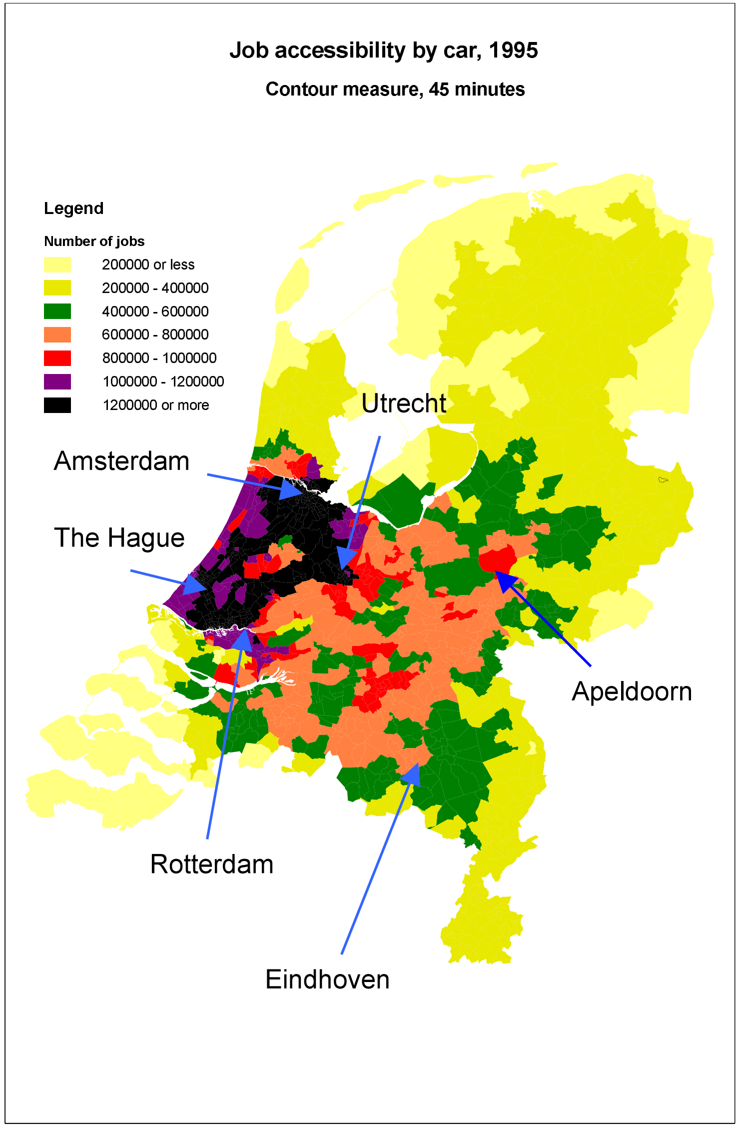

Figure 11.2: Job accessibility by car, contour measure 45 minutes, 1995.

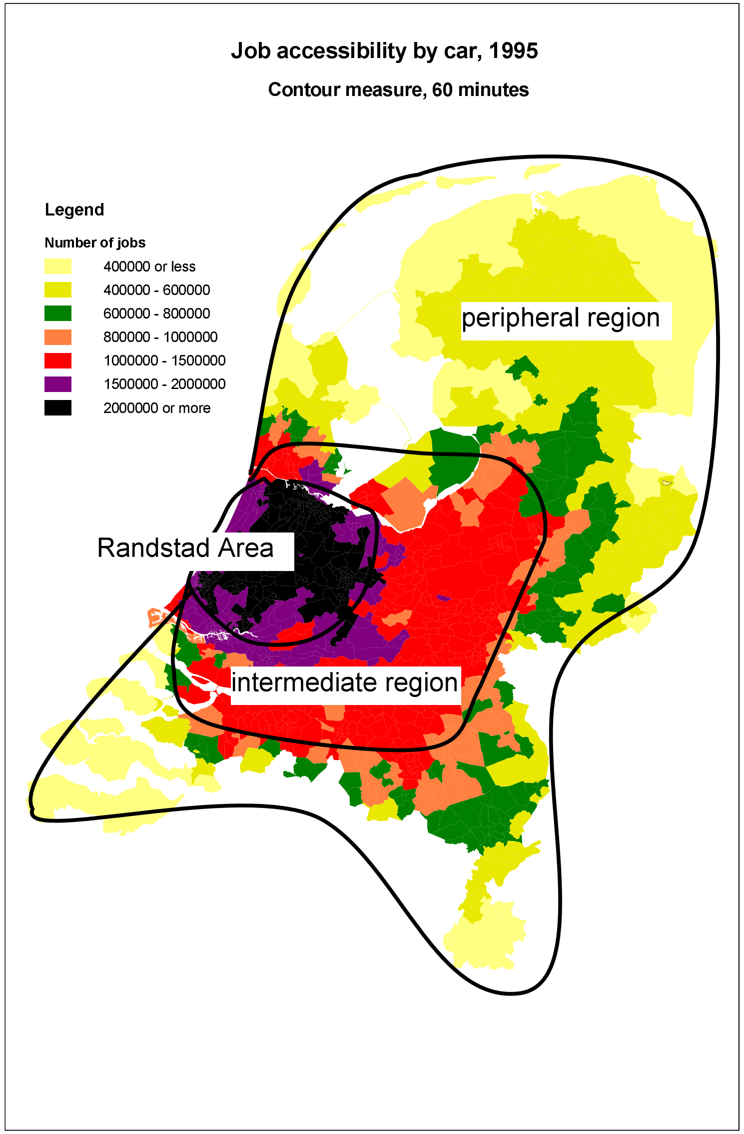

Figure 11.3: Job accessibility by car, contour measure 60 minutes, 1995.

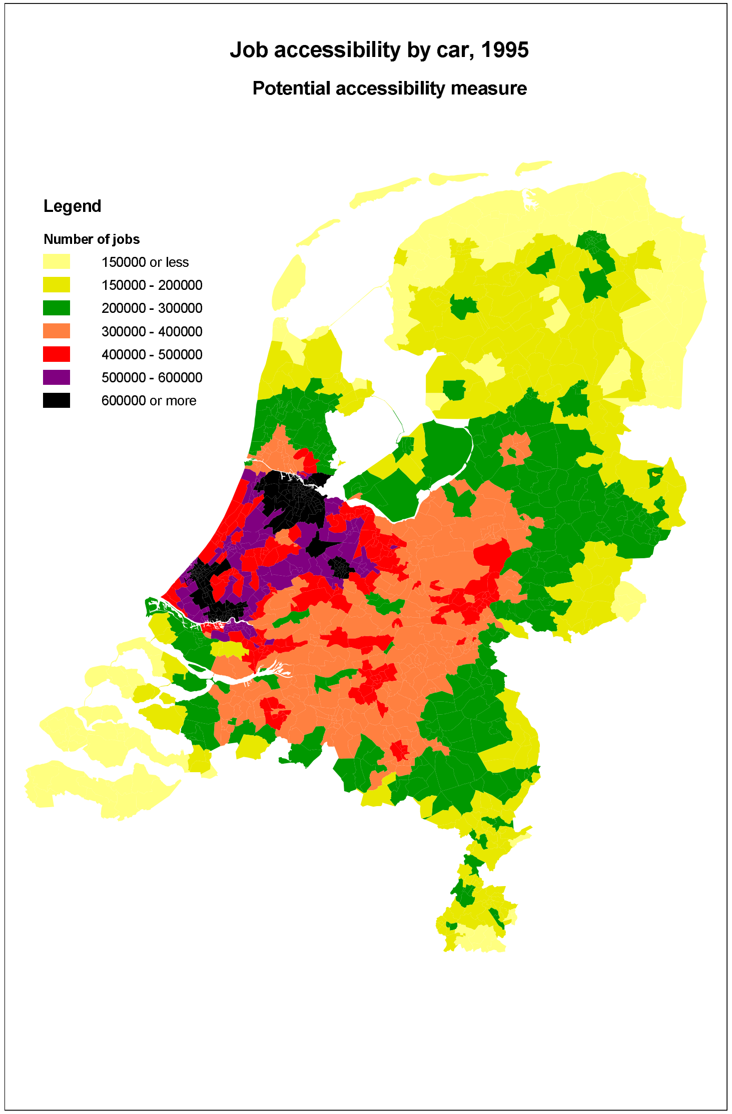

Figure 11.4: Job accessibility by car, potential measure, 1995.

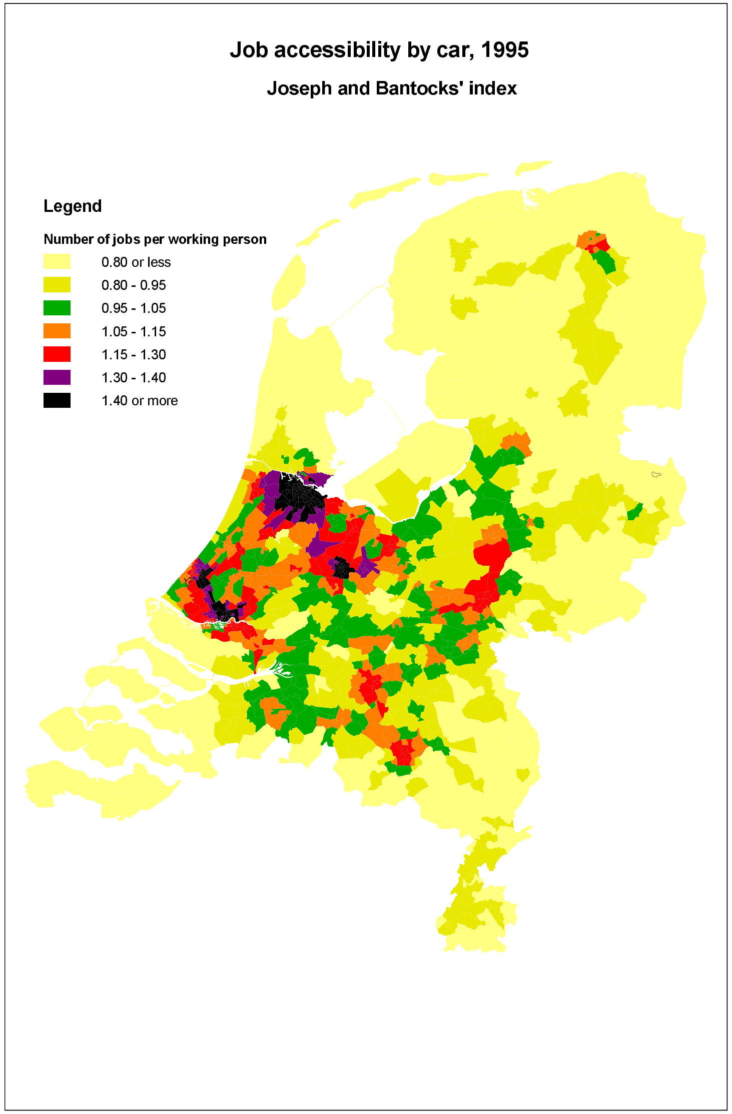

Figure 11.5: Job accessibility by car, Joseph & Bantock’s measure, 1995.

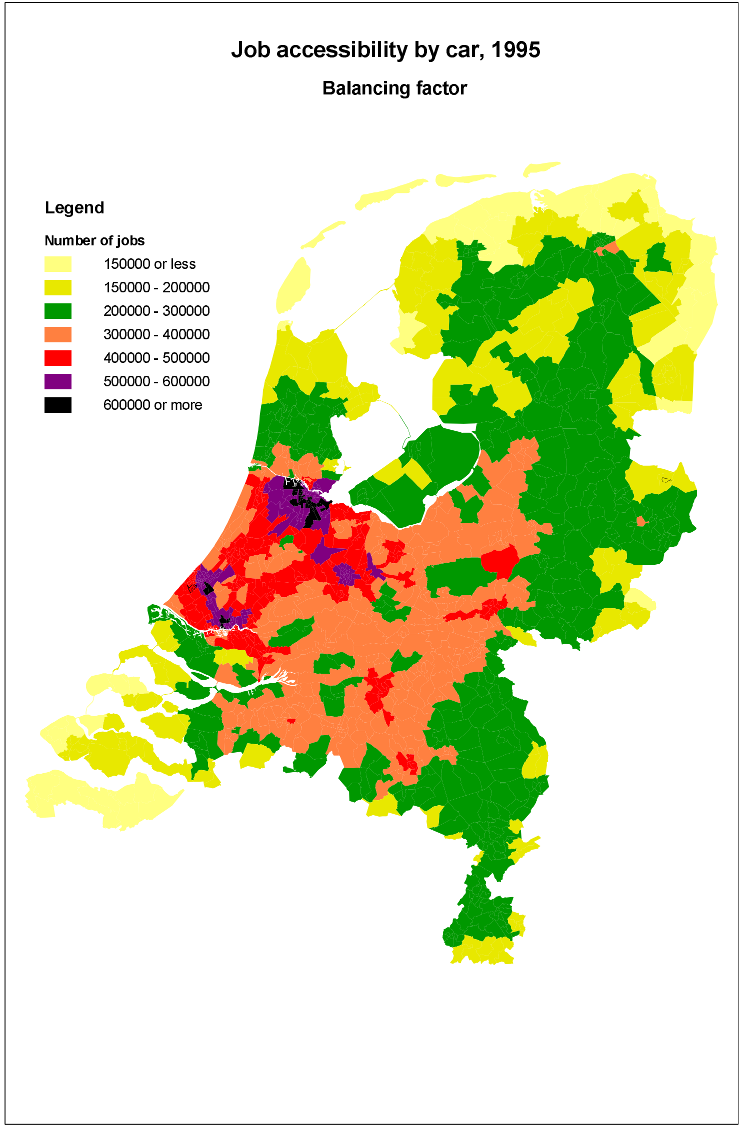

Figure 11.6: Job accessibility by car, unweighted by education level, balancing factor.

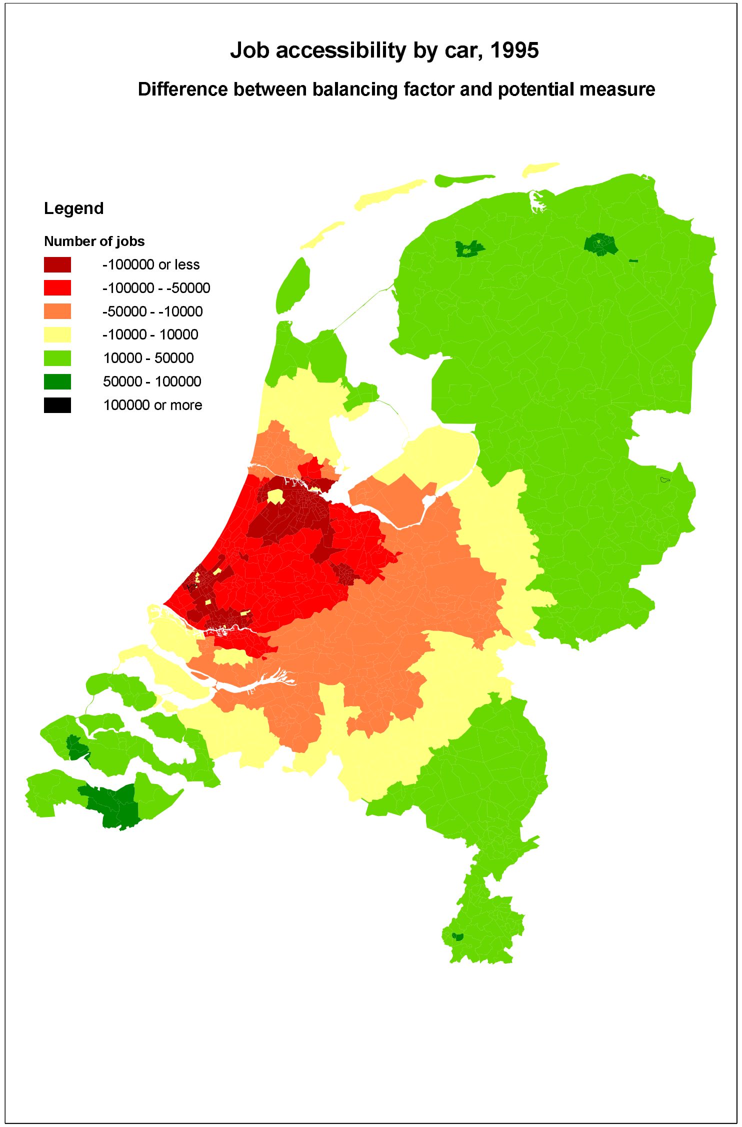

Figure 11.7: Difference between balancing factor and potential measure, 1995.

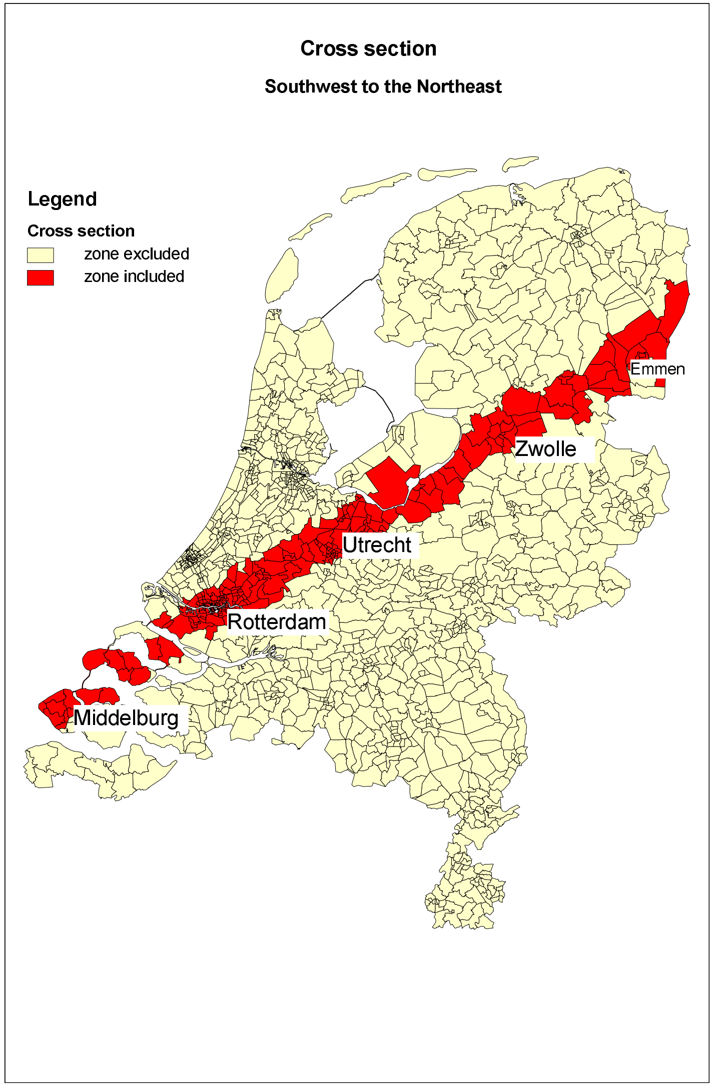

Figure 11.8: Cross-section of the Netherlands from the southwest to the northeast.

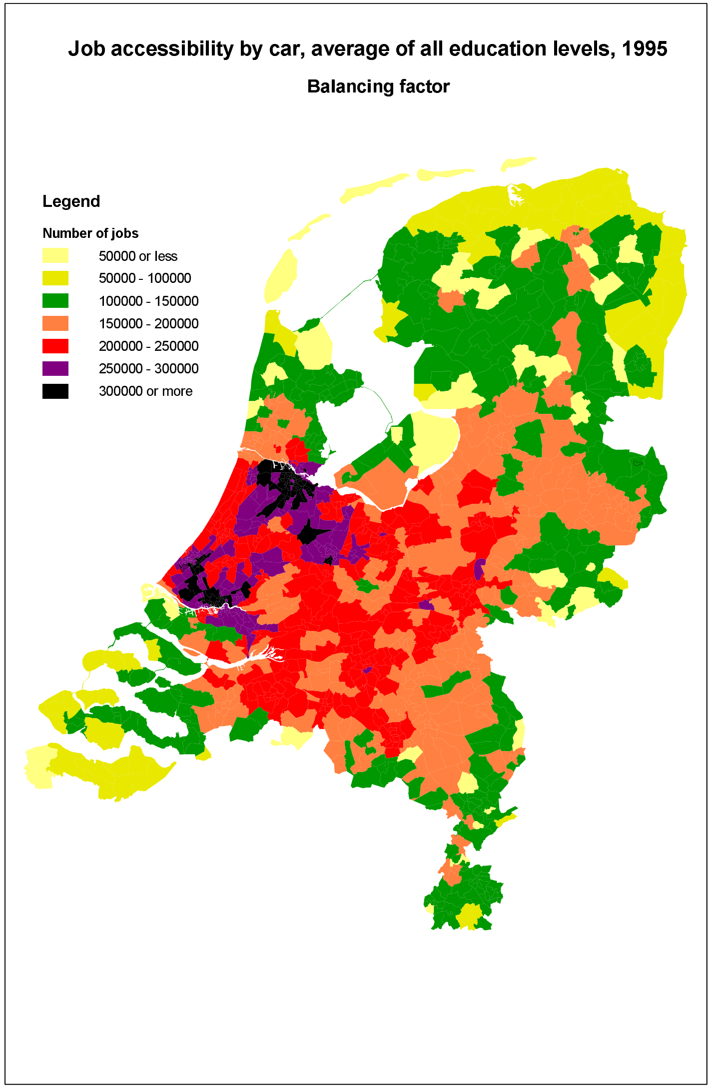

Figure 11.11: Job accessibility by car, weighted average by education level, balancing factor, 1995.

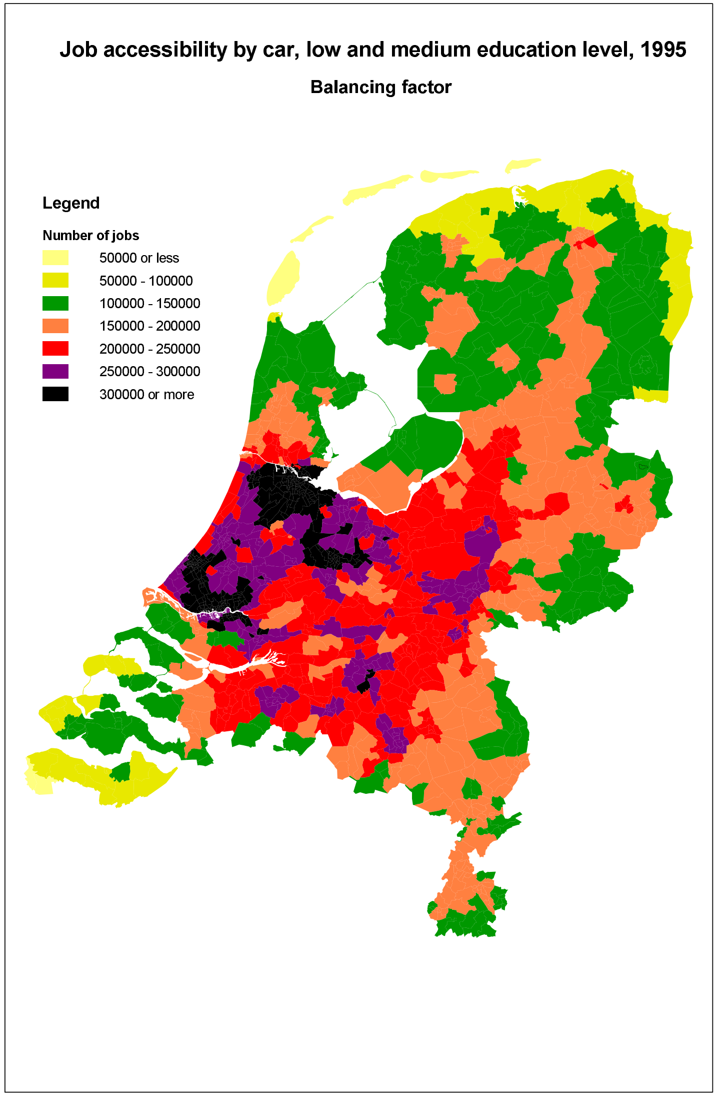

Figure 11.12: Job accessibility by car, high education level, balancing factor, 1995.

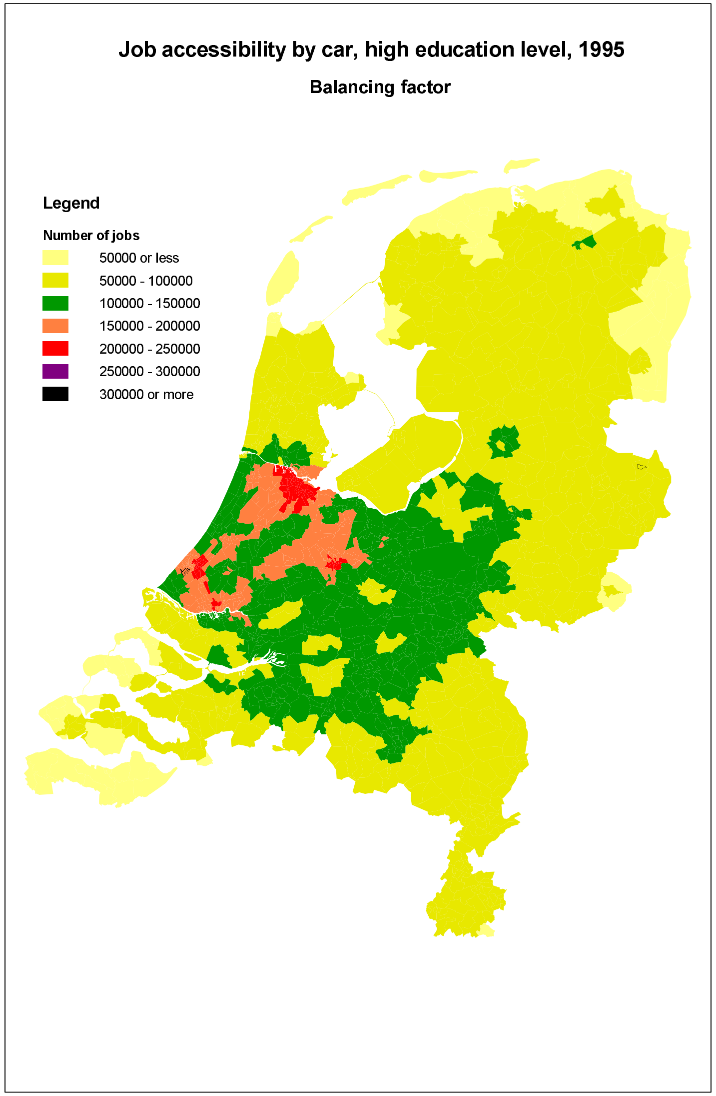

Figure 11.13: Job accessibility by car, low and intermediate education level, balancing factor.

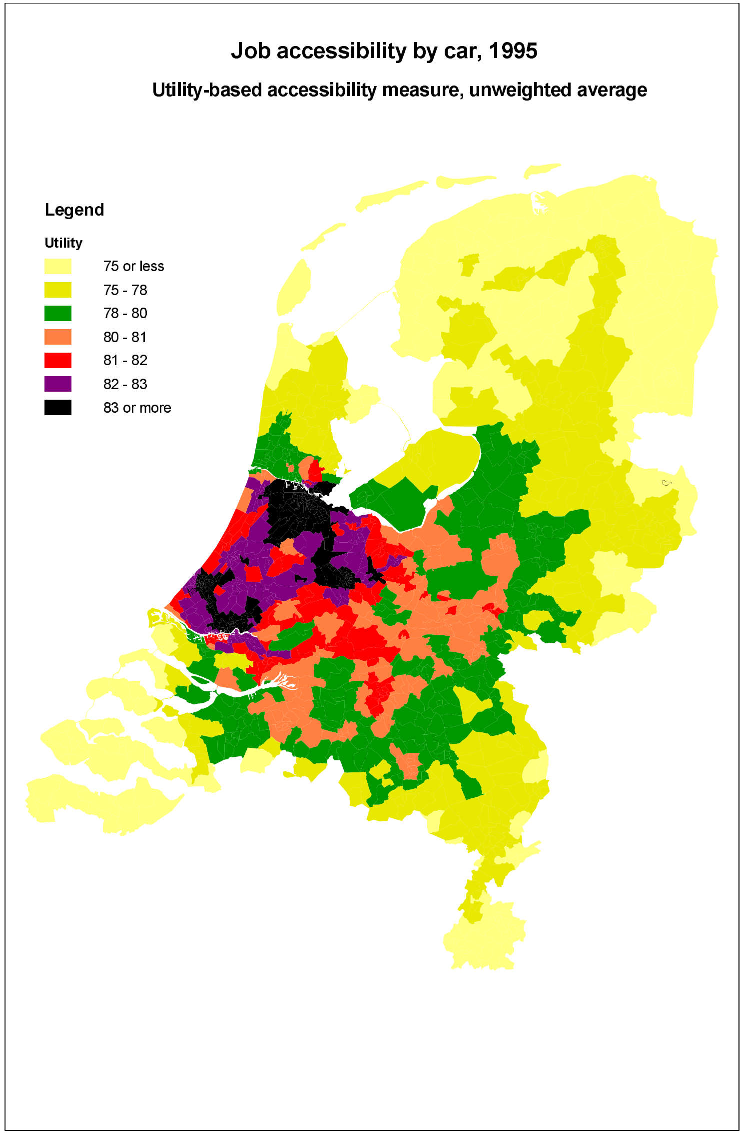

Figure 11.14: Job accessibility by car in 1995, unweighted by income, utility measure.

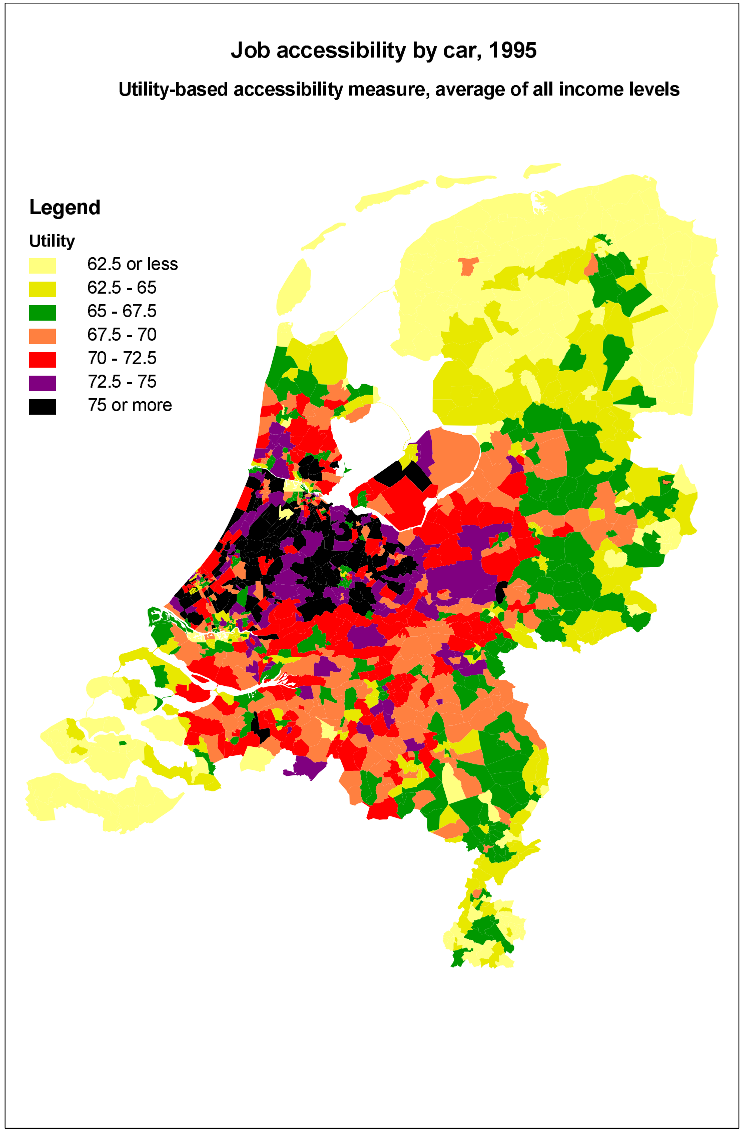

Figure 11.16: Job accessibility by car in 1995, weighted by income, utility measure.

11.4 Regional distribution of job accessibility by public transport

Contour measure

Figure 11.17 shows a contour measure with 45 minutes as maximum travel time and Figure 11.18 with 60 minutes. The spatial differentiation of job accessibility by public transport is relatively large compared to job accessibility by car (Figures 11.2 and 11.3). The Randstad Area is less dominant, although from the central urban areas of Amsterdam, Rotterdam, The Hague and Utrecht most jobs can be reached within 45 or 60 minutes travel time. Furthermore, the figures clearly show the spatial selective effect of public transport; accessibility is relatively high in central urban areas (near railway stations), moderate in suburban areas and low in rural areas.

Contrast to car accessibility, the spatial distribution of public transport accessibility does not change much if a 60 minute maximum travel time is assumed instead of 45 minutes; the increase in the number of jobs within reach (on average more than a doubling) is relatively equally distributed.

The total number of jobs which can be reached within 45 or 60 minutes by public transport is much lower than by car. Section 11.2 already stated that average job accessibility by public transport comes to a factor of 9 to 11 lower than by car. The regional differences are illustrated in Figure 11.19, where the contour measure for public transport (with 45 minutes as maximum travel time) is shown with same legend as for the car mode (legend from Figure 11.2). The figure shows that public transport accessibility is relatively high (compared to car transport) to and from the three largest towns in the Randstad area (i.e. Amsterdam, Rotterdam and The Hague). As an illustration, the total number of jobs which can be reached within 45 minutes travel time by public transport from the central urban areas of Amsterdam, Rotterdam and The Hague is, on average, about four times lower than by car, in surrounding suburban areas and middle-sized towns about 6-7 times lower, and in rural areas, on average, about 60-70 times lower. This low job accessibility level of public transport is the result of: (a) the assumed maximum travel time (45 or 60 minutes), which is less than the average travel time of a public transport trip (i.e. an average public transport trip in the Randstad Area, including access and egress time, took about 70 minutes in 1995 - Egeter *et al.,* 2000) and (b) the unfavourable location of jobs with respect to public transport in general.

The difference in job accessibility by car and public transport can be illustrated in absolute terms by showing accessibility in a cross-section of the Netherlands. Figure 11.20 shows the result of a cross-section for the contour measures (using 60 minutes as maximum travel time) from the southwest to the northeast of the Netherlands (see Figure 11.8). Figure 11.20 shows the job accessibility by public transport relatively high in the central urban areas of the major cities, e.g. about 500,000 jobs can be reached within 60 minutes travel time by public transport from the central urban area of Rotterdam. However, public transport accessibility is, compared to the car still very low, e.g. about 2,000,000 jobs can be reached within 60 minutes travel time (during peak hours) by car from the central urban area of Rotterdam.

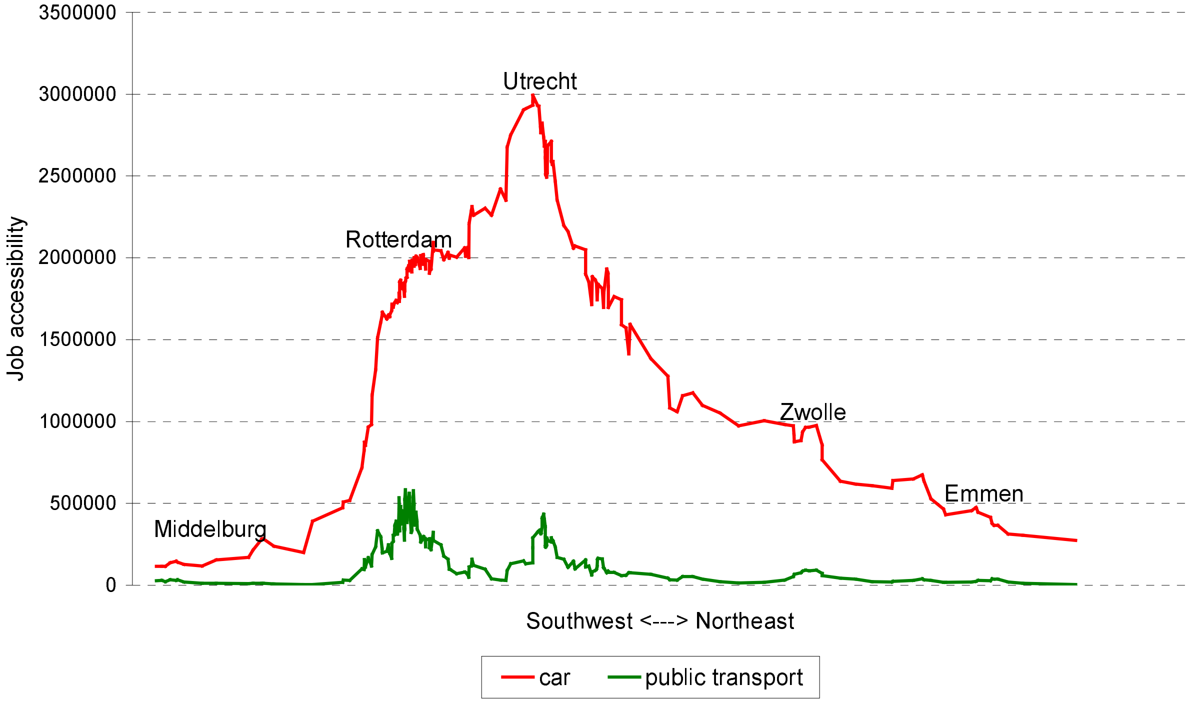

Figure 11.20: Cross-section of job accessibility by car and public transport, contour measure, 60 minutes.

Potential accessibility measure

The potential accessibility measure shows – compared to the contour measure – a somewhat smoother distribution of public transport accessibility, especially differences between suburban and rural areas are less (Figure 11.21). This is the result of the relatively large number of jobs which are accessible only within relatively long home-to-work travel times (e.g. more than 60 minutes), taken into account in the potential measure (although relatively less important than jobs nearby).

Furthermore, the large and some middle-sized towns in the Randstad Area have the highest public transport accessibility, followed by the middle-sized towns in the Brabantstad Area, eastward (Arnhem, Nijmegen) and northeastward; these are also relatively well served by public transport (regional railway stations).

If the potential substitution from car trips to public transport is the subject of interest, this can be analysed by using the parameters of the impedance function for the car mode to estimate potential accessibility by public transport. Figure 11.22 shows the resulting public transport accessibility, using the legend from the car mode (taken from Figure 11.4). Figure 11.22 also shows that only from the central urban areas of the (four) largest towns in the Randstad Area is public transport accessibility *relatively* high, i.e. average is about three times lower than by car. Compared to the contour measure (Figure 11.17), accessibility is higher in central urban areas and lower in surrounding suburban areas. Furthermore, the central urban area of the city of Utrecht also has a relatively high level of public transport accessibility.

Joseph and Bantock's measure

Compared to the potential accessibility measure, Joseph and Bantock's measure shows a more spatially differentiated picture (Figure 11.23). The measure shows the spatial selective effect of public transport more clearly: the number of jobs which can be reached by public transport per working person is the highest in the central urban areas where jobs are plentiful and relative level-of-service high, lower in surrounding suburban areas (moderate level-of-service; labour force surplus) and very low in rural areas (low level-of-service; labour force surplus).

Inverse balancing factor

The inverse balancing factor (Figure 11.24) shows a spatial distribution of job accessibility by public transport comparable to the potential measure (Figure 11.21). However, the Randstad Area is less dominant. Central urban and suburban areas in the Randstad Area show – compared to the potential measure - a lower accessibility level as the result of a large number of workers (competitors) within reach (thus a relatively strong competition for jobs). Figure 11.25 shows the differences between the balancing factor and the potential measure more clearly, also that peripheral regions in the northern, southern and southwestern parts of the Netherlands have higher accessibility levels as a result of the relatively low job competition level.

Job accessibility by public transport is more concentrated if the educational match is accounted for. Figure 11.26 shows the weighted-average job accessibility of low- and intermediate-educated and highly educated workers per zone. Job accessibility is lower in suburban and peripheral areas inside and outside the Randstad, as a result of the low accessibility level for high-educated workers (Figure 11.27). Job accessibility for low- and intermediate-educated workers (Figure 11.28) is relatively more disperse due to the availability of jobs outside central urban areas, although the highest accessibility levels are also found in central urban areas (due to the higher level-of-service of public transport).

Utility-based accessibility

Figure 11.29 shows the regional differentiation of the utility-based accessibility measure for public transport. The spatial distribution is similar to the potential accessibility measure (Figure 11.21). Figure 11.30 accounts for the different sensitivity to travel costs between socio-economic groups. The spatial distribution of the utility-based accessibility measure for public transport is very similar to the car mode (Figure 11.13). Again, the effect of the spatial distribution of socio-economic groups on the average utility level dominates the differences in job accessibility by public transport, i.e. central urban areas have a relatively low utility level as a result of low average household incomes despite the high number of jobs within reach by public transport. Utility is the highest in areas with a relatively high average household income combined with a relatively high to moderate potential job accessibility level, e.g. suburban areas between the large and middle-sized cities in the Randstad Area.

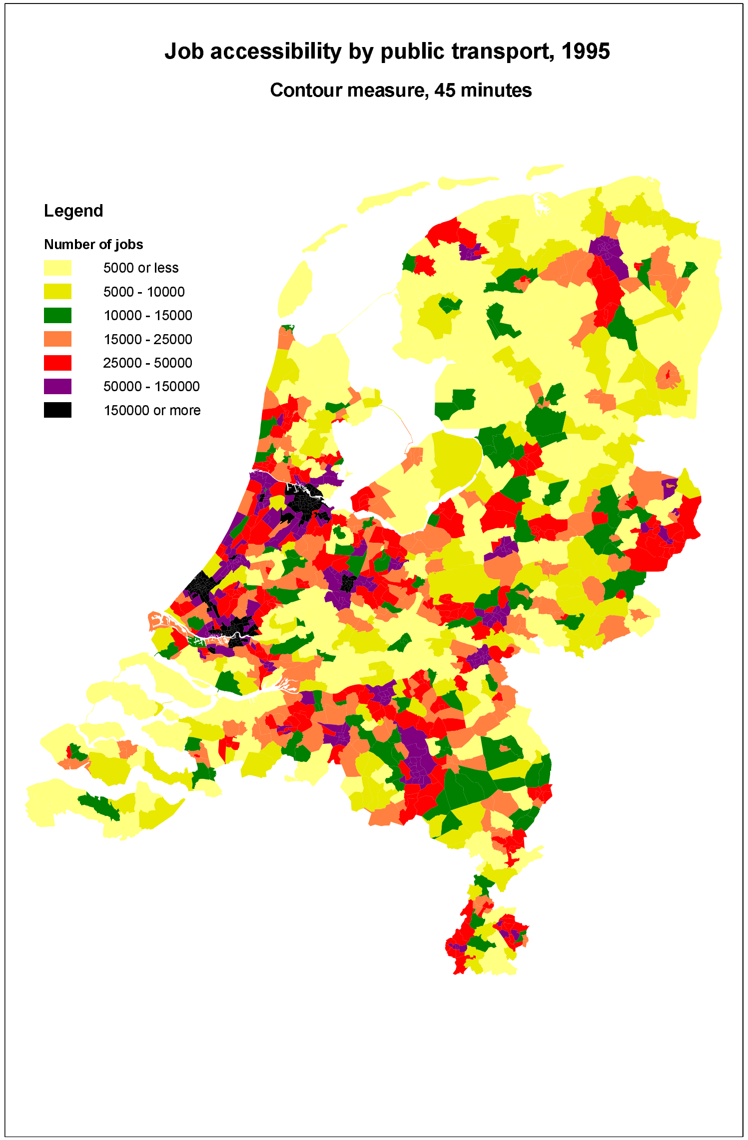

Figure 11.17: Job accessibility by public transport, contour measure 45 minutes, 1995.

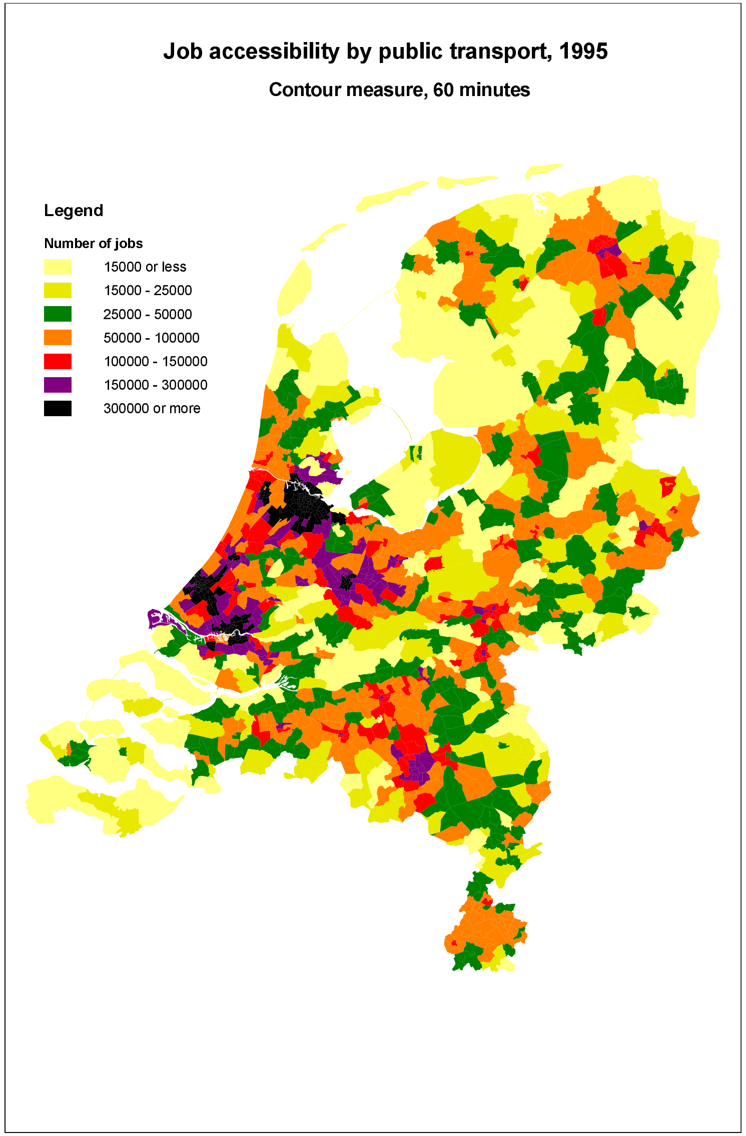

Figure 11.18: Job accessibility by public transport, contour measure 60 minutes, 1995.

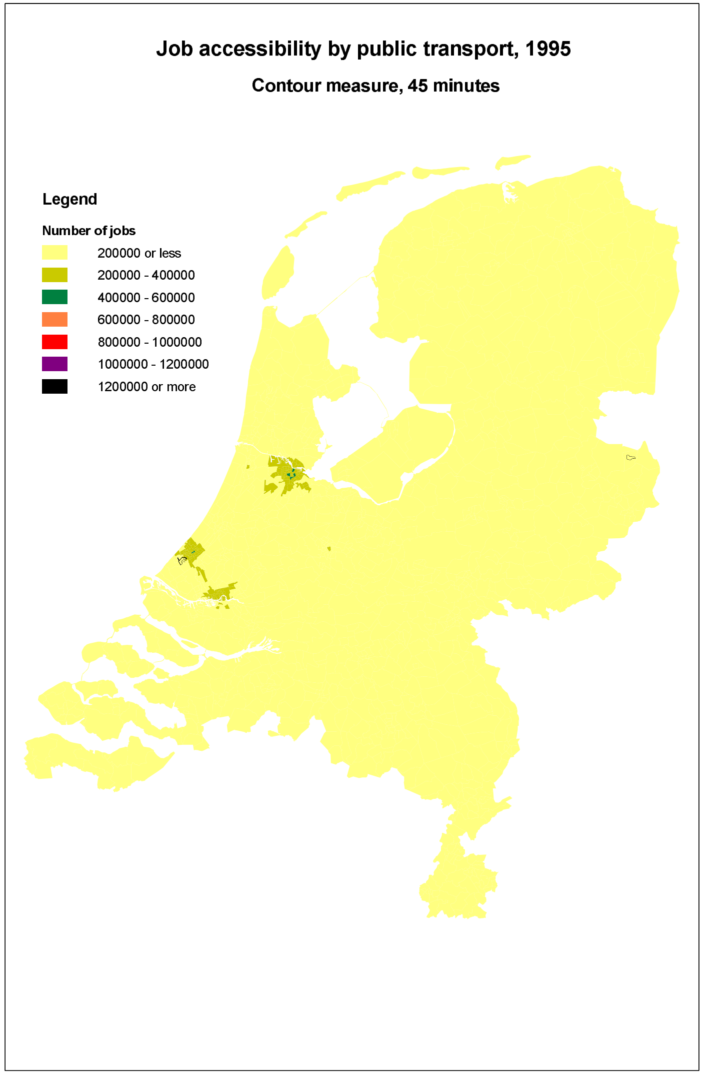

Figure 11.19: Job accessibility by public transport, contour measure 45 minutes, 1995; legend taken from Figure 11.2.

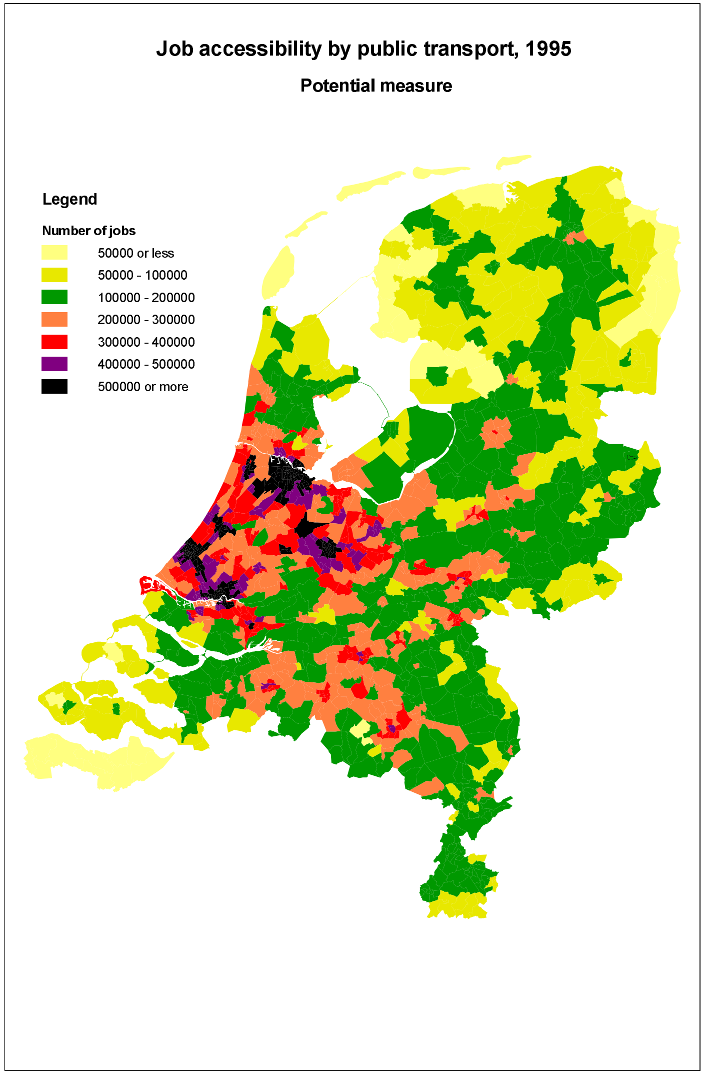

Figure 11.21: Job accessibility by public transport, potential measure , 1995.

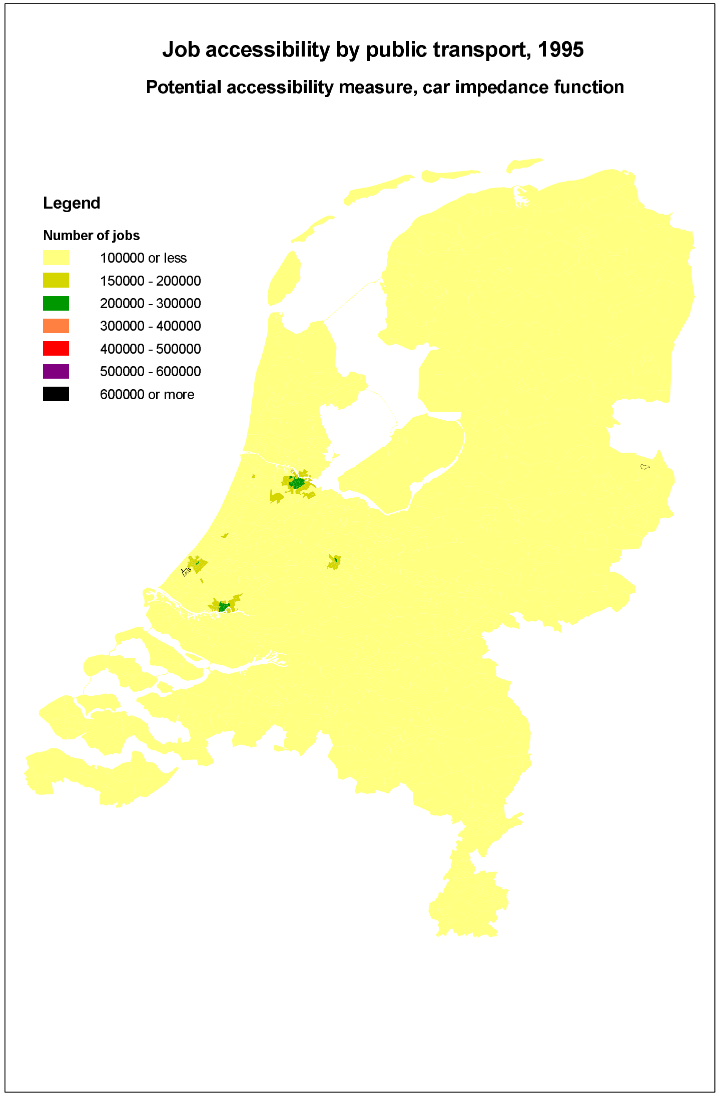

Figure 11.22: Job accessibility by public transport, potential measure using the impedance function from the car mode, 1995; legend from Figure 11.4.

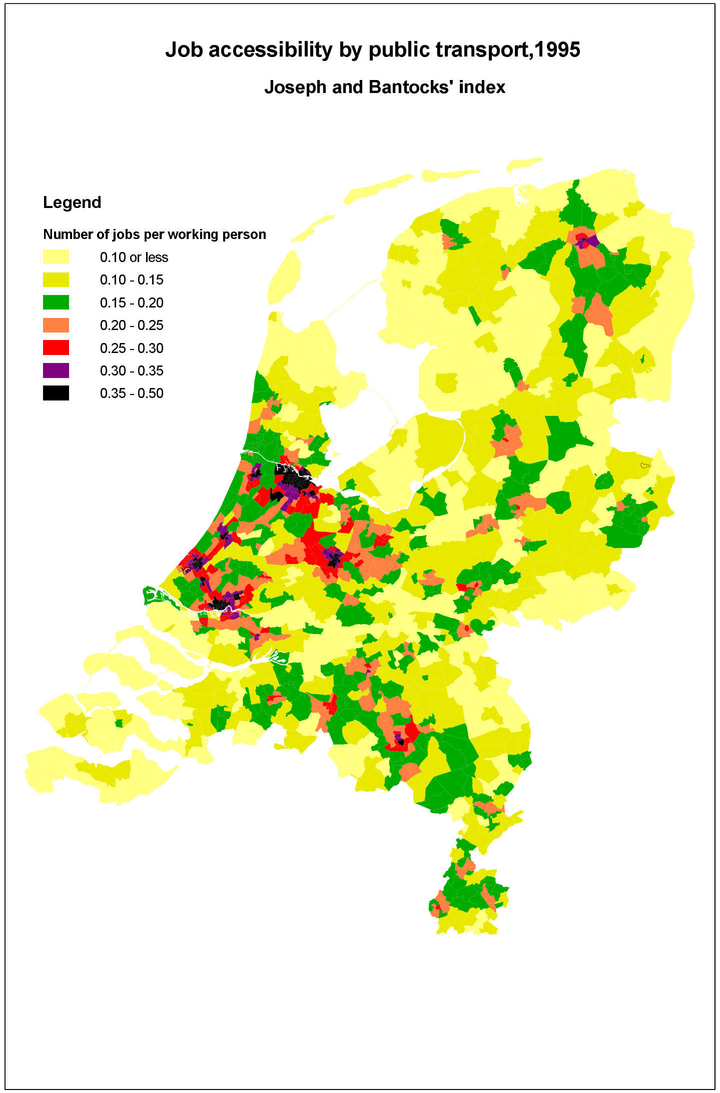

Figure 11.23: Job accessibility by public transport, Joseph & Bantock's measure, 1995.

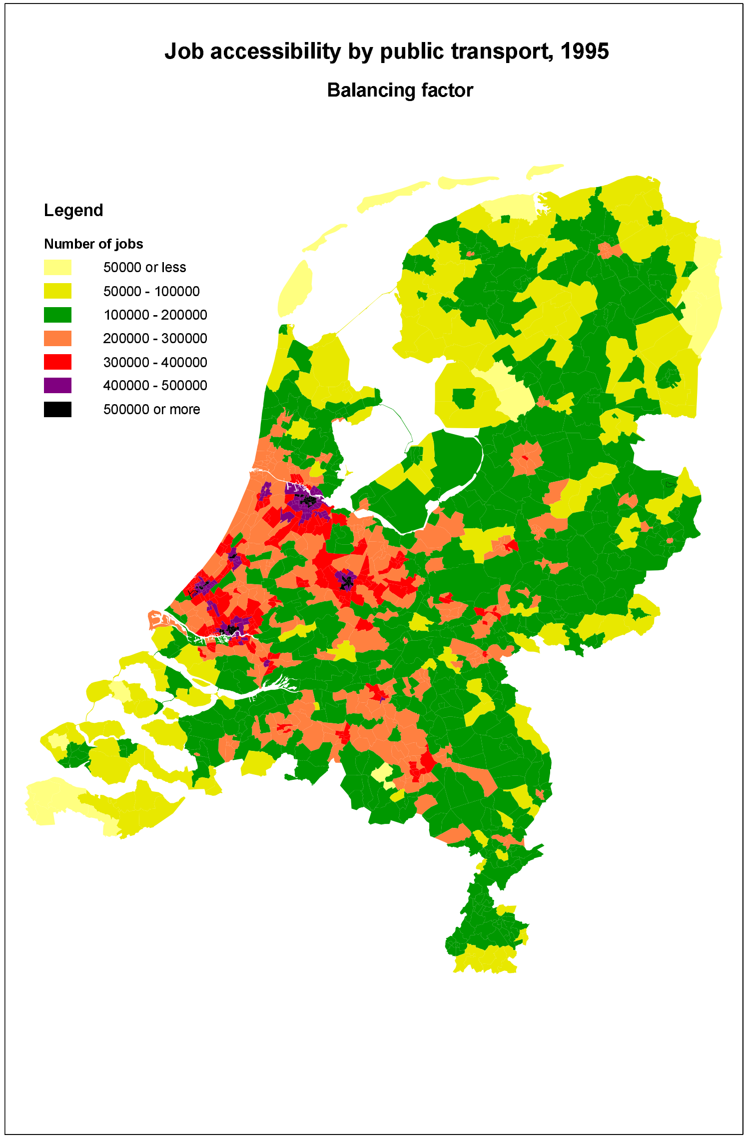

Figure 11.24: Job accessibility by public transport unweighted, balancing factor, 1995.

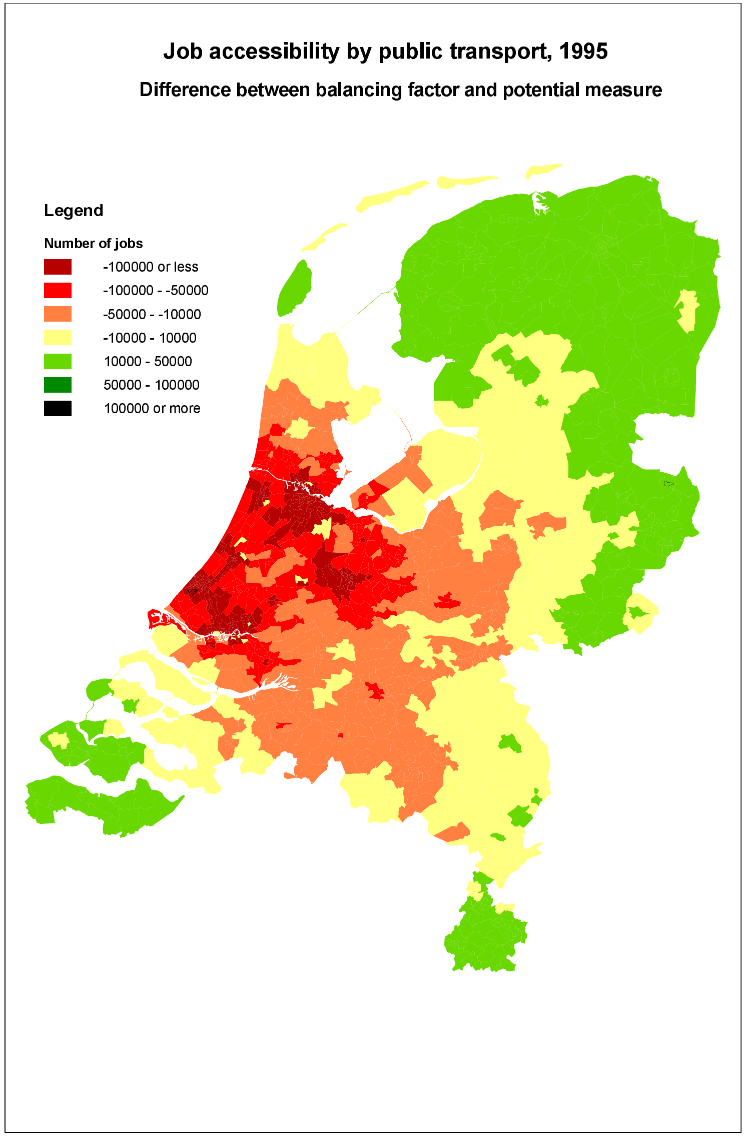

Figure 11.25: Difference between balancing factor and potential measure, 1995.

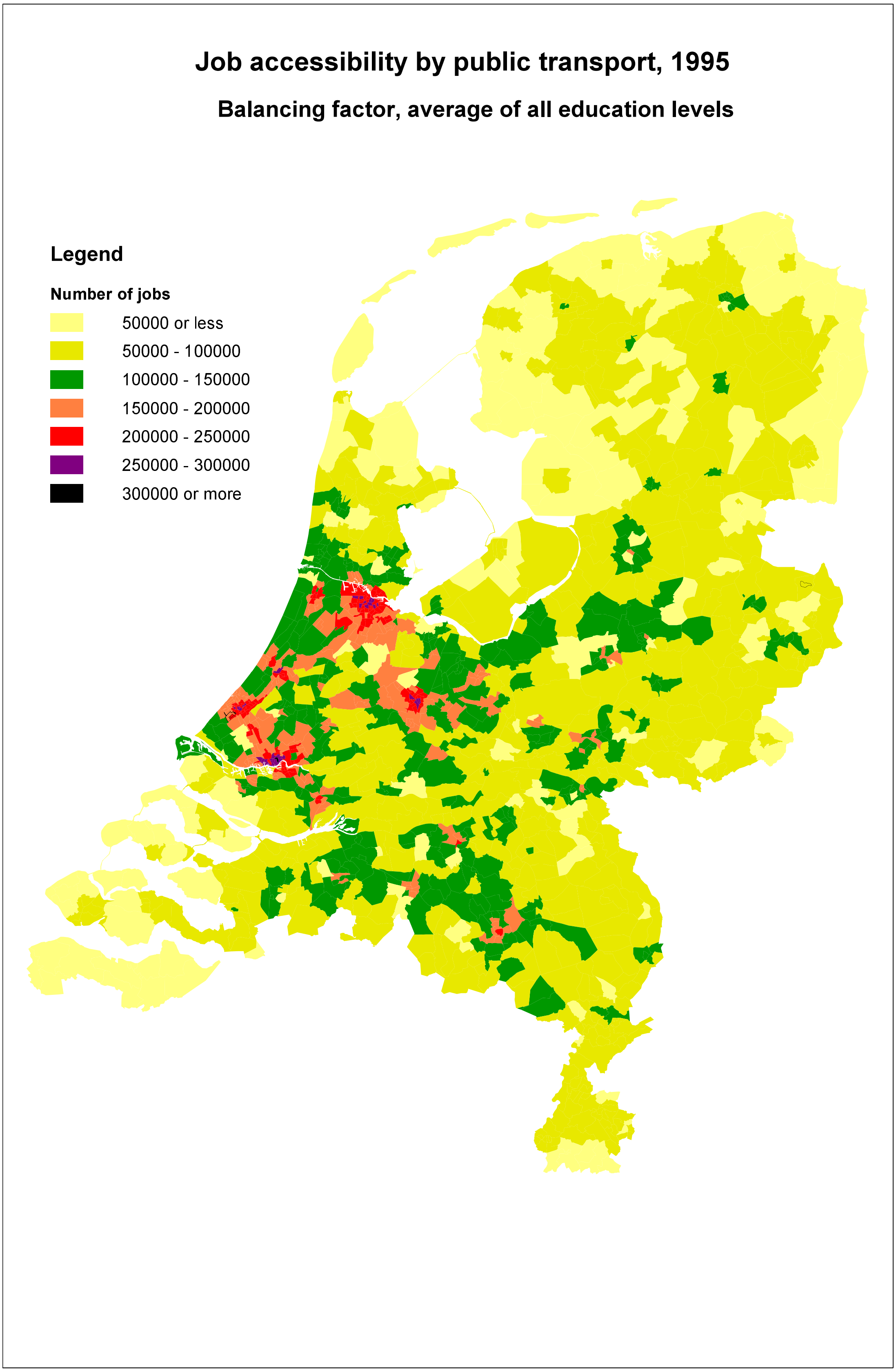

Figure 11.26: Job accessibility by public transport weighted by education level, balancing factor, 1995.

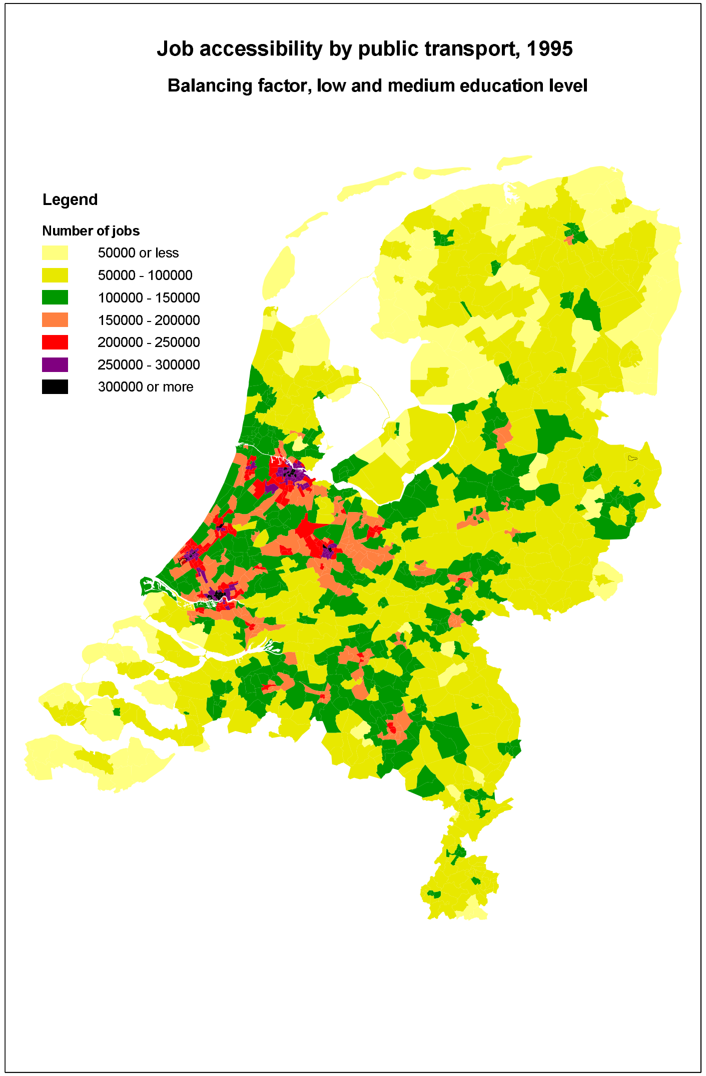

Figure 11.27: Job accessibility by public transport, high education level, balancing factor, 1995.

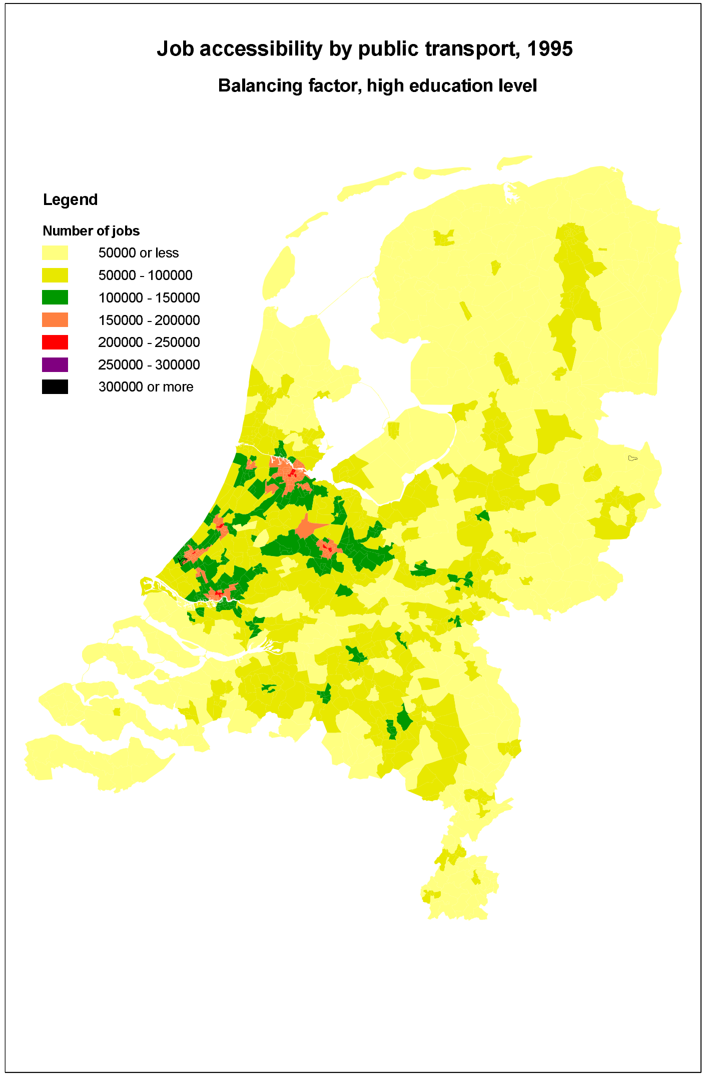

Figure 11.28: Job accessibility. by public transport, low and middle education level, balancing factor, 1995.

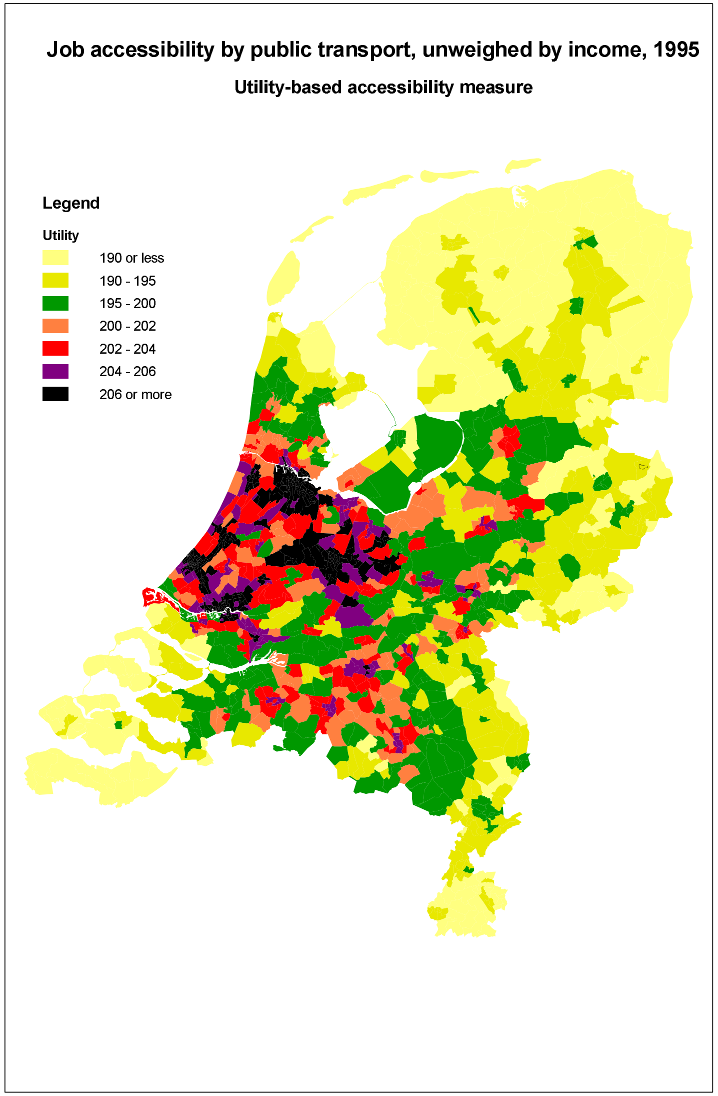

Figure 11.29: Job accessibility by public transport, unweighted by income, utility measure.

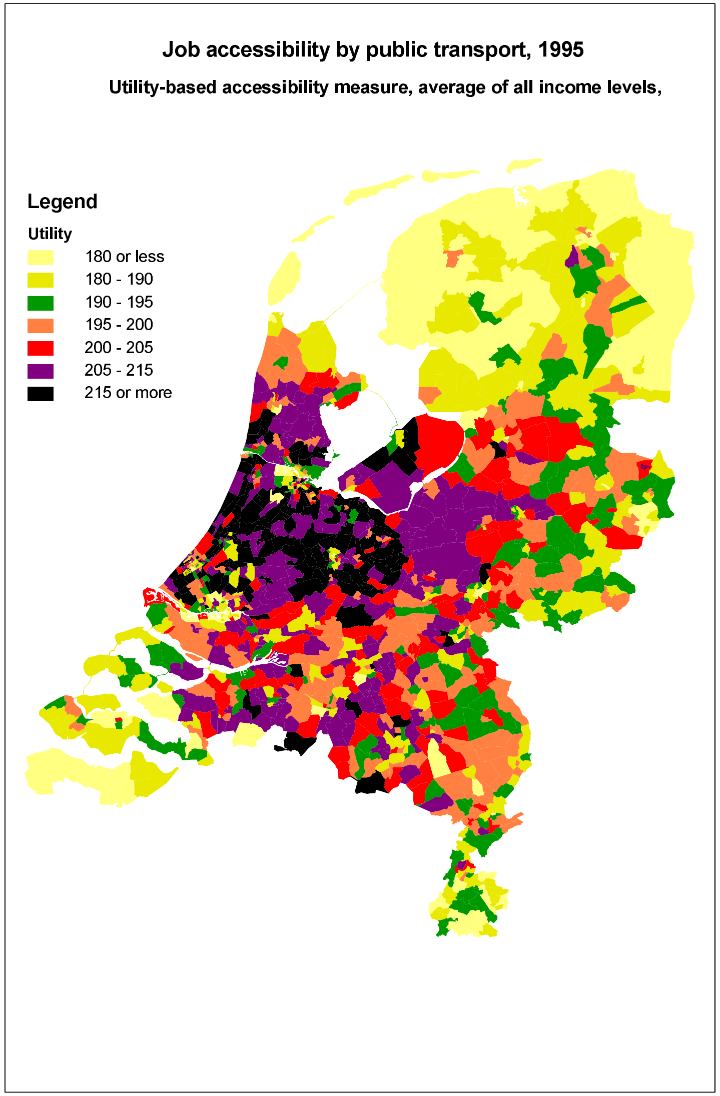

Figure 11.30: Average job accessibility by public transport, weighted by income, utility measure, 1995.

11.5 Conclusions

This section contains the conclusions of the first case study: the application of several activity-based accessibility measures (i.e. contour measure, potential accessibility measure, Joseph and Bantock's measure, the inverse balancing factor and the utility-based measure) to analyse job accessibility by car and public transport for 1995.

11.5.1 Job accessibility and related utility

The ***contour measure*** shows a "common sense" picture of (the regional distribution of) job accessibility by car and public transport, i.e. the measures show the total number of jobs that can be reached within a maximum travel time. Another advantage of the contour measure is that it allows a direct comparison of job accessibility between modes[10]. For example, for 1995 the contour measure shows that:

- The average number of jobs at national level which can be reached by car from a residence within 45 minutes is more than 11 times greater than by public transport;
- The spatial differentiation of job accessibility is relatively large for public transport: i.e., the total number of jobs which can be reached within 45 minutes by public transport is highest in the central urban areas of the largest cities in the Netherlands (Amsterdam, Rotterdam and The Hague). However, on average, it is about four times lower than by car. In surrounding suburban areas and medium-sized cities, job accessibility is about 6-7 times lower and in rural areas, on average, about 60-70 times lower.

The results of the ***potential accessibility measure*** differ greatly from the contour measure as a result of the absence of a maximum travel time and the use of an impedance function (thus destinations further away have less influence on the result). On the national level, job accessibility by car according to the potential measure is about 50% lower than according to the contour measure, whereas public transport accessibility is roughly 4.5 times higher. The potential measure shows higher accessibility levels in the central urban areas and lower in surrounding suburban regions. For public transport, job accessibility is smoother, with especially differences between suburban and rural areas being lower.

The ***utility-based measure*** estimates the utility people attach to accessibility. The spatial distribution of utility attached to job accessibility by car and public transport seems to be similar to the potential accessibility measure if no differences between socio-economic groups are assumed. However, the bandwidth of utility values is much smaller than for the potential accessibility measure. An important characteristic of the utility-based measure is that it shows diminishing returns of accessibility improvements: if job accessibility increases at locations

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[10] The other accessibility measures computed in this study (potential measure, Joseph and Bantocks' measure, the balancing factor and the utility-based measure) use impedance functions, which are based on single mode trip data (car or public transport). As the estimated impedance functions for car and public transport show large differences, the accessibility measures can not simply be used to analyse accessibility differences between modes (see Section 10.2).

with a low accessibility level (e.g. peripheral areas); this results in a relatively strong utility change, whereas an increase in accessibility at locations with an already relatively high accessibility level (e.g. central urban areas) results in a relatively small utility change.

11.5.2 Influence of competition effects on job accessibility

Joseph and Bantock's accessibility measure shows that central urban areas have a relative job surplus (the number of jobs which can be accessed per worker greater than one); surrounding (suburban) areas are relatively well-balanced and peripheral areas have a relative job shortage. Furthermore, the number of jobs per worker is much less for public transport users (on average 0.2 jobs within reach per working person) than for car users (on average 1.1 jobs within reach per working person).

Joseph and Bantock's measure has two major disadvantages. Firstly, the measure is expressed as an index (number of jobs per working person) and can thus essentially not be interpreted as an activity-based accessibility measure (i.e. expressing the number of opportunities within reach of an origin location). As a result, the measure is difficult to compare with other accessibility measures applied in this study. Secondly, the measure includes all workers within reach of a job location as potential competitors but does not account for the effect that workers have several job locations within reach (competition on the labour force).

The ***inverse balancing factor*** overcomes the disadvantages of Joseph and Bantock's measure, i.e. the inverse balancing factor can be expressed as a potential accessibility measure and the measure incorporates the interdependent relationship between job and labour-force competition. The spatial distribution of the inverse balancing factor for the car and public transport is, at a glance, very similar to the potential accessibility measure. However, significant differences exist. If job and labour force competition is accounted for, job accessibility by car (at the national level) is about 8% lower, whereas job accessibility by public transport is about 17% lower. Job accessibility in central and suburban urban areas within the Randstad is relatively sharply reduced (20-25% by car; 25-30% by public transport) as a result of a relative large labour force within reach, whereas peripheral areas show a relatively strong increase (on average 25% by car and public transport) as a result of a relative small labour force within reach. In conclusion, job competition has a significant influence on potential job accessibility for 1995, but does not radically change the regional distribution of job accessibility in the Netherlands.

11.5.3 Effect of socio-economic differences on job accessibility

As already described in Section 4.5, there may be significant differences in job accessibility due to socio-economic characteristics of the population and its distribution in space with respect to the spatial distribution of jobs. In this report, the effect of the (potential) match between the educational level of the population and job requirements on job accessibility was analysed for the potential accessibility measure and the inverse balancing factor using two education levels (high and low-intermediate). In conclusion, the “occupational match” strongly affects the absolute level of job accessibility and average job accessibility is reduced by 50-55%. Furthermore, job competition is the highest for high-educated workers using public transport and lowest for low- or intermediate-educated workers using the car.

Furthermore, the result of the utility-based measure is very different when the measure is computed for the entire population than when estimated for different income groups. Thus the result strongly depends on the selection of socio-economic groups, and resulting differences in time valuation (value of time) and sensitivity to travel costs between the population groups. The results for 1995 show the spatial distribution of the population by income groups (here: three groups) to dominate the utility level aggregated (weighted average) for the entire population; e.g. central urban areas have a relatively low average utility level as a result of the low average household incomes despite the relatively high job accessibility level by car and public transport.

In conclusion, the differentiation of the population by socio-economic characteristics results in significant changes in average job accessibility and related utility, this being the result of a more accurate estimation.

12. Case study 2: Trend Scenario

12.1 Introduction

This section describes the development of job accessibility for the Trend Scenario for the 1995-2020 period, according to the selected accessibility measures (contour measure, potential measure, Joseph and Bantock's measure, inverse balancing factor and utility-based measure).

Section 12.2 describes the aggregate results at national level. Unfortunately, for the Trend scenario, the development of job accessibility can not be split up according to socio-economic groups (educational level or income level) due to a lack of data. Section 12.3 describes the regional development of job accessibility according to the Trend scenario. To reduce the number of possible figures, results are presented for the car mode only, and the contour measure is presented using only 45 minutes as the maximum travel time. In addition, to increase the interpretability of the development of job accessibility, the separate influence of land-use changes is described, along with delays and congestion and infrastructure construction on the development of the potential accessibility.

12.2 National development of job accessibility

Table 12.1 shows the development of the average job accessibility by car and public transport per zone according to the Trend scenario for the 1995-2020 period. Table 12.2 shows the development of average job accessibility per person by car and public transport.

Table 12.1: Development of average job accessibility per zone by car and public transport for 1995-2020, Trend scenario (index 1995=100)

	Car	Public transport
Contour measure, 45 minutes	104	139
Contour measure, 60 minutes	104	145
Potential accessibility measure	108	152
Joseph & Bantock's measure	99	137
Inverse balancing factor	108	149
Utility-based measure	100	103

Table 12.2: Development of average job accessibility per person by car and public transport for the 1995-2020, Trend scenario (index 1995=100)

	Car	Public transport
Contour measure, 45 minutes	104	140
Contour measure, 60 minutes	105	146
Potential accessibility measure	109	153
Joseph & Bantock's measure	99	137
Inverse balancing factor	109	150
Utility-based measure	100	103

Tables 12.1 and 12.2 show that the increase in job accessibility by car and public transport is according to the ***contour measure*** smaller (4-5% and 40-45% increase, respectively) than the according to the potential accessibility measure (8-9% and 52-53% increase, respectively) and the inverse balancing factor (8-9% and 49-50%, respectively). The differences between the contour measure and the potential measure can be illustrated by describing the influences of the components. As already described in Section 10.3, the development of job accessibility can, using the available data from the land-use and transport models from this study, be explained by different components, for which impacts may be opposite: (a) a land-use component, i.e. changes in the amount and spatial distribution of activities, (b) a transport component, i.e. travel time changes as a result of increased or decreased delays and congestion and/or road capacity expansion, and (c) an interaction component, i.e. changes in accessibility as the result of the combination of land-use and transport changes. Figure 12.1 shows the contribution of the different factors on the development of job accessibility by car for the 1995-2020 period according to the contour measure (with 45 minutes as maximum travel time), Figure 12.2 according to the potential accessibility measure.

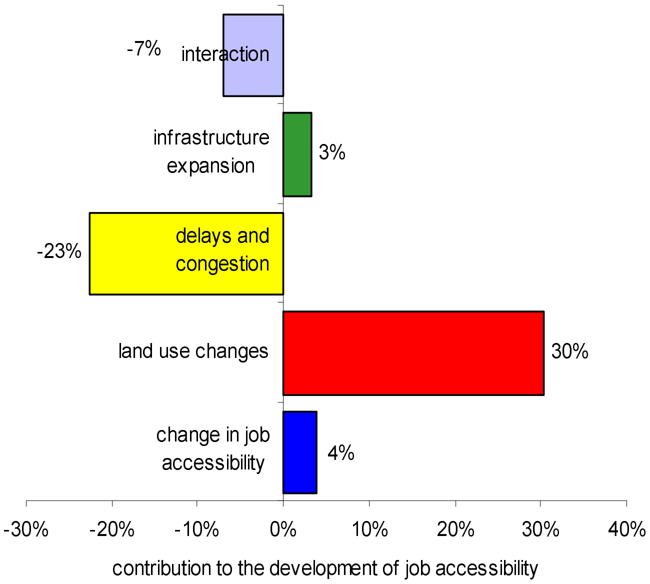

Figure 12.1: Contour measure, 45 minutes: contribution of land-use changes, congestion and infrastructure expansion to the development of job accessibility by car, Trend scenario 1995-2020.

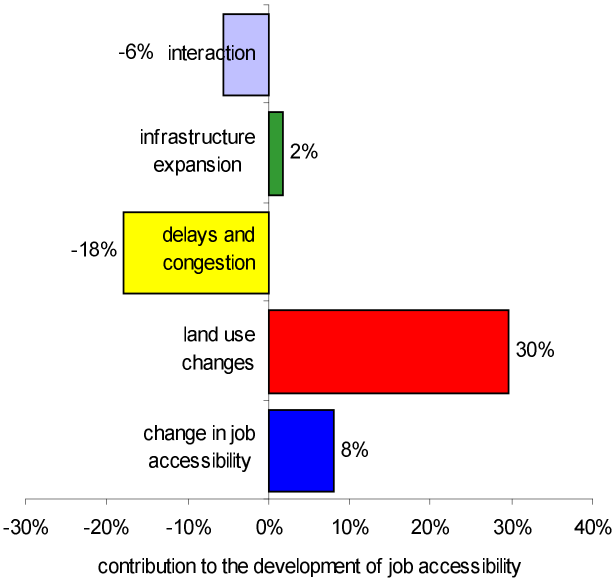

Figure 12.2: Potential measure: contribution of land-use changes, congestion and infrastructure expansion to the development of job accessibility by car, Trend scenario 1995-2020.

Figures 12.1 and 12.2 shows that on the national level, job accessibility by car increases in the 1995-2020 period as a result of (a) the growth of the total number of jobs (about 30%) and (b) infrastructural improvements (on the national level by about 2-3%). However, this increase is largely counterbalanced by the increase in delays and congestion (at national level by about 18%). Interestingly, the influence of increased delays and congestion on the development of accessibility is much stronger for the contour measure than for the potential measure, whereas the impact of land-use changes is the same (both 30% increase). This can be explained as follows. A travel time increase reduces the radius of the "circle" around each location and thus the total surface people can reach within the assumed maximum travel time. A reduction of the travel time results, according to a contour measure, in a more than proportional reduction of the total surface within reach. For example, a 10% travel time increase, reduces the total surface of the "circle" by about 20%, assuming a 45 minutes maximum travel time and an average travel speed of 30 km/h. If all activities would be equally distributed in space, the contour measure would also be reduced by 20%. In contrast, land-use changes have a proportional impact on the contour measure, i.e. an overall 10% increase in the number of jobs results, ceteris paribus, in a 10% increase of job accessibility. The impact of travel times is much less for the potential measure as the result of the use of an impedance function. For example, with the impedance function used, 100 jobs at a location 45 minutes away from an origin location are included in the accessibility index of that location as 15 jobs. In reality, the impact of land-use and travel times changes is more complex because activities are not equally distributed in space, and the interaction between the land-use and transport components. Figures 12.1 and 12.2 show that average job accessibility by car increases by about 4% according to the contour measure and about 8% according to the potential measure.

Figure 12.2 shows the contribution of the different components on the development of job accessibility by public transport according to the contour measure (with 45 minutes as maximum travel time), Figure 12.2 according to the potential measure.

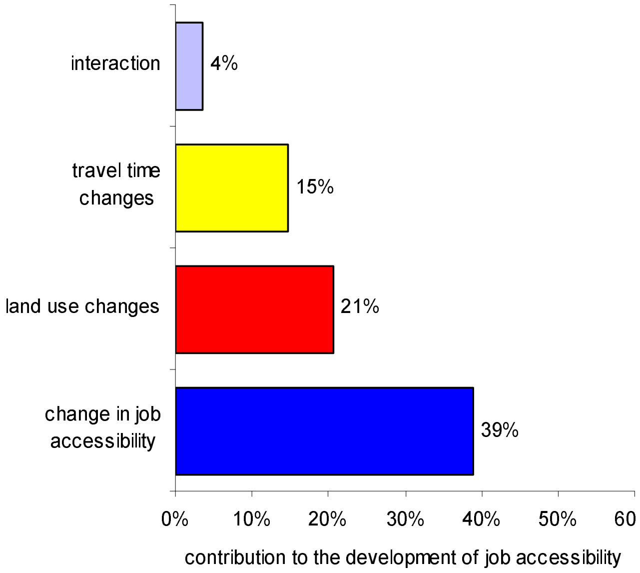

Figure 12.3: Contour measure, 45 minutes: contribution of land-use change and average travel times to the development of job accessibility by public transport, Trend scenario 1995-2020.

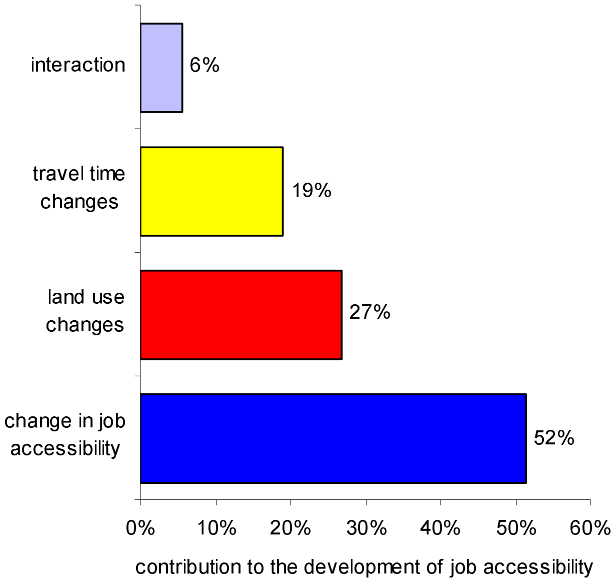

Figure 12.4: Potential measure: contribution of land-use change and average travel times to the development of job accessibility by public transport, Trend scenario 1995-2020.

Figures 12.3 and 12.4 shows that the increase in job accessibility by public transport as the result of the increase of the number of jobs is strengthened by decreased average travel times due to improved public transport supply (increased travel speed and frequency). Interestingly, the contribution of land-use and travel time changes to the accessibility development is smaller for the contour measure than for the potential measure. As a result, the average increase in job accessibility by public transport is according to the contour measure is smaller (39% increase) than the according to the potential accessibility measure (52% increase). This is primarily the result of the (arbitrary) maximum travel time used in the contour measure: only land-use or transport changes within the maximum travel time (of 45 minutes) are taken into account. Thus, land-use or transport changes relatively far away from the origin zones (46 minutes respectively) are not taken into account. However, most locations are farther away than 45 minutes travel time by public transport, e.g. in 1995 an average public transport trip took about 70 minutes - Egeter *et al.* (2000). Furthermore, not all travel-time changes are theoretically taken into account because of the absence of a distance decay function, i.e. if the travel time to a job location, already within reach in 1995, is improved (say from 30 to 10 minutes), this has no effect on the result (all jobs within the maximum travel time are equally weighed), only if as a result other jobs become accessible within the maximum travel time.

Furthermore, Tables 12.1 and 12.2 show that the ***inverse balancing factor*** estimates the same growth in job accessibility by car as the potential accessibility measure; job accessibility by public transport is three percentage points lower. Thus, on the national level, average job competition among car users does not increase in the Trend scenario, whereas job competition among public transport users increases slightly.

According to ***Joseph and Bantock's measure,*** average job accessibility by car is slightly reduced, i.e. from 0.97 jobs accessible per worker for 2020 to 0.96 for 1995, whereas job accessibility by public transport increases, i.e. from 0.19 jobs accessible per worker to 0.26. As Joseph and Bantock's measure is expressed as an index, this result is difficult to compare with the other accessibility measures. Essentially, the measure shows that the spatial distribution of jobs becomes somewhat less well balanced with the spatial distribution of the working population for car users, and better balanced for public transport users.

The ***utility-based accessibility measure*** shows a constant average utility level for the car in the 1995-2020 period, implying that the effect of increased job accessibility at locations as a result of the increase in the number of jobs is balanced by the increased average travel times. The increase in job accessibility and improved public transport supply result in a very small increase in utility for public transport users. This can be explained as follows. The utility-based measure takes the natural logarithm of the potential job accessibility index, so that a change of job accessibility at locations which already have a high accessibility level has relatively little impact on the utility level. As a result, improvement of existing public transport supply (higher travel speed and/or frequency) improves job accessibility at locations which already have a relatively high job accessibility level (i.e. central urban areas), but does not strongly influence the utility level of public transport users.

Furthermore, Tables 12.1 and 12.2 show little differences between the average accessibility level per zone or per person; the population is relatively well distributed over the zones.

12.3 Regional development of job accessibility by car

12.3.1 Results per accessibility measure

Contour measure

The contour measure shows an extremely spatially differentiated development of job accessibility for the Trend scenario for 1995-2020 (Figure 12.3). Regions with a substantial increase in accessibility can be located near regions with a substantial decrease in accessibility. Furthermore, the contour measure shows many regions with a decrease in job accessibility: about 40% of all zones show a job accessibility decrease, compared to about 20% for the potential accessibility measure (Figure 12.4). This is mainly the result of the (arbitrary) maximum travel time: a small change in the travel time may result in the inclusion or exclusion of a job location from the accessibility value of an origin zone. For example, job locations which are accessible within 44 minutes travel time in 1995 and, as a result of increased delays or congestion require a few minutes longer travel time in 2020, are not included in the accessibility value of a location for 2020. Thus, travel time changes (here: an overall increase as a result of increased delays and congestion) have a much stronger impact on the result of contour measures than on the (regional) potential measure.

Potential accessibility measure

The potential accessibility shows a more plausible spatially differentiated development of job accessibility by car compared to the contour measure (see Figure 12.6). Most areas in the Randstad, the central region and the east, northeast and southeast show an increase in job accessibility by car. Regions which profit the most from the increased number of jobs (see Figure 12.15) or improved road infrastructure are located in suburban regions within the Randstad (e.g. the region between Rotterdam and The Hague and southwest of Amsterdam) and the Brabantstad area. Furthermore, Figure 12.6 also clearly shows regions where job accessibility decreases as a result of increased delays and congestion, e.g. south of Utrecht and in the Brabantstad area. Interestingly, a number of regions in peripheral regions also show a decrease in job accessibility due to increased average travel times for local traffic as a result of the barrier put up by motorway expansions. The separate influence of land-use changes, congestion and road infrastructure improvements to the potential job accessibility is described in Section 12.3.2.

Joseph and Bantock's measure

At a glance, Joseph and Bantock's measure shows a negative development in the number of jobs accessible per worker by car (Figure 12.7), i.e. more than 60% of all zones show a reduced level of job accessibility by car. This is the result of a relatively sharper development of the working population compared to job growth (e.g. in peripheral regions in the north the Netherlands) and/or increased travel times (e.g. around Utrecht). The measure only shows an increase in the number of jobs within reach per working person for locations where potential job accessibility substantially increases due to new employment locations and/or infrastructure expansion (see Figure 12.6), e.g. the region between The Hague and Rotterdam. Overall, Joseph and Bantock's measures shows that the land-use changes according to the Trend scenario result in a less well-balanced spatial distribution of jobs relative to the working population. In other words, overall job competition increases for the Trend scenario.

Inverse balancing factor

The development of job accessibility according to the inverse balancing factor (Figure 12.8) is very similar to the potential accessibility measure (see Figure 12.6). Most areas in the Randstad, the central, east, northeast and southeast regions show an increase in job accessibility by car. However, the average increase in job accessibility for these areas is less than for the potential accessibility measure. This is the result of increased job competition, i.e. the increase in job accessibility is less if new working locations are established in areas with a relative large labour force. Figure 12.9 clearly shows the development of job competition by showing the differences between the development of the inverse balancing factor and the potential accessibility measure for the Trend scenario for the period 1995-2020. The figure shows that job competition increases, i.e. the labour force increases more substantially than the number of jobs within reach, in (a) central and surrounding regions of the large cities in the Randstad, especially in Amsterdam and the suburban region between The Hague and Rotterdam, and (b) in urban and peripheral regions in the northern part of the Netherlands, especially in and around the city of Groningen. Job competition decreases, i.e. job growth is higher than population growth, west of Utrecht and in the southwestern and southern regions of the Netherlands. However, the current spatial structure remains dominant, for example, for the Randstad, the percentage reduction of job accessibility due to job competition increases only by 1-2% to 20-25%.

Utility-based accessibility measure

On the national level, the utility-based accessibility measure shows a constant average utility level for the car for the 1995-2020 period. The relative change in utility for the 1995-2020 period is small, i.e. utility changes are found within a range of -3.5% to 2.5%, whereas job accessibility changes are found within a range of –30% to 50%. Figure 12.10 shows the regional differences in the development of utility. The figure shows that the largest utility changes are found mostly outside the Randstad: relatively large decreases in utility are found in peripheral regions (northern, eastern, southern and western parts of the Netherlands) and suburban areas, where job accessibility substantially decreases (by 15-30%); relatively large increases in utility are found in middle-sized towns and suburban areas where job accessibility substantially increases (by 25-30%). Central urban areas show relatively little utility change as the result of diminishing returns of marginal changes, i.e. relatively small changes of job accessibility at locations with a relatively low accessibility level (peripheral and rural areas) have a relatively large impact on the utility level, and relatively large changes at locations with a relatively high accessibility level (central urban areas) have a relatively little impact on the utility level.

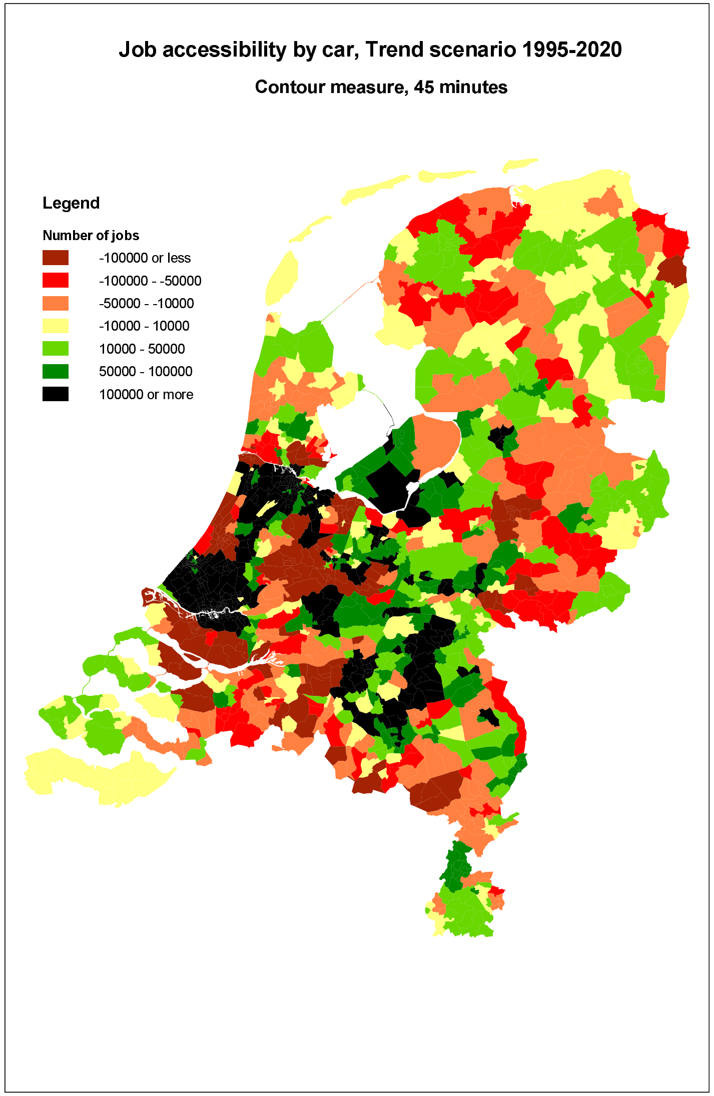

Figure 12.5: Development of job accessibility by car, Trend scenario, contour measure.

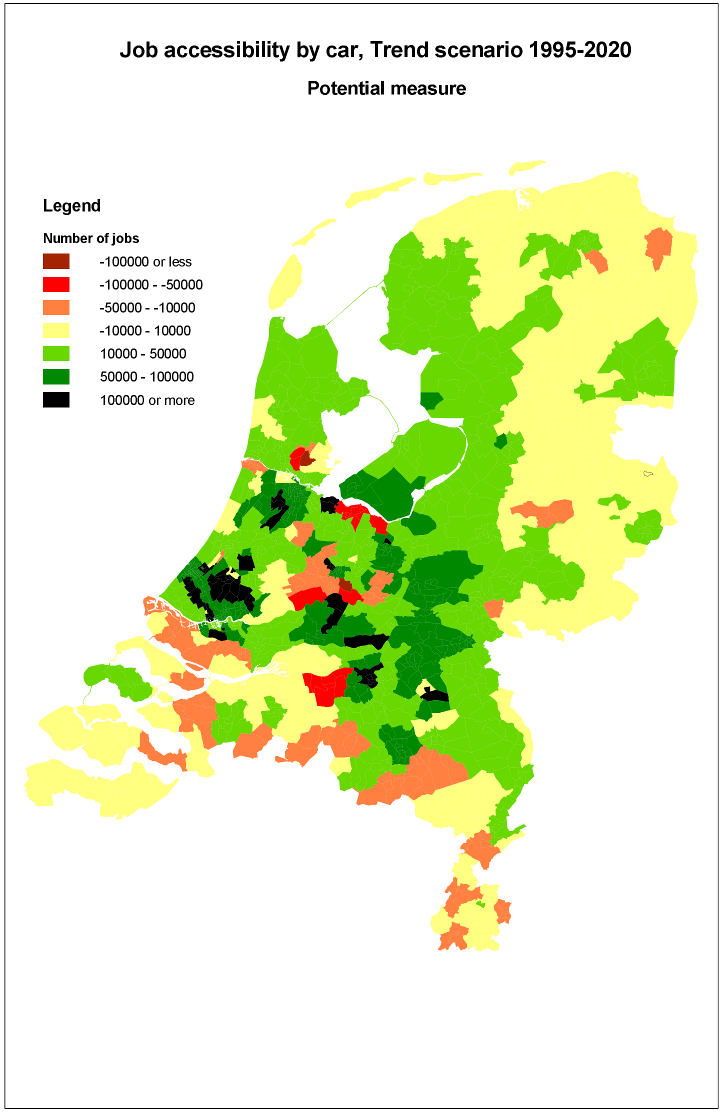

Figure 12.6: Development of job acc. by car, Trend scenario, potential measure

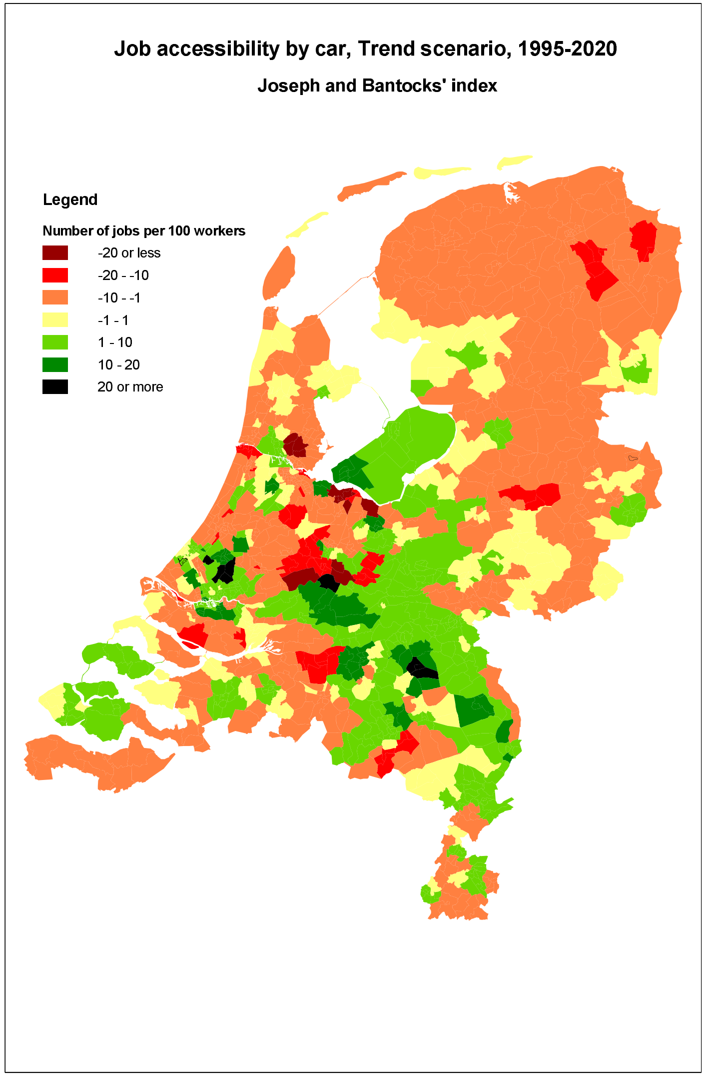

Figure 12.7: Development of job accessibility by car, Trend scenario, 1995-2020, Joseph and Bantock's measure.

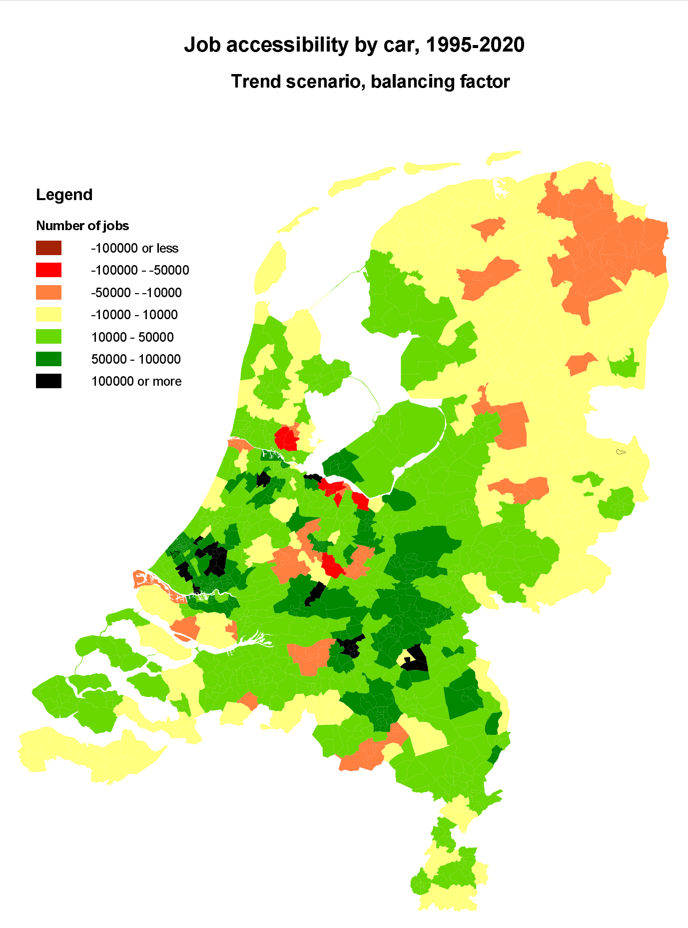

Figure 12.8: Development of job accessibility by car, Trend scenario, 1995-2020, balancing factor.

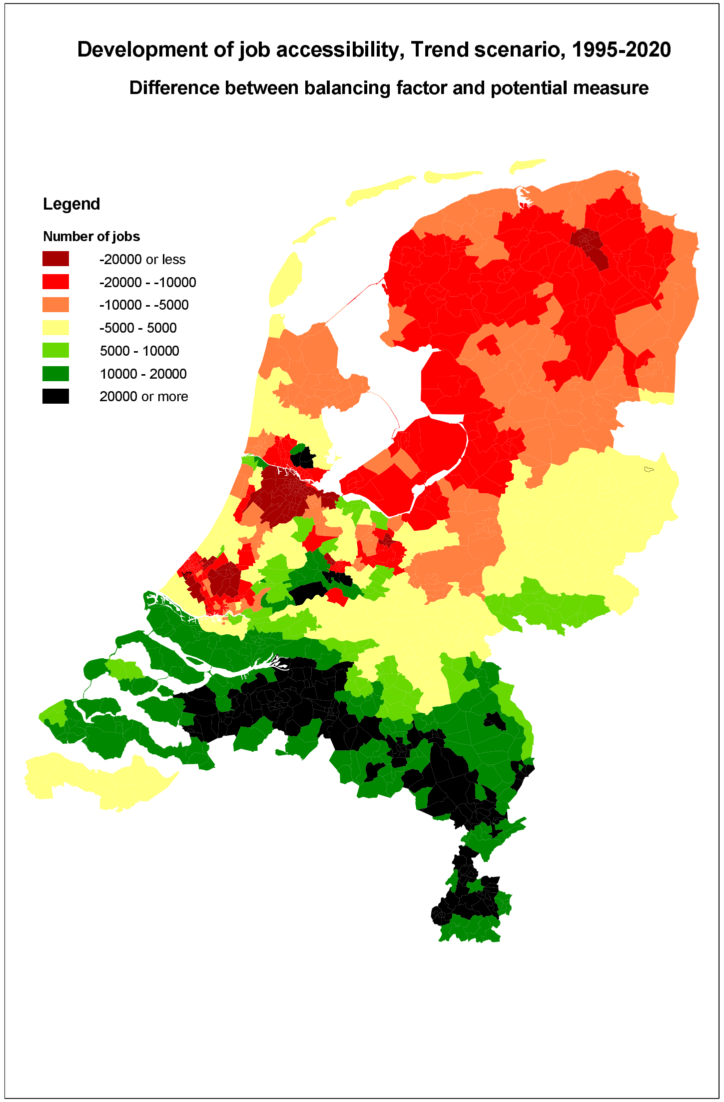

Figure 12.9: Development of job accessibility by car, difference between balancing factor and potential measure, Trend scenario, 1995-2020.

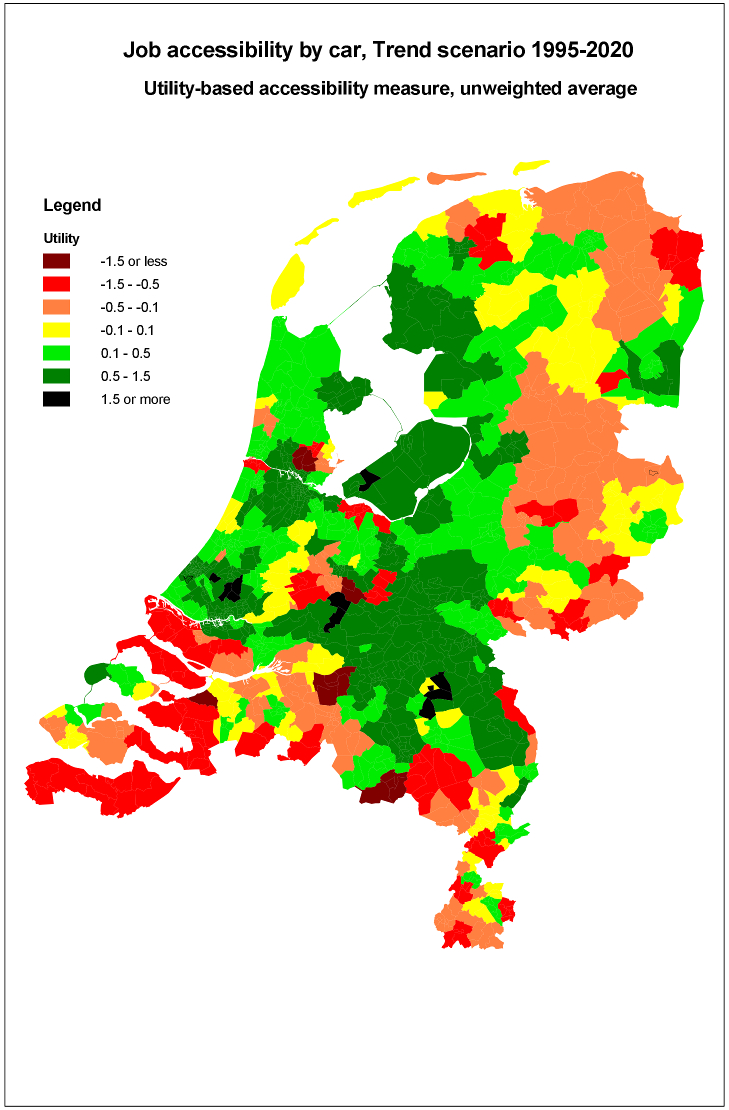

Figure 12.10: Development of job accessibility by car, Trend scenario, 1995-2020, utility-based measure.

12.3.2 Influence of land-use and transport changes on job accessibility

The regional differentiation of job accessibility by car is relatively large as a result of different developments: (a) regional development of the number of jobs, (b) changes in travel times due to increased congestion and delays, and (c) changes in travel times due to road infrastructure improvements. Figure 12.11 shows the net development of potential job accessibility by car.

Influence of land-use changes on the development of job accessibility
Figure 12.12 shows the influence of the spatial distribution of job growth on the accessibility development for the Trend scenario for the 1995-2020 period. Essentially, the figure shows a spatially moving average of the development of a number of jobs within reach between 1995 and 2020, i.e. the increase in the number of jobs within reach, assuming no change in travel times, with the increase in jobs within reach found in the range of 15 to 45%. The largest absolute growth in jobs within reach is found in the Randstad, especially in the central and suburban areas of Amsterdam and Utrecht (30-32% increase of jobs within reach). This figure clearly reflects the development of jobs according to the Trend scenario, as described in Section 9 (see also Figure 10.13). In conclusion, the land-use changes for the Trend scenario for the 1995-2020 period have a significant impact on the development of job accessibility.

Influence of delays and congestion on the development of job accessibility
Figure 12.13 shows the influence of the development of delays and congestion on the development of potential job accessibility. Essentially, the figure shows the development in the difference between forecasted travel times (including road capacity restrictions) and free flow travel times (excluding road capacity restrictions) between 1995 and 2020, according to the National Model System. Figure 12.13 shows the influence of delays and congestion on the development of job accessibility to be highest in the Randstad and gradually decreasing towards the intermediate and peripheral regions. On average, the development of delays and congestion during peak hours reduces potential job accessibility by about 20% on average for the year 2020. In conclusion, increased delays and congestion have a significant impact on the regional development of job accessibility; increased travel times may counterbalance or outweigh the effect of land-use changes on job accessibility.

Influence of road infrastructure improvements on the development of job accessibility
Figure 12.14 shows the influence of changes in road infrastructure supply on the development of the accessibility value. On the national and regional level, the influence of infrastructural changes on the development of job accessibility is modest; i.e. average job accessibility increases by about 2%. The figure clearly shows the locations where road infrastructure is improved (see also Figure 10.17) and peak hour travel times are reduced, e.g. the area between The Hague and Amsterdam. Furthermore, the figure shows the effect of reduced traffic speed in urban areas on job accessibility; e.g. job accessibility in Amsterdam, The Hague, Rotterdam and Utrecht slightly decreases. It is interesting to note that a number of regions in peripheral regions also show a decrease in job accessibility as a result of the barrier put up by motorway expansions, e.g. the region eastward of Rotterdam and some parts of peripheral regions.

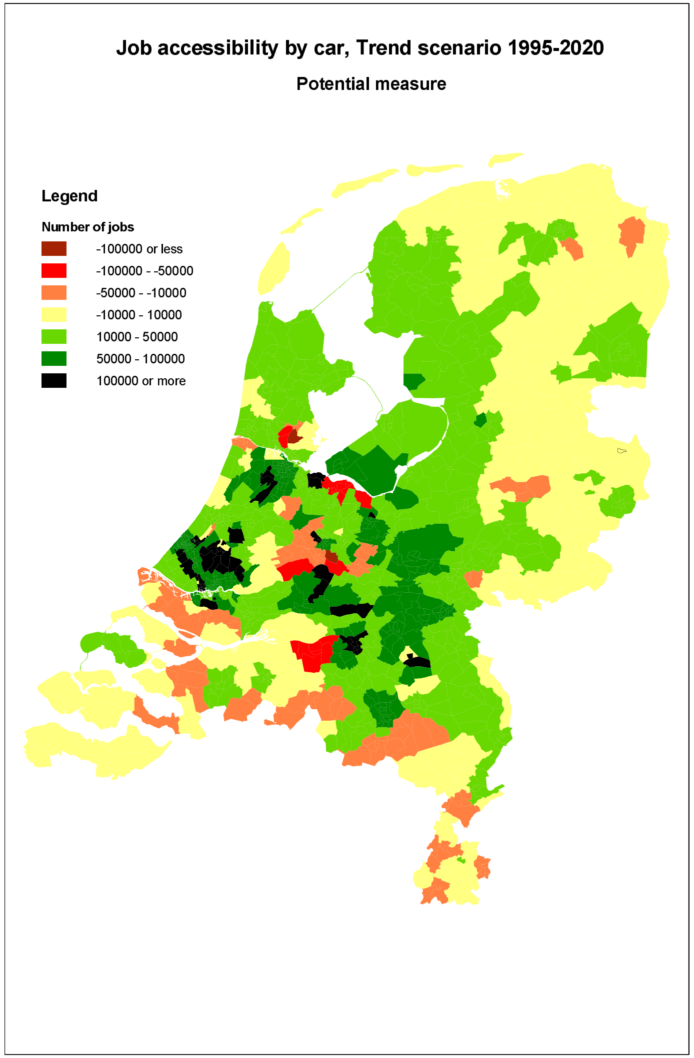

Figure 12.11: Development of job accessibility by car, Trend scenario, 1995-2020.

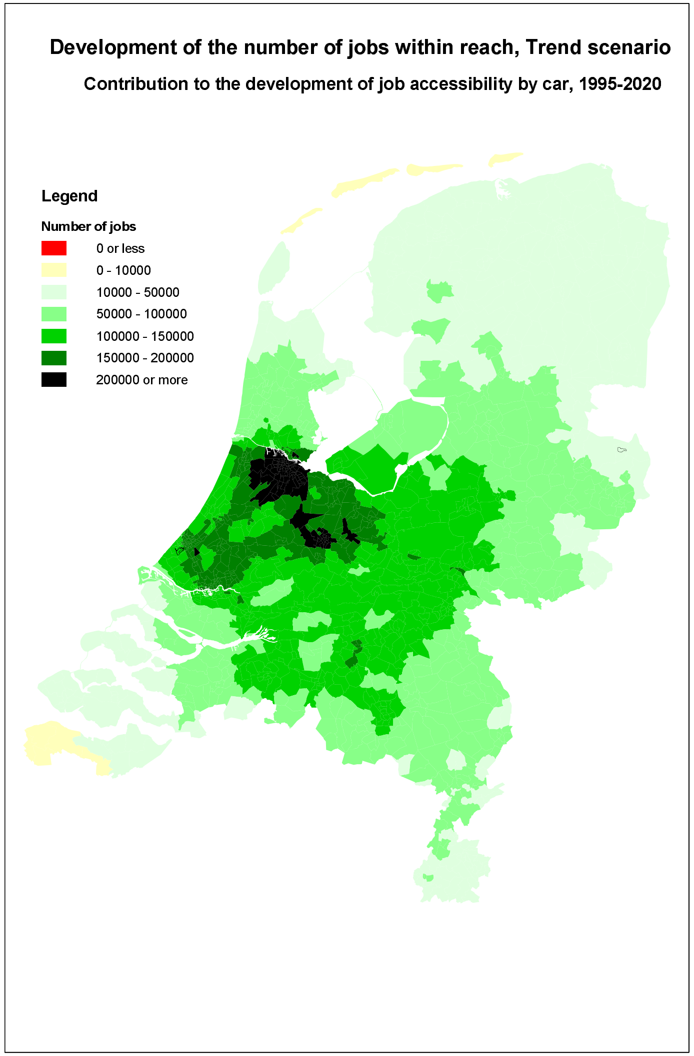

Figure 12.12: Influence of land-use changes on the development of potential job accessibility by car, Trend scenario.

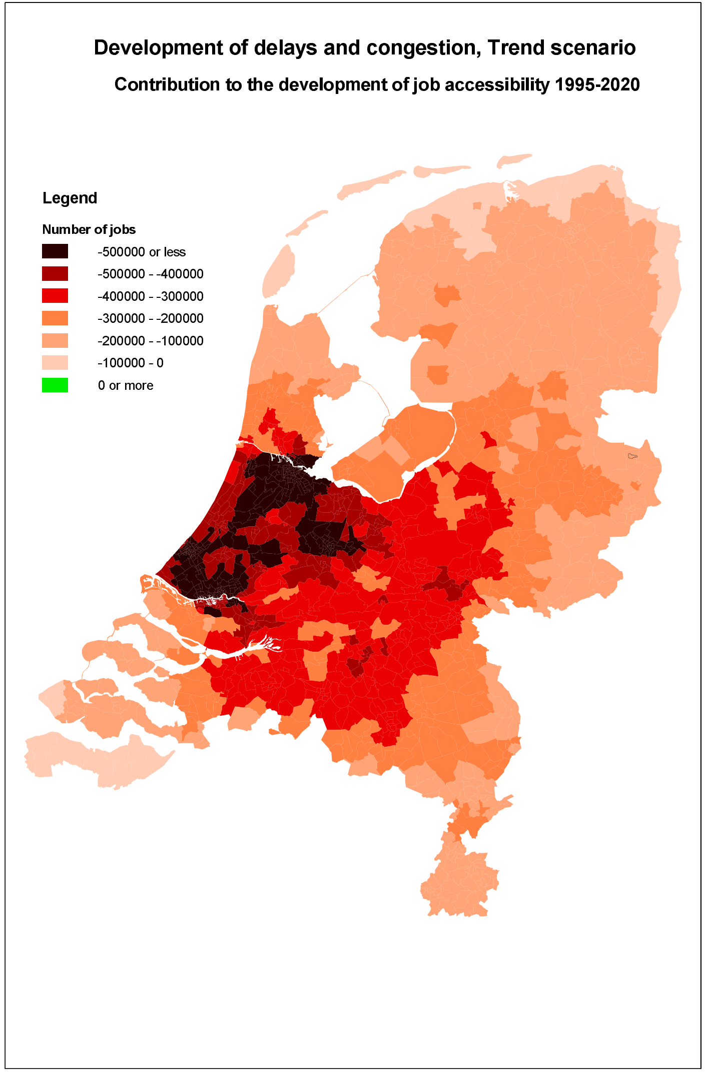

Figure 12.13: Influence of delays and congestion on the development of potential job accessibility by car, Trend scenario, 1995-2020.

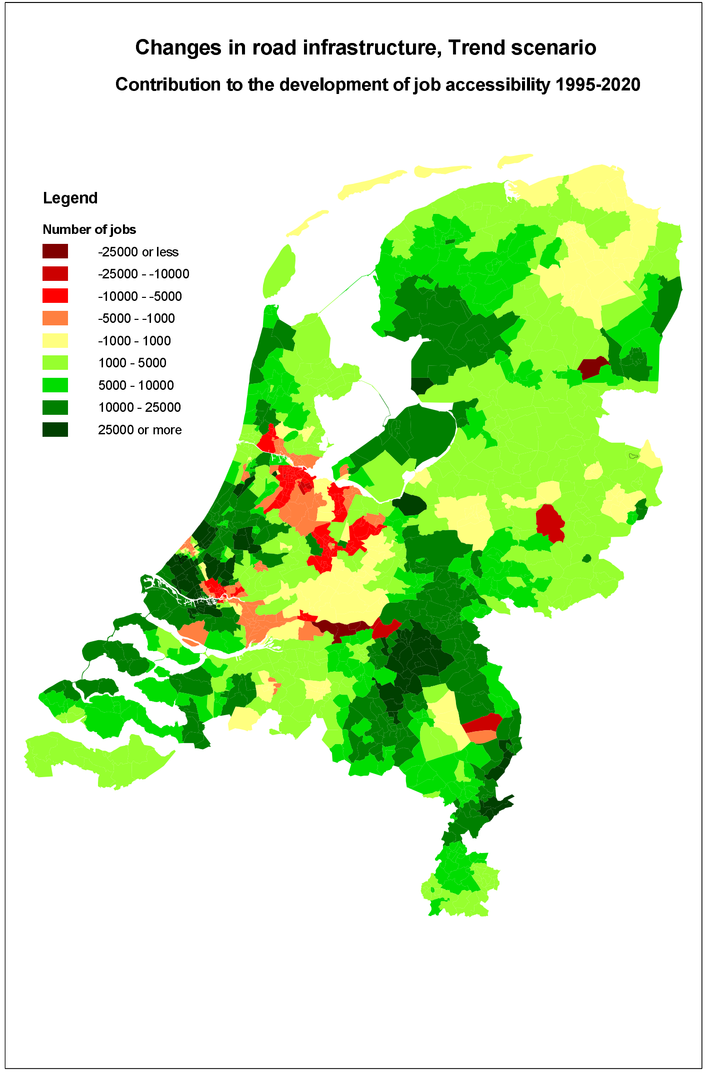

Figure 12.14: Influence of road infrastructure changes on the development of potential job accessibility by car, Trend scenario, 1995-2020.

12.4 Conclusions

This section presents the conclusions of the second case study, aimed at evaluating the capacity of selected accessibility measures to describe the accessibility of a land-use transport scenario. In this case study job accessibility by car is analysed for the Trend scenario, showing the continuation of current land-use trends and land-use policies according to the Fourth National Policy Document on Spatial Planning Extra for the 1995-2020 period.

12.4.1 Development of job accessibility and related utility

The development of job accessibility by car for 1995-2020 is the result of different developments: (a) changes in the number and spatial distribution of jobs and the size of the working population, (b) changes in travel times as a result of traffic changes, i.e. increased delays and congestion due to car traffic growth, and (c) changes in travel times as a result of changes of the road infrastructure supply, e.g. reduced travel times due to road capacity expansions. For public transport, the development of job accessibility is the result of (a) land-use changes and (b) changes in public transport supply.

The contribution of these components to the development of job accessibility by car for the Trend scenario is analysed using the ***potential accessibility measure.*** In conclusion, land-use changes have a significant impact on the regional development of job accessibility. In other words, the increase of jobs within reach is 15 to 45% (assuming no travel time changes), whereas the largest absolute growth in jobs within reach is found in the Randstad, especially in the central and suburban areas of Amsterdam and Utrecht. Increased delays and congestion also have a significant impact on the regional development of job accessibility; increased travel times may counterbalance or outweigh the effect of land-use changes on job accessibility. The infrastructural improvements as assumed in the Trend scenario have a modest influence on the development of job accessibility, i.e. average job accessibility increases by about 2%. The net effect is that on the national level, job accessibility by car increases modestly by about 8% in the 1995-2020 period. Regions which profit the most from the increased number of jobs or improved road infrastructure are located in suburban regions within the Randstad (e.g. the region between Rotterdam and The Hague, southwest of Amsterdam) and the Brabantstad Area.

For public transport, the increase in job accessibility (52%) is the result of the increase of the number of jobs (27%), strengthened by decreased average travel times due to improved public transport supply (increased travel speed and frequency result in 19% lower average travel times).

Compared to the potential accessibility measure, the ***contour measure*** shows a much smaller increase in job accessibility by car and public transport, and shows an extremely spatially differentiated development of job accessibility. This is the result of (a) the (arbitrary) maximum travel time, i.e. a small change in the travel time may result in the inclusion or exclusion of a job location from the accessibility value of an origin zone, (b) the absence of an impedance function, i.e. land-use changes relatively far away from the origin location have a relatively large impact on the accessibility measure. In conclusion, the contour measure shows a regional distribution of accessibility for a certain point in time that is easy to interpret, however, the measure is not very capable of describing accessibility developments in time.

The development of the ***utility-based accessibility measure,*** which expresses the utility people derive from potential access to jobs, contrasts with the other accessibility measures. On the national level, car users have a constant average utility level for the 1995-2020 period; public transport users' utility increases slightly. Regional differences in utility development are small, i.e. utility changes are found within a range of -3.5 to 2.5% for car users and 0.5 to 7% for public transport users, whereas job accessibility changes are found within a range of –30% to 50% and 5 to 170%, respectively. The largest utility changes for car users are found primarily outside the Randstad: the largest increases in utility in middle-sized towns, suburban and peripheral areas with a high percentage increase of job accessibility, and the largest decreases in utility in suburban and peripheral areas, with a high percentage decrease of job accessibility. Central urban areas have a relatively small utility change, despite the relatively large (absolute) increases in job accessibility. This result is explained by the non-linear relationship between job accessibility and utility, i.e. a relatively large increase in potential job accessibility at locations which already had a high accessibility level in 1995 (e.g. central urban areas), which leads to a relatively small change in utility, whereas a relative small increase in job accessibility at locations with a low accessibility level (peripheral regions) leads to a relatively large utility change.

In conclusion, the utility-based accessibility measure suggests that utility (estimated for the total population) increases more substantially if job accessibility is improved for inhabitants in relatively job-poor areas (e.g. peripheral areas outside the Randstad); this is preferred to further increasing job accessibility for inhabitants living in already relatively job-rich areas (e.g. central and suburban areas in the Randstad).

12.4.2 Influence of competition on the development of job accessibility

Joseph and Bantock's measure shows that, on the national level, the number of jobs accessible per worker by car is slightly reduced and increases for public transport users. The development of Joseph and Bantock's measure is different from the other accessibility measures, which show an increase in job accessibility by car and a sharper increase in job accessibility by public transport. This is because the measure essentially shows the development of job competition. As a result, if Joseph and Bantock's measure is interpreted as an accessibility measure, wrong conclusions may be drawn. That is, job accessibility does not have a one-to-one relationship with job competition: if job competition increases by a certain percentage, job accessibility is not necessarily reduced by the same percentage. This is further illustrated by the balancing factor.

On the national level, the (inverse) ***balancing factor*** shows the same development of job accessibility by car for the Trend scenario as the potential accessibility measure, whereas job accessibility by public transport is somewhat higher. However, significant regional differences exist. Compared to the potential accessibility measure, the inverse balancing factor shows a slower job accessibility growth for the Randstad and a reduction of job accessibility for peripheral areas in the northern part of the Netherlands. In these areas job competition increases, i.e. the difference between the balancing factor and the potential measure increases by a few percentage points for the Randstad and up 15 percentage points for peripheral areas. This is the result of the sharper growth in accessibility to the working population (population increase) relative to job accessibility growth for 1995-2020. This indicates that densely populated areas in the Randstad (central and suburban regions) and sparsely populated areas become somewhat less attractive housing locations for job-seeking workers in the period 1995-2020. Job competition decreases west of Utrecht and in the southwestern and southern regions of the Netherlands, which makes these areas more attractive as a housing location.

In conclusion, the Trend scenario shows a significant impact of job competition on job accessibility. In other words, job accessibility for 2020 is, according to the (inverse) balancing factor (which incorporates competition effects), 20-25% lower for central and suburban areas than the potential accessibility measure (which does not incorporate competition effects), and more than twice that of the peripheral areas. However, the inclusion of job competition effects does not radically change the spatial distribution of job accessibility and job competition for the Trend scenario for 2020; the current spatial structure remains dominant. Furthermore, the land-use developments of the Trend scenario have a relatively small effect on the development of job competition for the 1995-2020 period.

13. Case study 3: Tolerant Scenario

13.1 Introduction

This section describes the results of the development of job accessibility for the Tolerant land-use scenario for the 1995-2020 period. Section 13.2 describes the results of selected accessibility measures on the national level, Section 13.3 the regional developments, and Section 13.4 the contribution of land-use and transport changes to the development of job accessibility by car. In Section 13.5 the differences in regional development of job accessibility between the Tolerant and the Trend scenario are outlined and in Section 13.6 the differences in equity.

13.2 Results on the national level

Table 13.1 shows the development of the average job accessibility per zone by car and public transport according to the Tolerant and the Trend scenarios for the 1995-2020 period; Table 13.2 shows the development of the average job accessibility per person, both by car and public transport.

Table 13.2: Development of average job accessibility per person by car and public transport for the Trend and Tolerant scenarios, 1995-2020 (index 1995=100)

	Trend scenario		Tolerant scenario	
	Car	Public transport	Car	Public transport
Contour measure, 45 minutes	104	139	93	121
Contour measure, 60 minutes	104	145	94	131
Potential accessibility measure	108	152	101	149
Joseph & Bantock's measure	99	137	101	145
Inverse balancing factor	108	149	103	153
Utility-based measure	100	103	100	103

Table 13.2: Development of average job accessibility by car and public transport for the Trend and Tolerant scenarios, 1995-2020 (index 1995=100), average per worker or inhabitant

		Trend scenario		Tolerant scenario	
		Car	Public transport	Car	Public transport
Contour measure, 45 minutes [a)]		104	140	93	121
Contour measure, 60 minutes [a)]		105	146	97	131
Potential measure [a)]	Total	109	153	102	150
	low/medium education level	n.a.	n.a.	102	149
	high education level	n.a.	n.a.	99	144
	average, weighted by education level	n.a.	n.a.	96	145
Joseph & Bantock's measure [a)]		99	137	103	146
Inverse balancing factor [a)]	Total	109	150	104	153
	low/medium education level	n.a.	n.a.	105	153
	high education level	n.a.	n.a.	100	151
	average, weighted by education level	n.a.	n.a.	98	148
Utility-based measure [b)]	Total	100	103	100	103
	low income (0-13,600 Euro)	n.a.	n.a.	100	103
	medium income (13,600-30,600 Euro)	n.a.	n.a.	100	103
	high income (> 30,600 Euro)	n.a.	n.a.	100	103
	weighted by income level	n.a.	n.a.	128	124

n.a. = non-applicable

[a)] average per worker

[b)] average per inhabitant

Table 13.1 and 13.2 show that the results of the ***contour measure*** contrast with the other accessibility measures, a decrease in job accessibility by car. The difference with the potential measure can be further illustrated by showing the contribution of the different factors on the development of job accessibility for the 1995-2020 period. Figure 13.1 shows the influence of the land-use and transport components of accessibility according to the contour measure with 45 minutes as maximum travel time, Figure 13.2 according to the potential measure.

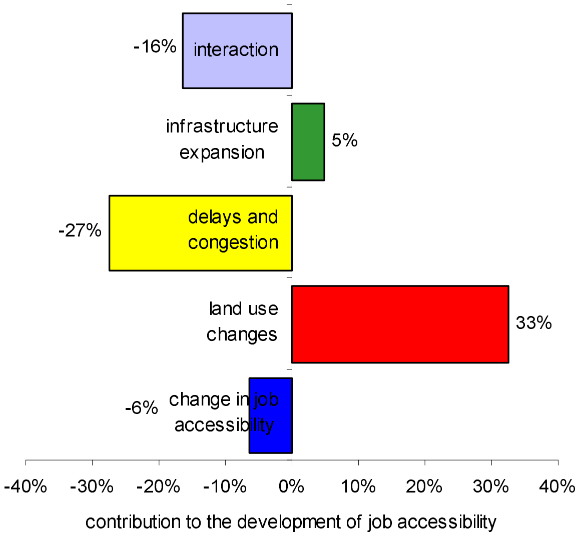

Figure 13.1: Contour measure, 45 minutes: contribution of land-use changes, congestion and infrastructure expansion to the development of job accessibility by car, Tolerant scenario 1995-2020.

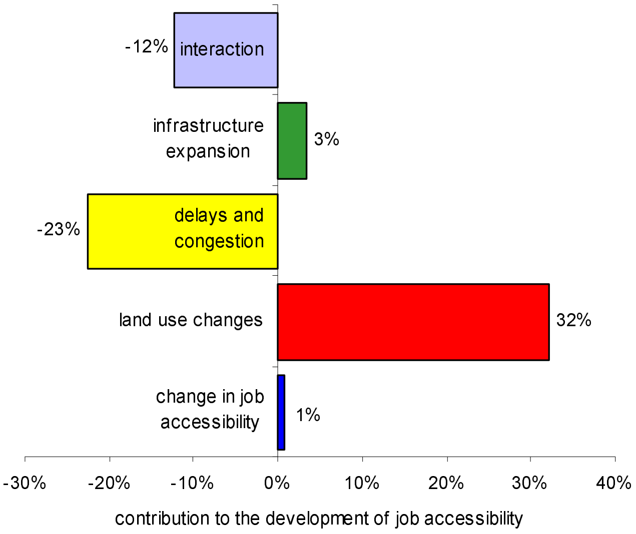

Figure 13.2: Potential measure: contribution of land-use changes and average travel times to the development of job accessibility by public transport, Tolerant scenario 1995-2020.

Figures 13.1 and 13.2 show that on the national level, the contour measure shows a 6% decrease in job accessibility by car for 1995-2020. Increased delays and congestion outweigh the growth in the total number of jobs (about 33%) and infrastructural improvements (about 5%). As also noted for the Trend scenario (see Section 12.2), the contour measure is more sensitive to travel time changes (resulting in a 27% reduction of job accessibility) than the potential measure (23% reduction). Furthermore, the interaction component is, for both the contour measure and the potential measure, much higher for the Tolerant scenario than for the Trend scenario (see Figures 12.1 and 12.2). Apparently, a reduction of job accessibility as a result of increased delays and congestion is more often combined with a reduction of the number of jobs within reach.

Furthermore, the contribution of land-use changes to the development of job accessibility by car for the Tolerant scenario (32-33%) is somewhat higher than for the Trend scenario (30%). However, this is more than compensated by a greater increase in delays and congestion (18 to 23% decrease in the Trend scenario).

The contour measure shows a relatively modest increase in job accessibility by public transport for the Tolerant scenario. Figure 13.3 shows the contribution of the different components according to the contour measure, Figure 13.4 according to the potential measure.

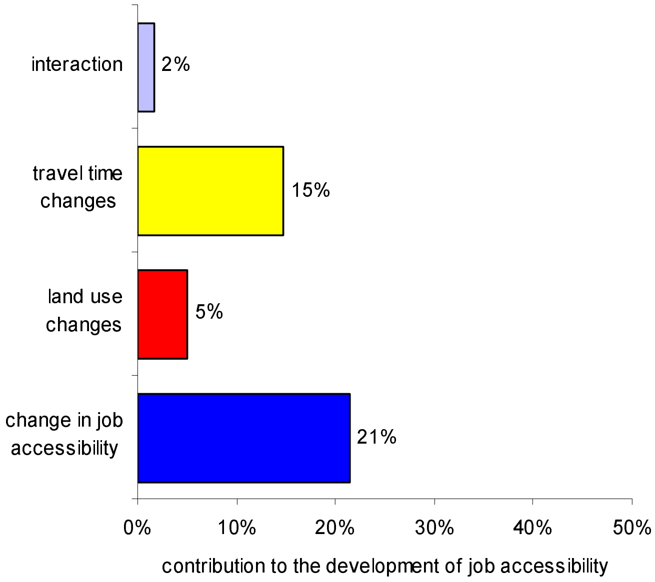

Figure 13.3: Contour measure, 45 minutes: contribution of land-use change and average travel times to the development of job accessibility by public transport, Tolerant scenario 1995-2020.

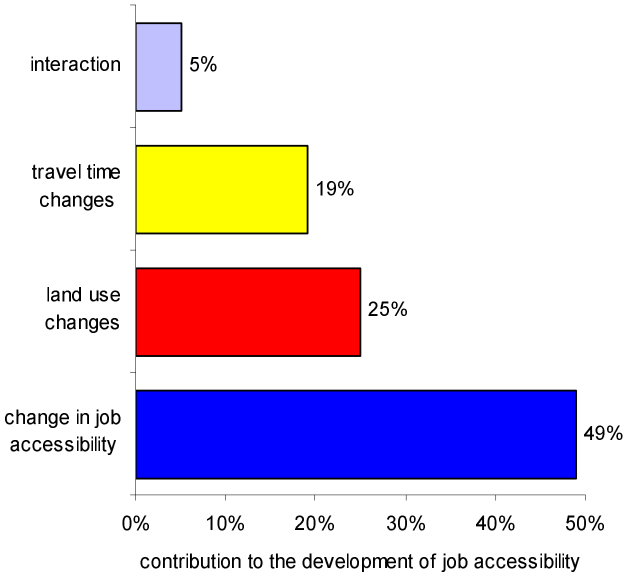

Figure 13.4: Potential measure: contribution of land-use change and average travel times to the development of job accessibility by public transport, Tolerant scenario 1995-2020.

Figures 13.3 and 13.4 show that the increase in job accessibility by public transport as the result of the increase in the number of jobs is strengthened by decreased average travel times due to improved public transport supply (increased travel speed and frequency). However, the contribution of land-use and travel time changes to the job accessibility is much lower for the contour measure than for the potential measure. This is the result of the chosen maximum travel time of 45 minutes in combination with the relatively long public transport travel times (see also Section 12.2). Furthermore, the contribution of land-use changes to the development of job accessibility is, for both the contour and potential measure, lower compared to the Trend scenario (5-25% compared to 21-27% growth in the Trend scenario), although total job growth is higher. Thus, relatively stronger processes of national deconcentration and regional suburbanisation (as in the Tolerant scenario) negatively influences average job accessibility by public transport (i.e. fewer jobs at locations which are readily accessible by public transport), whereas job accessibility by car is, if travel times remain constant, positively influenced.

Furthermore, the ***potential measure*** shows a growing mismatch between workers' educational skills and job requirements. If the occupational match is accounted for, job accessibility by car decreases (by 4%) in the Tolerant scenario and the growth in job accessibility by public transport is also less (5 percentage points). This is the result of the relatively substantial increase in workers' education level compared to the job requirements; i.e. according to the Tolerant scenario, the number of highly educated workers increases by more than 75% in 1995-2020, whereas the number of jobs requiring a high-education level increases by about 40%. As a result, the average job accessibility level per person decreases.

Joseph and Bantock's measure shows an increase in the number of jobs within reach by car per working person for the Tolerant scenario, whereas the average index for the Trend scenario decreases. The index for public transport is also higher. This is the result of (a) the relatively sharp increase in the number of jobs (33% compared to 28% growth on national level for the Trend scenario for the period 1995-2020) compared to the working population (28% compared to 29% growth for the Trend scenario) in the Tolerant scenario, and (b) the job shift from the (relatively job-rich) Randstad to the (relatively job-poor) middle (central) and peripheral regions (see also Section 13.3). Thus, on the national level, job competition decreases in the Tolerant scenario and increases in the Trend scenario.

The ***inverse balancing factor*** on the national level, average job accessibility growth by car for the Tolerant scenario is lower than for the Trend scenario (3% and 8% growth, respectively), whereas public transport accessibility is higher (53% and 49% growth, respectively). The influence of job competition is clearly shown: job accessibility growth by car and public transport for the Tolerant scenario is higher than for the potential accessibility measure. As a result, job accessibility growth by public transport is higher for the Tolerant scenario than for the Trend scenario.

Furthermore, the inverse balancing factor also shows the relatively strong influence of socio-economic developments on the development of job accessibility. That is, if the educational match is accounted for, average job accessibility by car decreases (instead of increasing) and the growth of job accessibility by public transport is lower. The Tolerant scenario clearly shows a growing mismatch between workers' education level and access to jobs with the required education level, especially among car users. In other words, average accessibility to jobs requiring a high education level is roughly constant by car and increases by more than

50% by public transport, whereas the total number highly educated workers increases by more than 75% up to 2020; for low- and intermediate-educated workers job accessibility increases by 4% by car to more than 50% by public transport, whereas the number of workers increases by more than 10%.

The ***utility-based accessibility measure*** shows for both the Tolerant and the Trend scenario a constant average utility level for car users and a relatively small increase for public transport users for the 1995-2020 period. This indicates that on the national level, the changes in the spatial distribution of jobs and population according to the Tolerant scenario do not result in a very different utility level, despite regional differences in the utility.

However, Table 13.2 shows a totally different development of the weighted average utility-based accessibility measure. This measure shows the development of utility when the distribution of socio-economic groups (by income level) and related differences in travel costs sensitivity are taken into account. The development of household incomes (i.e. the number of people in the highest income category increasing from 37% in 1995 to 60% in 2020, as found in Section 12.4) has a large effect on the utility people derive from the land-use transport system (i.e. average utility derived from job accessibility by car and public transport increasing by about 25 to 30%). This means that if incomes increase, people are willing to travel further (less sensitive to travel cost), and potential job accessibility and related utility increases. The table shows that the effect of higher incomes on utility is apparently much stronger than the forecasted land-use and travel time changes for 1995-2020.

13.3 Regional development of job accessibility

Contour measure

The contour measure (Figure 13.5) shows a very spatially differentiated development of job accessibility by car for the Tolerant scenario for 1995-2020; regions with a sharp increase in accessibility can be located next to regions with a sharp decrease in accessibility. Furthermore, job accessibility decreases sharply in almost the entire Randstad Area (due to the job shift from the Randstad to eastward regions, and increased travel times), and moderate to substantial decreases in peripheral areas in the east, northern, southeastern regions (mainly due to increased travel times). As already described in Section 12.3, this is mainly the result of the (arbitrary) maximum travel time used in a contour measure; i.e. a small change in the travel time may result in the inclusion or exclusion of a job location from the accessibility value of a zone and thus have relatively large impacts on the accessibility measure.

Potential accessibility measure

The potential accessibility shows a more plausible regional development of job accessibility by car (Figure 13.6). Most areas in the Randstad Area, show a decrease of job accessibility by car as a result of the job shift from the Randstad to the intermediate- (central) and eastward regions, and increased travel times. Regions that profit the job shift are located eastward of the intermediate region and peripheral regions in the northern, eastern and southeastern areas of the Netherlands. Furthermore, the figure also shows regions where the increase in the number of jobs is outweighed by increased delays and congestion, e.g. south of Utrecht. Section 13.3 gives a more elaborate description of the separate influences of land-use changes, congestion and road infrastructure improvements on the development of the potential job accessibility measure.

Joseph and Bantock's measure

Joseph and Bantock's measure (Figure 13.7) clearly shows a mixed picture of the development of job accessibility for the Tolerant scenario, i.e. about 50% of all zones show a decrease in accessibility level. An increased level of job accessibility per working person is found at locations where potential job accessibility substantially increases because of new employment locations and/or infrastructure expansion. The measure leads to a much more extreme development of accessibility than the inverse balancing factor (Figure 13.8); i.e. the number of jobs within reach by car per working person decreases substantially in the (relatively job-rich) Randstad and increases substantially in the (relatively job-poor) central intermediate and eastern peripheral regions.

Inverse balancing factor

The regional development of job accessibility according to the inverse balancing factor (Figure 13.8) is very similar to the potential accessibility measure (see Figure 13.6). Compared to the potential accessibility measure, job accessibility decreases less in the Randstad. This is the result of decreased competition in the labour force in the Randstad Area as a result of the job shift toward the intermediate and peripheral regions (a smaller job surplus). This is illustrated by Figure 13.9, which shows the development of job competition. Here one sees the development of the difference between the inverse balancing factor and the potential accessibility measure for the Tolerant scenario for 2020 and 1995. The figure shows that job competition decreases (i.e. job surplus decreases) in the Randstad, especially the area between The Hague, Rotterdam and Utrecht. However, job competition remains relatively high in the Randstad: job competition reduces potential job accessibility reduced by about 15-20% for 2020, approximately 1-5 percentage points less than in 1995. Thus, the current spatial structure remains dominant. Furthermore, job competition decreases (i.e. fewer workers surplus) in the western part of the Brabantstad Area (Breda, Tilburg) and in the eastern and southwestern peripheral regions of the Netherlands. In some suburban areas of Amsterdam, the central urban area of Utrecht and some areas north (e.g. the area between Utrecht and Amsterdam, Almere) and northeast of Utrecht (e.g. roughly the area between Utrecht and Zwolle), competition in the labour force increases (i.e. job surplus increases) due to the relative substantial growth in the number of jobs within reach. In these areas, potential job accessibility in 2020 is reduced by about 20-23%, roughly 5-10 percentage points more than in 1995.

If the match between workers' educational skills and job requirements is accounted for, average job accessibility by car slightly decreases. Figure 13.10 shows the regional development of the balancing factor by education level if the weighted average of workers' job accessibility by educational level (low and intermediate, high) is estimated for each zone. Figure 13.11 shows the regional development of accessibility to jobs requiring a low or intermediate education level; Figure 13.12 for jobs requiring a high education level. Figures 13.11 and 13.12 show that the job shift from the Randstad to middle (central) and eastern (peripheral) areas is mainly concentrated on jobs requiring a low- and intermediate educational level. Job accessibility for highly educated workers remains relatively high in the Randstad (see Figure 13.11 for the 1995 figure), despite the increased delays and congestion in this area. As a result, when compared to Figure 13.8, the decrease in job accessibility in the Randstad area and the increase in job accessibility in the middle (central) and eastern (peripheral) areas is smaller. The net effect is a small decrease of job accessibility.

Utility-based accessibility measure

On the national level, the utility-based accessibility measure shows a constant average utility level for the car for the 1995-2020 period. Figure 13.13 shows the regional differences in the development of utility, where all socio-economic groups are assumed to have the same sensitivity to travel costs. The figure shows that the largest utility changes are found mostly outside the Randstad Area: relatively large decreases in utility (2-3% decrease compared to 1995) are found in peripheral regions (northern, eastern, southern and western parts of the Netherlands) and suburban areas, where job accessibility sharply decreases. Relatively large increases in utility (2-3% increase compared to 1995) are found in large (e.g. Utrecht) or middle-sized cities (e.g. Zwolle, Leeuwarden) of the middle (central) and peripheral (eastern) region, where job accessibility sharply increases (30-50% increase compared to 1995).

Figure 13.14 shows a radically different development in the utility-based accessibility measure. This figure shows the development in utility when the distribution of socio-economic groups (by income level) and related differences in travel costs sensitivity are taken into account. The figure shows that the effect of changes in the population composition (relative increase of high- and middle-income groups) on the average utility of a person outweighs the negative effects of land-use changes and increased travel times. If the income effect is accounted for, the highest increases in utility will be found in central urban areas and surrounding areas, all of which had relatively low utility levels in 1995 (see Figure 13.13).

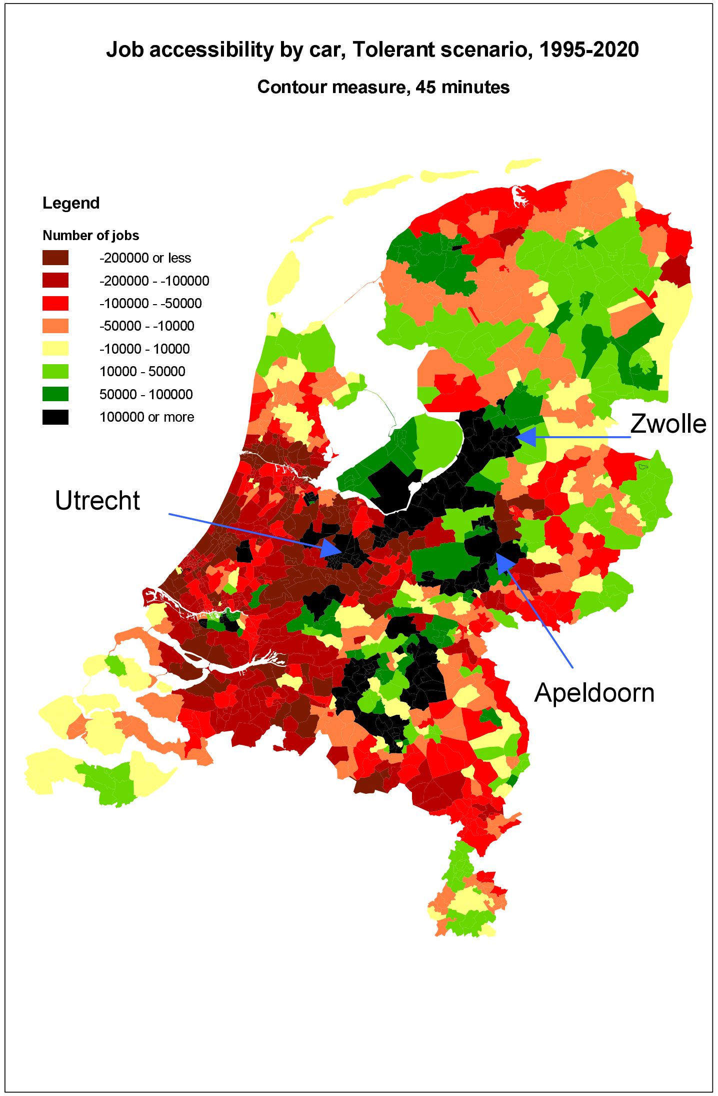

Figure 13.5: Development of job accessibility by car 1995-2020, Tolerant scenario, contour measure.

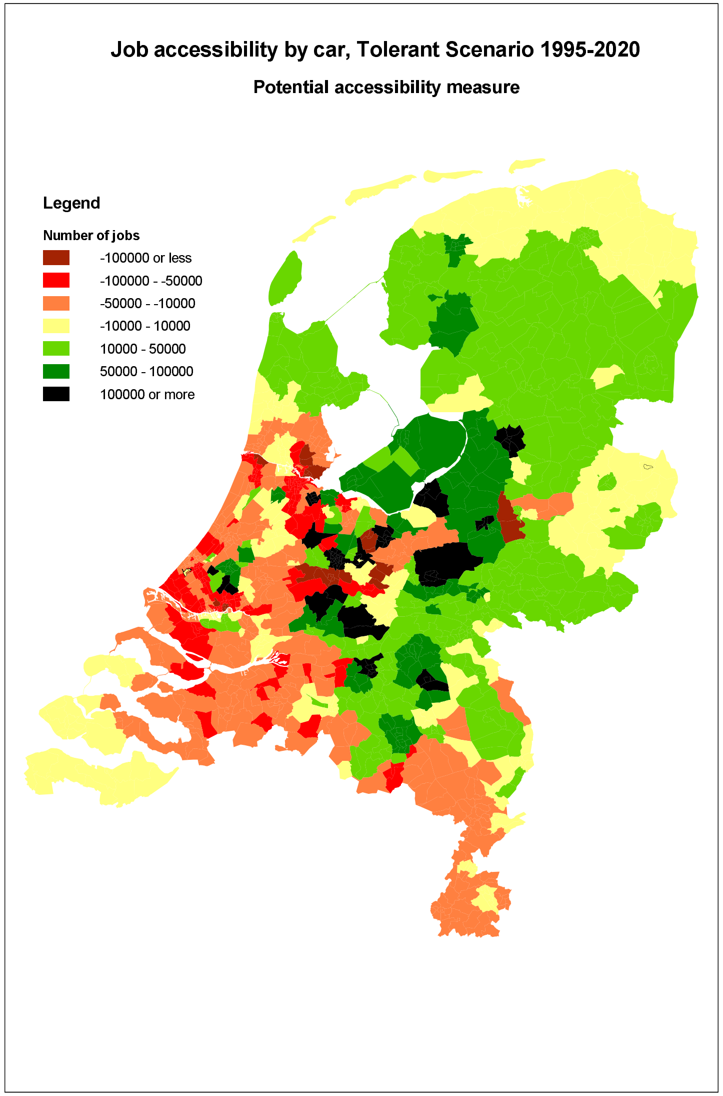

Figure 13.6: Development of job accessibility by car 1995-2020, Tolerant scenario, potential measure.

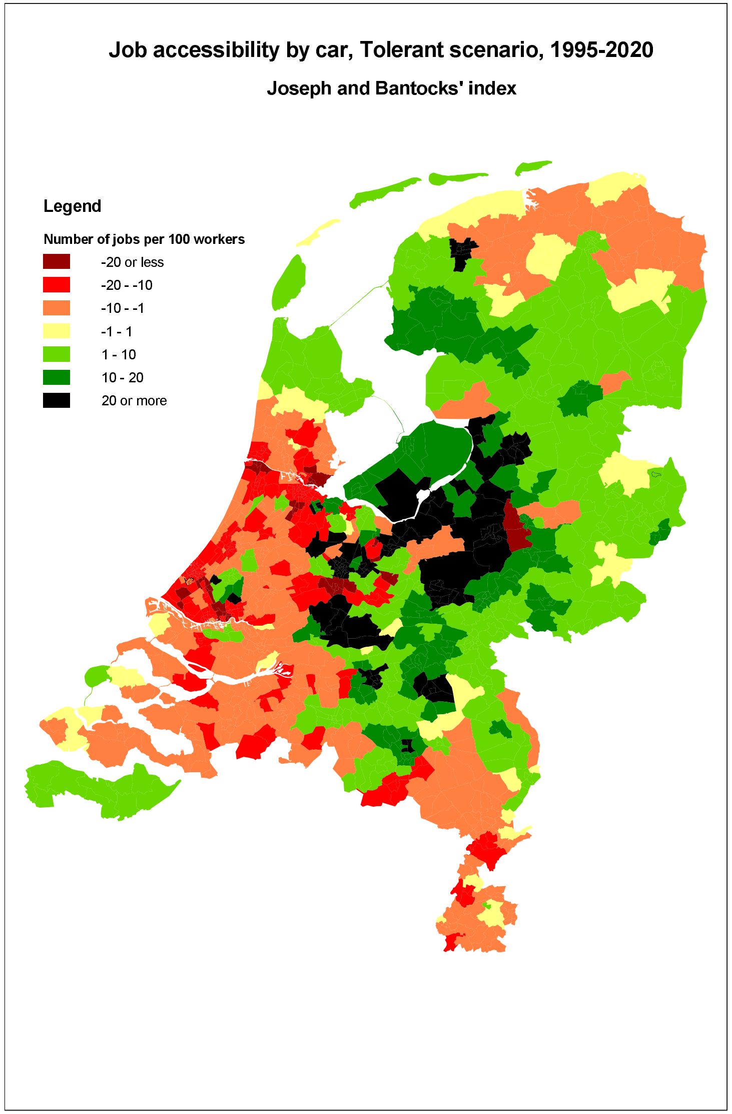

Figure 13.7: Development of job accessibility, Tolerant scenario, 1995-2020, Joseph & Bantock's measure.

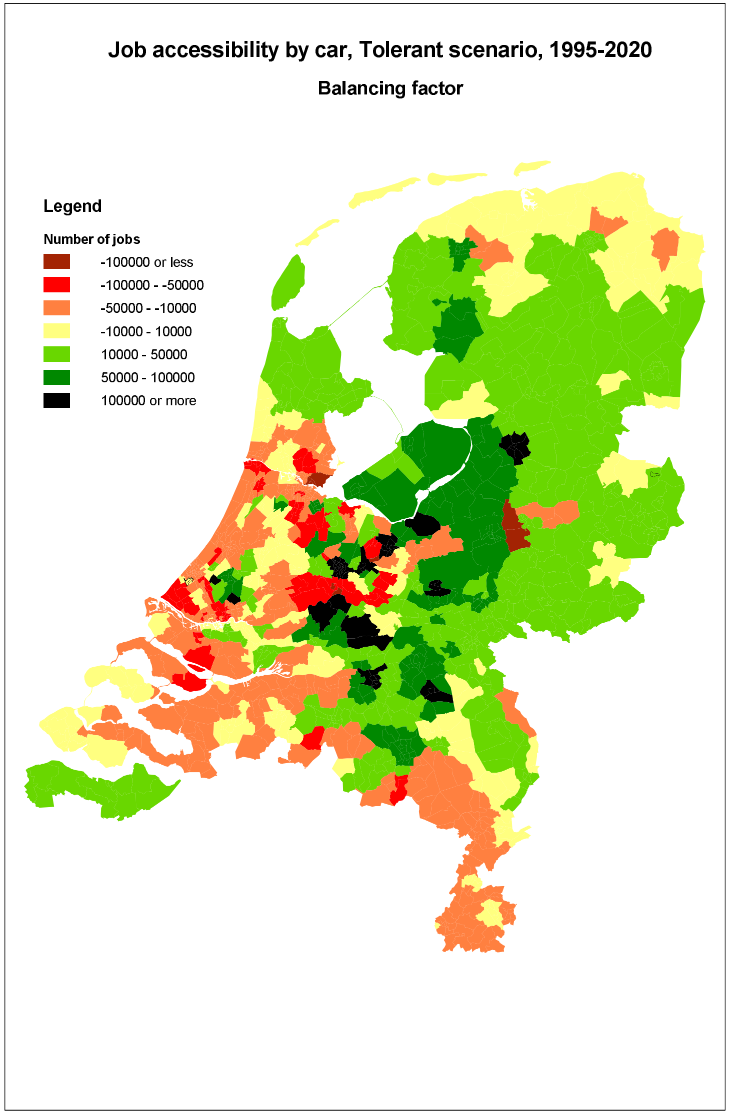

Figure 13.8: Development of job accessibility by car 1995-2020, Tolerant scenario, balancing factor.

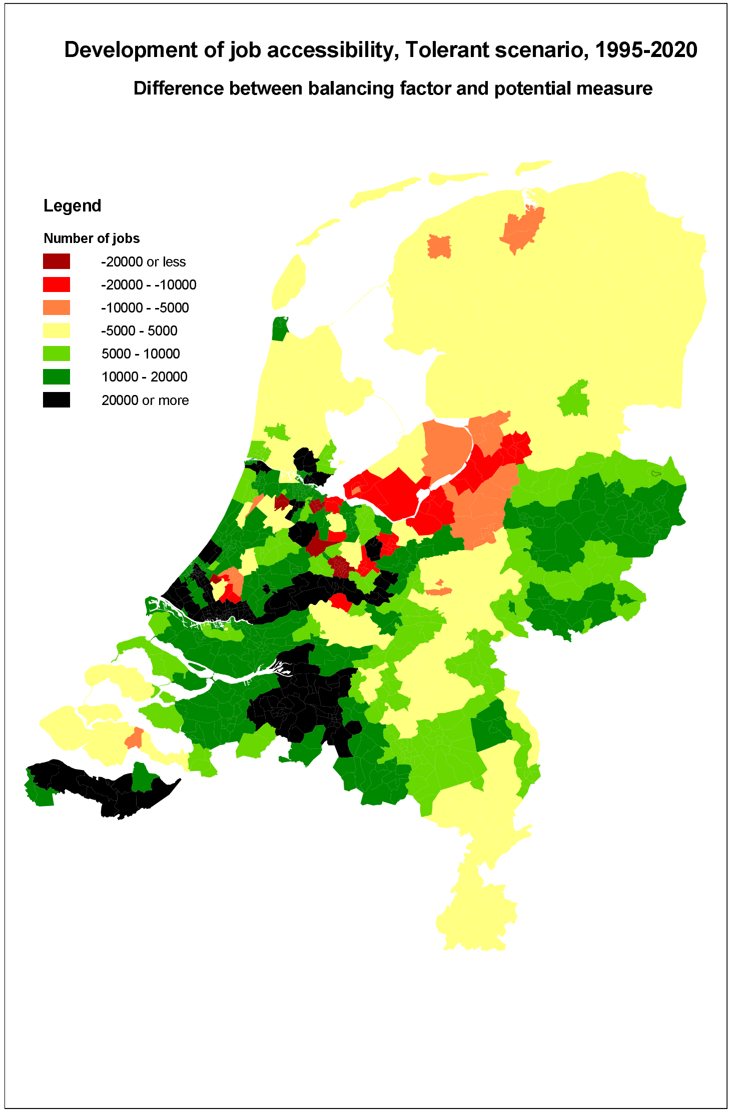

Figure 13.9: Development of job accessibility, difference between the inverse balancing factor and potential measure, Tolerant scenario, 1995-2020.

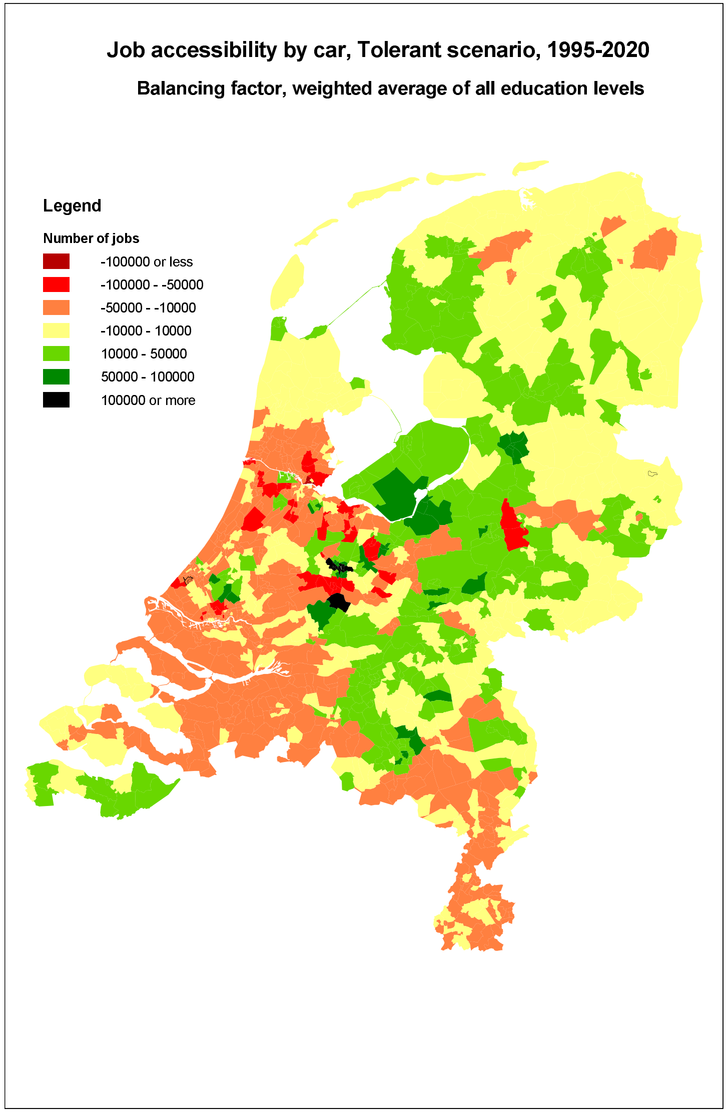

Figure 13.10: Development of job accessibility by car, weighted average, Tolerant scenario, 1995-2020.

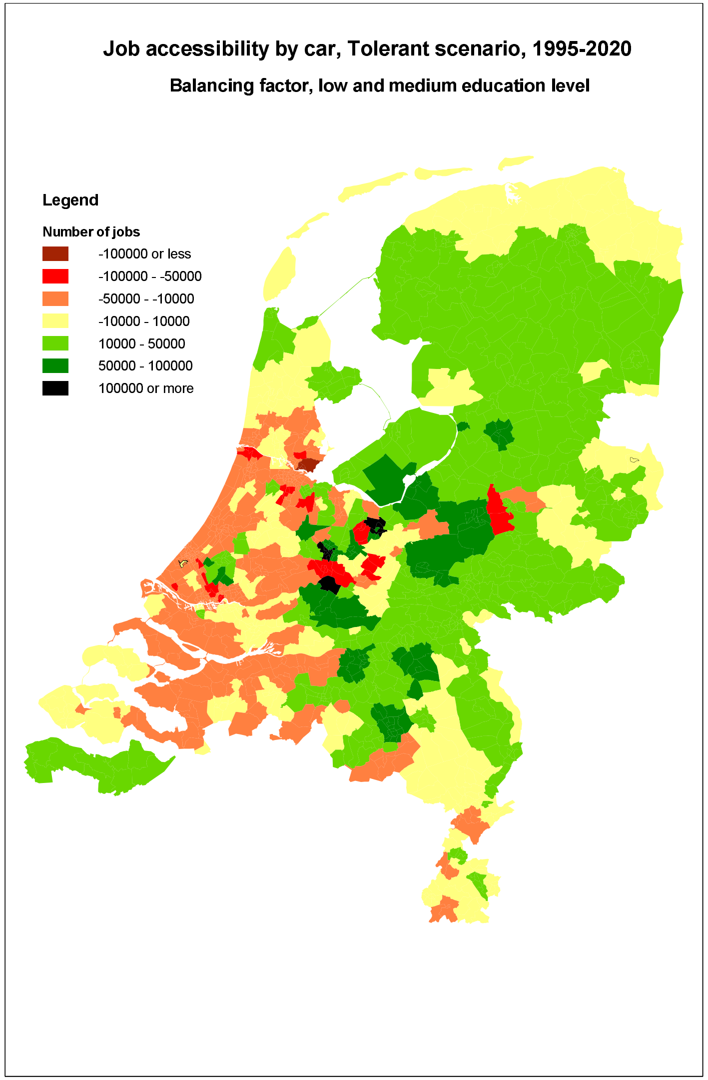

Figure 13.11: Development of job accessibility by car 1995-2020, low and intermediate education level, Tolerant scenario, balancing factor.

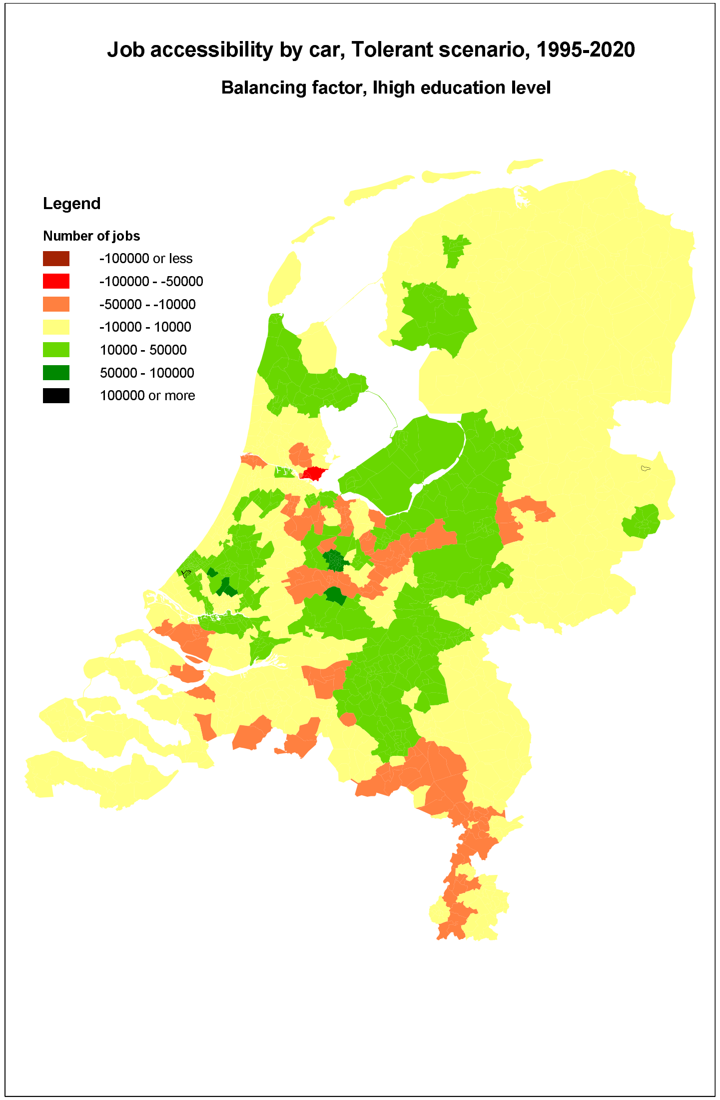

Figure 13.12: Development of job accessibility by car 1995-2020, high education level, balancing factor.

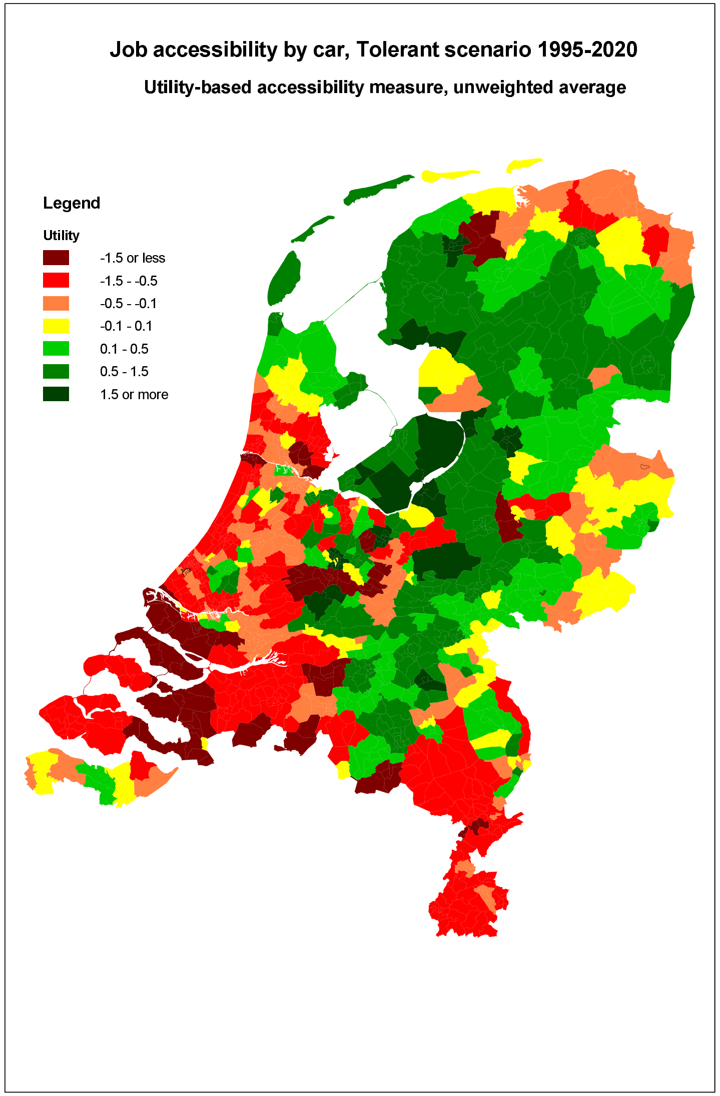

Figure 13.13: Development of job accessibility by car, Tolerant scenario, utility-based measure, unweighted average.

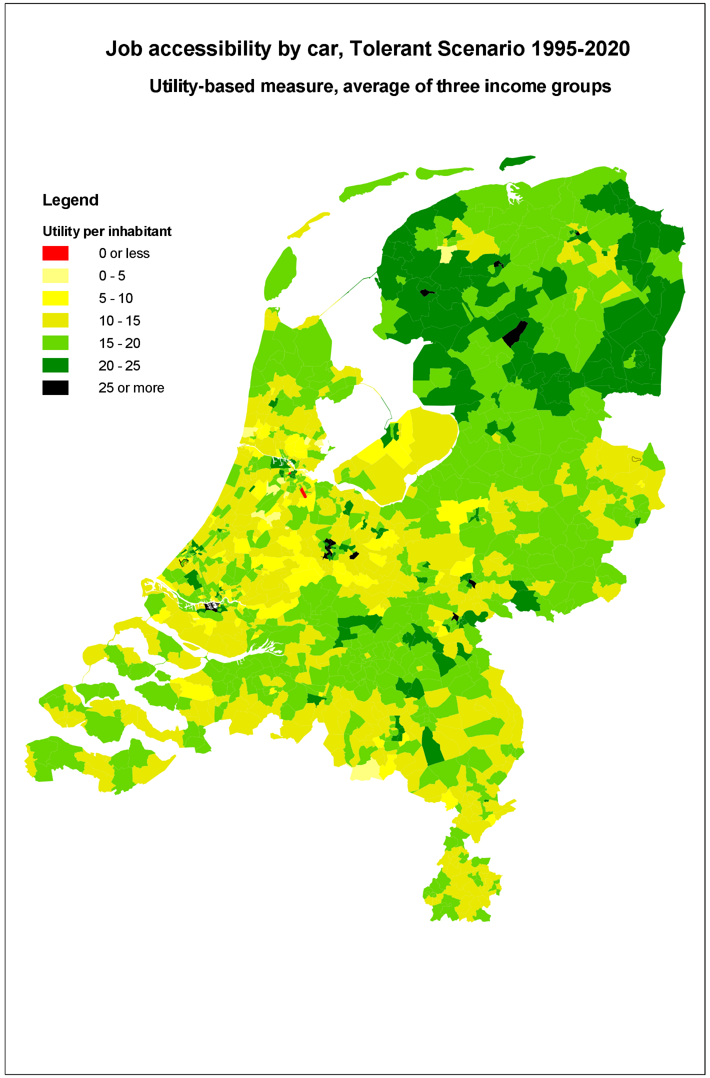

Figure 13.14: Development of job accessibility by car, Tolerant scenario, utility-based measure, weighted by income level.

13.4 Influence of land-use and transport changes on job accessibility

The regional differentiation of job accessibility by car is relatively large as a result of several different developments: (a) the regional development of the number of jobs, (b) changes in travel times due to increased congestion and delays, and (c) changes in travel times due to road infrastructure improvements. Figure 13.15 shows the net development of potential job accessibility by car.

Influence of land-use changes on the development of job accessibility

Figure 13.16 shows the influence of the spatial distribution of job growth on the accessibility development for the Tolerant scenario for the 1995-2020 period. The figure shows the development of the number of jobs within reach, assuming no change in travel times. On average, the regional development of jobs increases the job accessibility level by car by about 32%. Compared to the Trend scenario (see Figure 12.12), job growth is concentrated in the middle (central) region and eastern regions. In and around the central urban area of Utrecht, job growth contributes to a 70-75% increase of job accessibility (compared to about 30% for the Trend scenario), contrasted to about 20-25% for Amsterdam, 10-15% for Rotterdam, and 5-10% for The Hague. This figure clearly reflects the process of regional deconcentration of employment according to the Tolerant scenario (see Section 10.3.4).

Influence of delays and congestion on the development of job accessibility

Figure 13.17 shows the influence of the development of delays and congestion on the development of potential job accessibility. The figure shows the development in the difference between forecasted travel times (including road capacity restrictions) and free-flow travel times (excluding road capacity restrictions) between 1995 and 2020, according to the National Model System. The figure shows that the influence of delays and congestion on the development of job accessibility is highest in the Randstad and gradually decreases towards the middle and peripheral regions. The absolute reduction of potential job accessibility as a result of increased delays and congestion for the large towns in the Randstad Area (Amsterdam, Rotterdam and The Hague) is higher than the increase of job accessibility as a result of job growth (see Figure 13.16); the net effect is a reduction of job accessibility (see Figure 13.15). On average, the development of delays and congestion during peak hours reduces potential job accessibility by 23% for the year 2020.

Note that the regional distribution of the reduction of job accessibility as a result of delays and congestion for the Tolerant scenario does not highly differ from the Trend scenario (Figure 12.13); i.e. both scenarios show the greatest absolute reduction of job accessibility in the Randstad Area. This implies that the current spatial-infrastructure construction dominates the development of congestion; land-use changes for the 1995-2020 period have a relatively modest effect on the development of delays and congestion.

In short, the influence of delays and congestion on the development of job accessibility is relatively large. However, the development of congestion is not very sensitive to the land-use changes estimated for the Trend and Tolerant scenario for the 1995-2020 period.

Influence of road infrastructure improvements on the development of job accessibility

Figure 13.17 shows the influence of changes in road infrastructure supply on the development of the accessibility value. The figure clearly shows the impact of road infrastructure improvements (see Figure 10.17) on job accessibility. Furthermore, some areas show a decrease in job accessibility as the result of increased average travel times for local traffic due to barriers on account of motorway expansions. In contrast to the Trend scenario (see Figure 12.14), the reduction of traffic speed limits in urban areas does not result in a reduction of job accessibility in central urban areas. Apparently, average travel speed increases in urban areas. The influence of infrastructural changes on the development of job accessibility is relatively low, i.e. average job accessibility increases by about 3%.

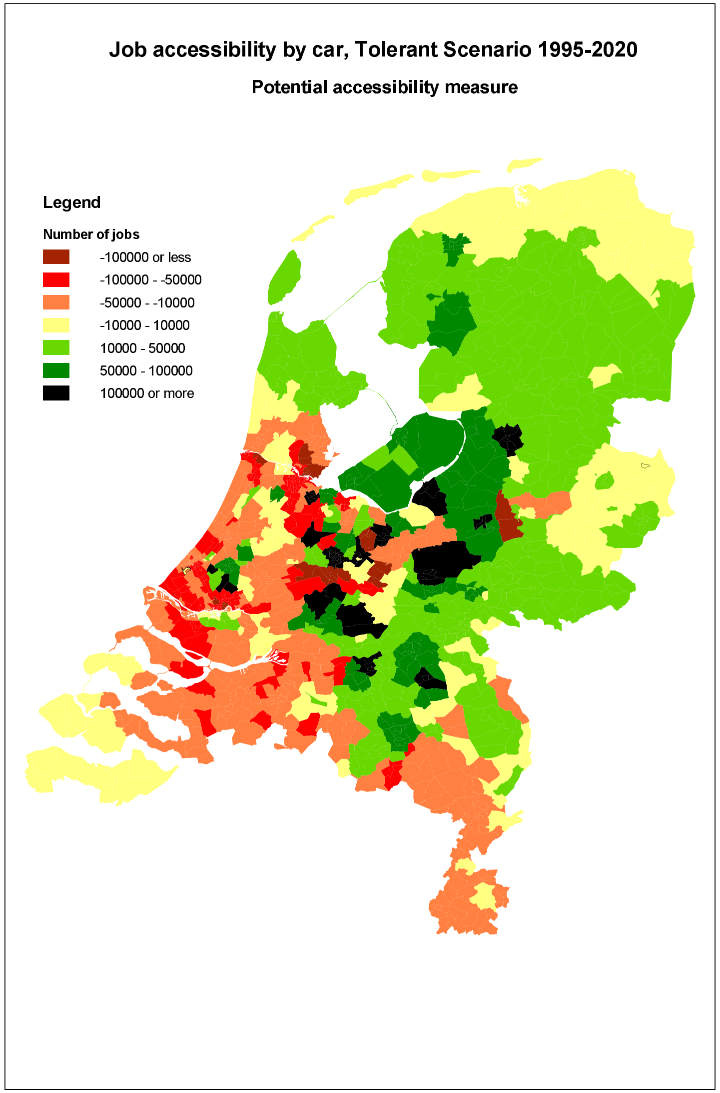

Figure 13.15: Development of the accessibility index, Tolerant scenario, 1995-2020.

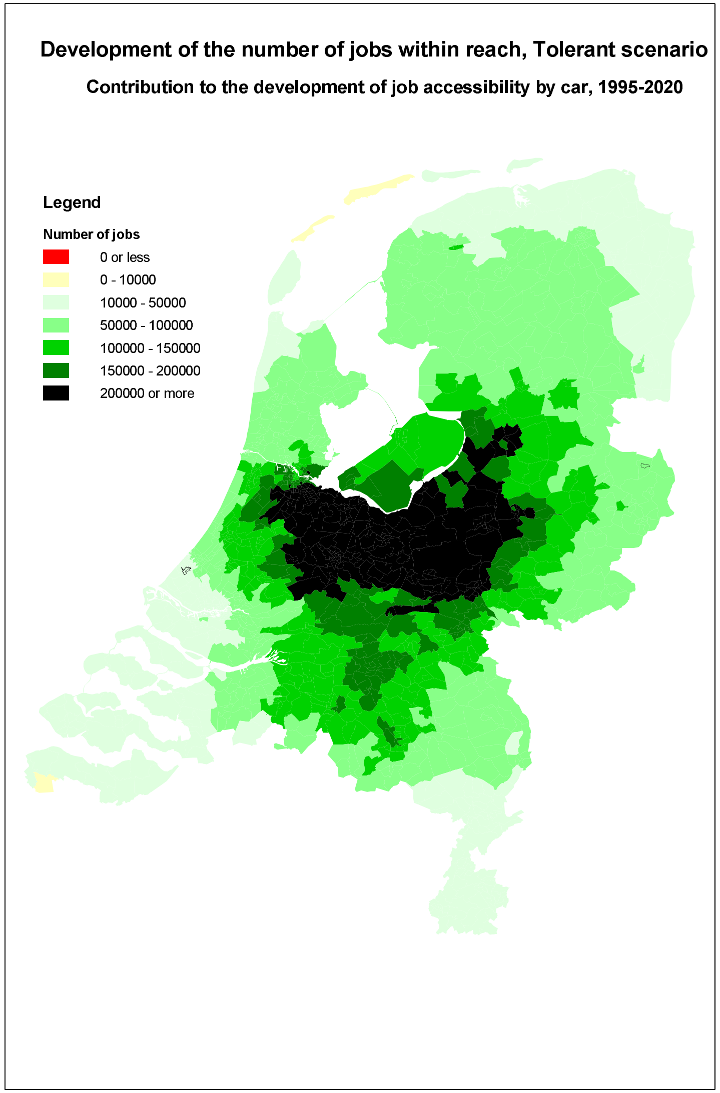

Figure 13.16: Influence of land-use changes on the development of potential job accessibility, Tolerant scenario, 1995-2020.

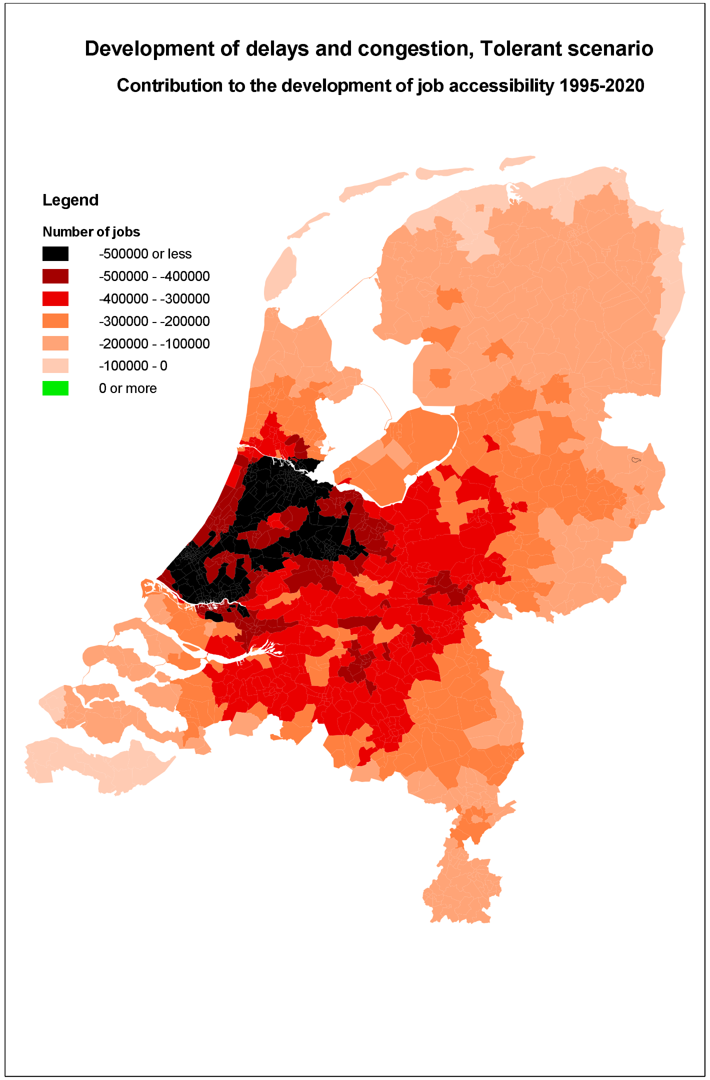

Figure 13.17: Influence of congestion and delays on the development of potential job accessibility, Tolerant scenario, 1995-2020.

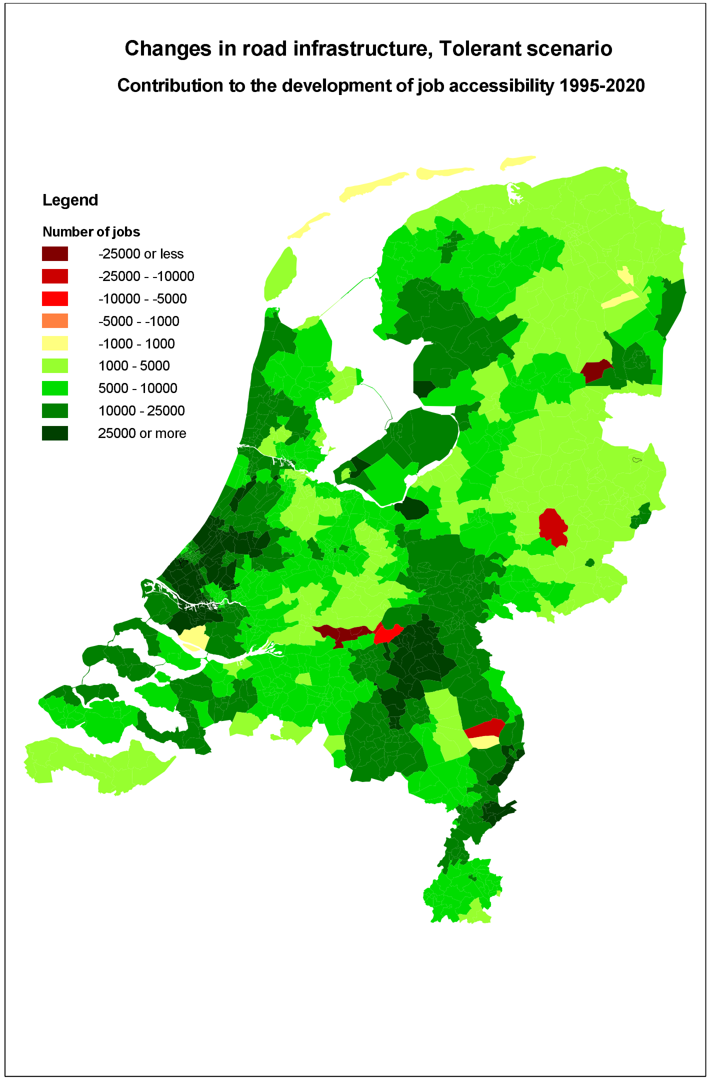

Figure 13.18: Influence of road infrastructure expansion on the development of potential job accessibility, Tolerant scenario, 1995-2020.

13.5 Differences between the Tolerant and Trend scenarios

This section describes the differences in regional development of job accessibility by car between the Tolerant and the Trend scenarios for 2020, using the selected accessibility measures.

Contour measure

Figure 13.19 shows the relatively sharp differences in job accessibility by car between the Tolerant scenario (see Figure 13.5) and Trend scenario (Figure 12.5) for 2020 using the contour measure, with 45 minutes as maximum travel time. In the figure one sees that the Tolerant scenario, when compared to the Trend scenario, shows a sharp decrease in job accessibility for the Randstad Area (due to the job shift from the Randstad to eastern regions, and increased travel times), and a relatively sharp increase in job accessibility in and around Utrecht, tailing of to the northeast (towards Zwolle), and around Apeldoorn.

Potential accessibility measure

The potential accessibility measure (Figure 13.20) shows that that the largest changes in job accessibility between the Tolerant scenarios (see Figure 13.6) and the Trend scenario (see Figure 12.4) are concentrated in central urban areas and less in suburban and peripheral areas. The Tolerant scenario shows much a lower job accessibility level for the central and suburban areas of Amsterdam, Rotterdam and The Hague, whereas the central urban areas of Utrecht and Zwolle shows the largest increase in job accessibility.

Joseph and Bantock's measure

Joseph and Bantock's measure (Figure 13.21) shows that the number of jobs within reach per working person for the Tolerant scenario increases substantially for the relatively job-poor central region (roughly situated between Utrecht, Apeldoorn and Zwolle, except the areas where the congestion level is higher), and decreases substantially for the relatively job-rich central and suburban areas of Amsterdam, Rotterdam and The Hague. Thus, according to Joseph and Bantock's measure, the level of job competition will be lower for the Tolerant scenario.

Inverse balancing factor

The inverse balancing factor (see Figure 13.22) shows roughly the same spatial pattern at the potential accessibility measure. However, the differences in job accessibility between the Tolerant and Trend scenarios are smaller. In other words the decrease in job accessibility in central middle and suburban areas within the Randstad is lower, especially for Amsterdam and The Hague, as the result of the relative decrease in labour force competition (lower job surplus) in these areas. Furthermore, the increase in job accessibility in the central middle and peripheral region, e.g. for central urban area of Zwolle, is somewhat lower as a result of increased labour force competition (higher job surplus).

Utility-based accessibility measure

Figure 13.23 shows the regional differences in average utility per region between the Tolerant and Trend scenarios for 2020. More specific, the figure shows the difference in utility which individuals derive from access to jobs for each region, assuming no differences in sensitivity to travel costs between socio-economic groups. The figure shows that average utility is lower for the Randstad, especially for the central urban and suburban areas of The Hague and Rotterdam, and southwestern and southeastern regions of the Netherlands, especially for sparsely populated areas. Relatively large increases in utility are found in Utrecht and areas tailing off to the east and northeast.

Figure 13.24 shows the regional differences in total utility, i.e. average utility per region multiplied by the number of inhabitants in that region, between the Tolerant and Trend scenarios for 2020. The spatial differentiation of total utility per region (Figure 13.24) is much sharper than average utility per person region (Figure 13.23); this is the result of population developments. The largest increase in utility is found in regions with an increase in utility as a result of improved job accessibility combined with population growth, e.g. the suburban areas between Utrecht and Amsterdam and the area roughly situated between Utrecht, Arnhem, Apeldoorn and Zwolle. Central urban and suburban areas of the large and middle-sized cities in the Randstad show a total utility decrease as the result of reduced average utility levels (see Figure 13.23) and a population reduction (see Figure 10.10).

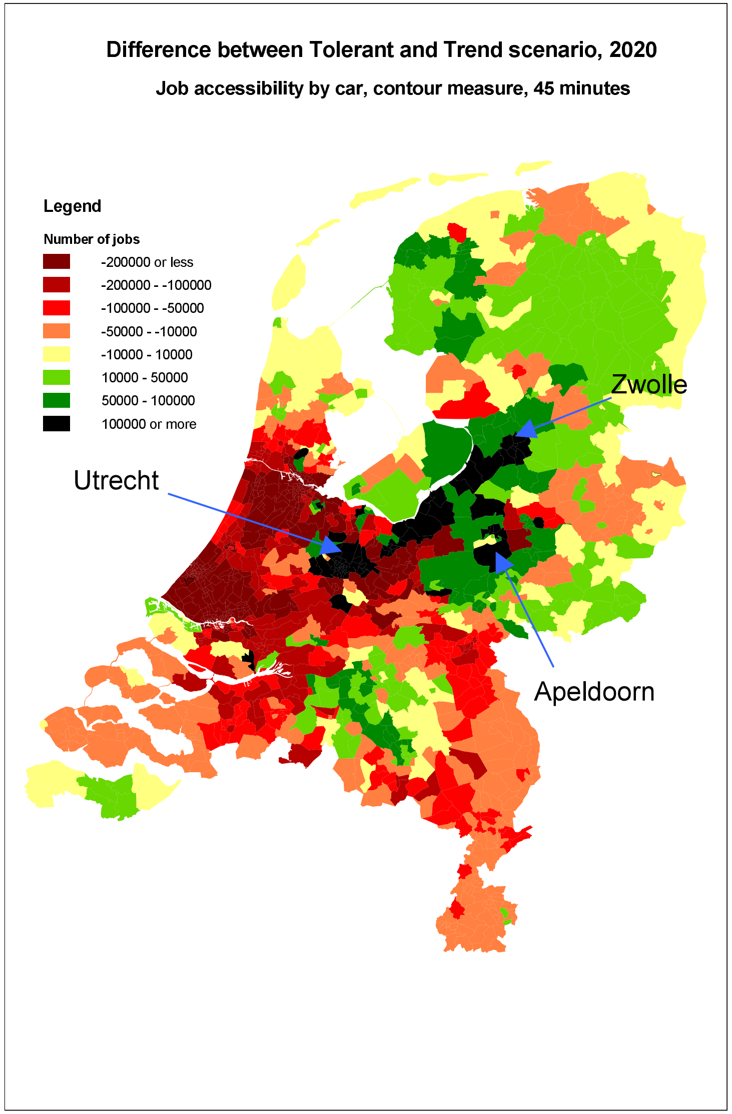

Figure 13.19: Job accessibility by car, difference between Tolerant and Trend scenarios, 2020, contour measure, 45 minutes.

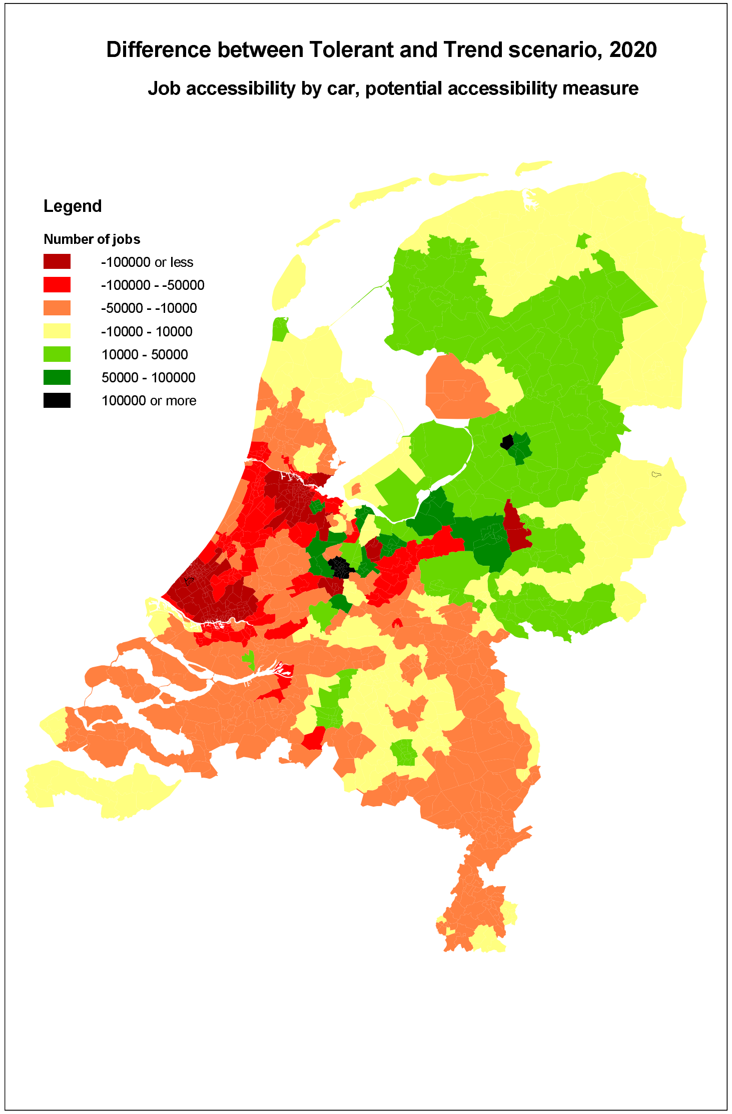

Figure 13.20: Job accessibility by car, difference between Tolerant and Trend scenarios, 2020, potential accessibility measure.

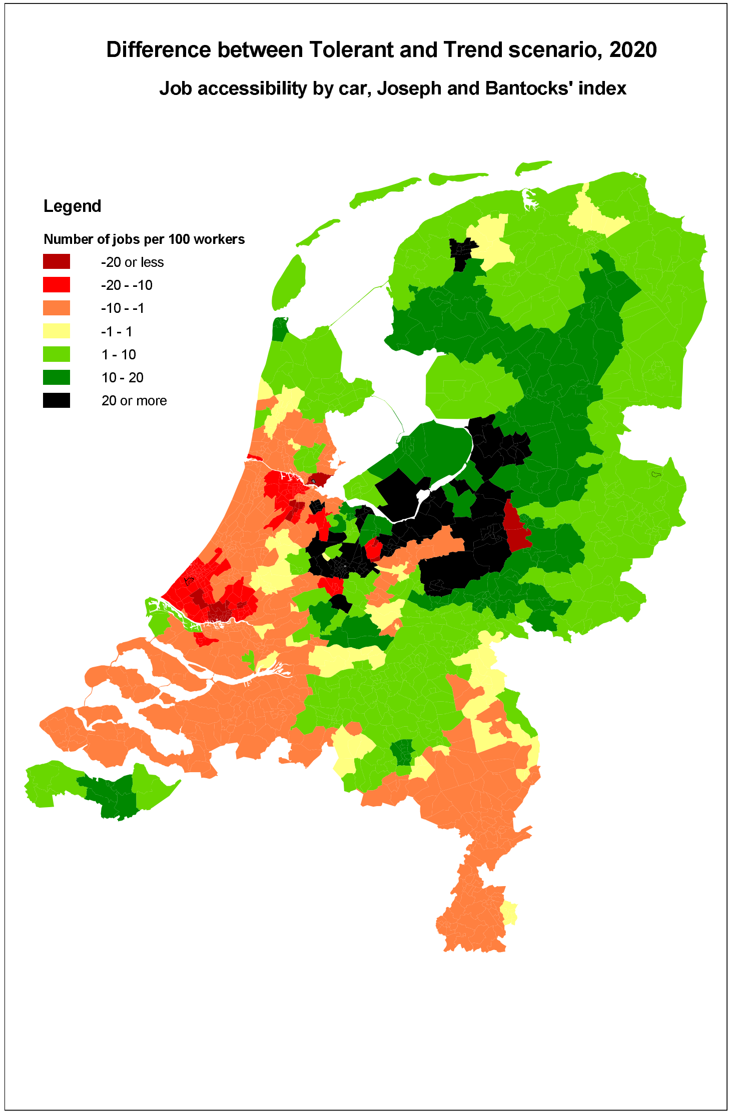

Figure 13.21: Job accessibility by car, difference between Tolerant and Trend scenarios, 2020, Joseph and Bantock's measure

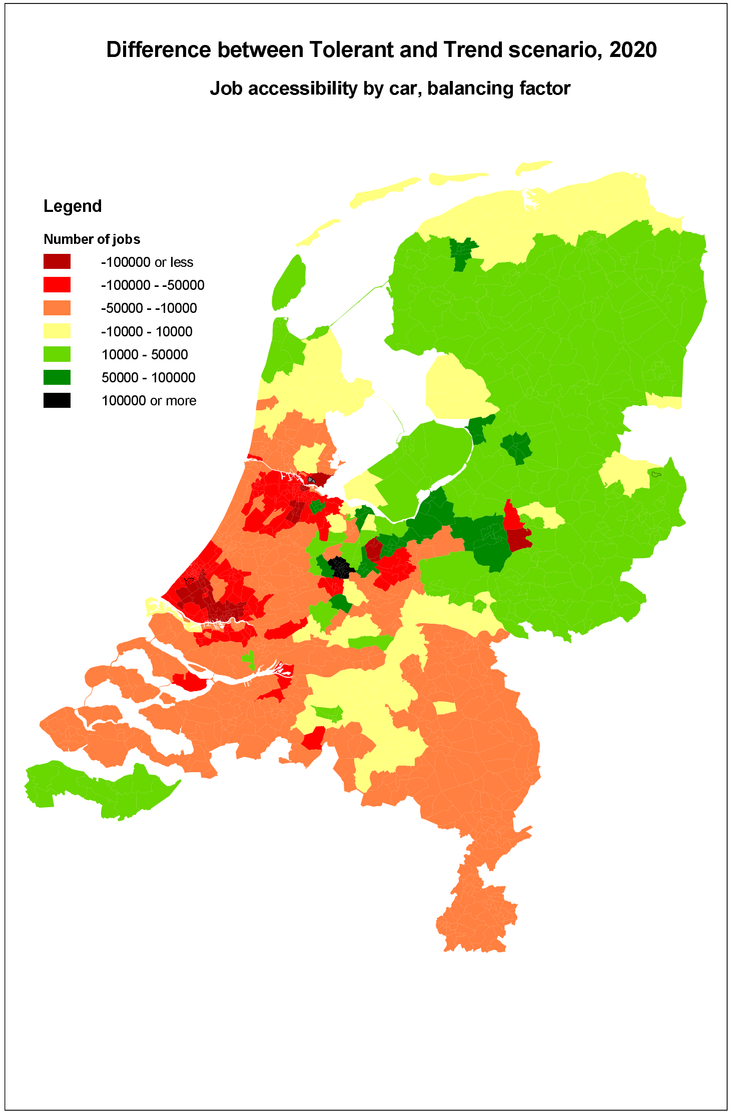

Figure 13.22: Job accessibility by car, difference between Tolerant and Trend scenarios, 2020, inverse balancing factor

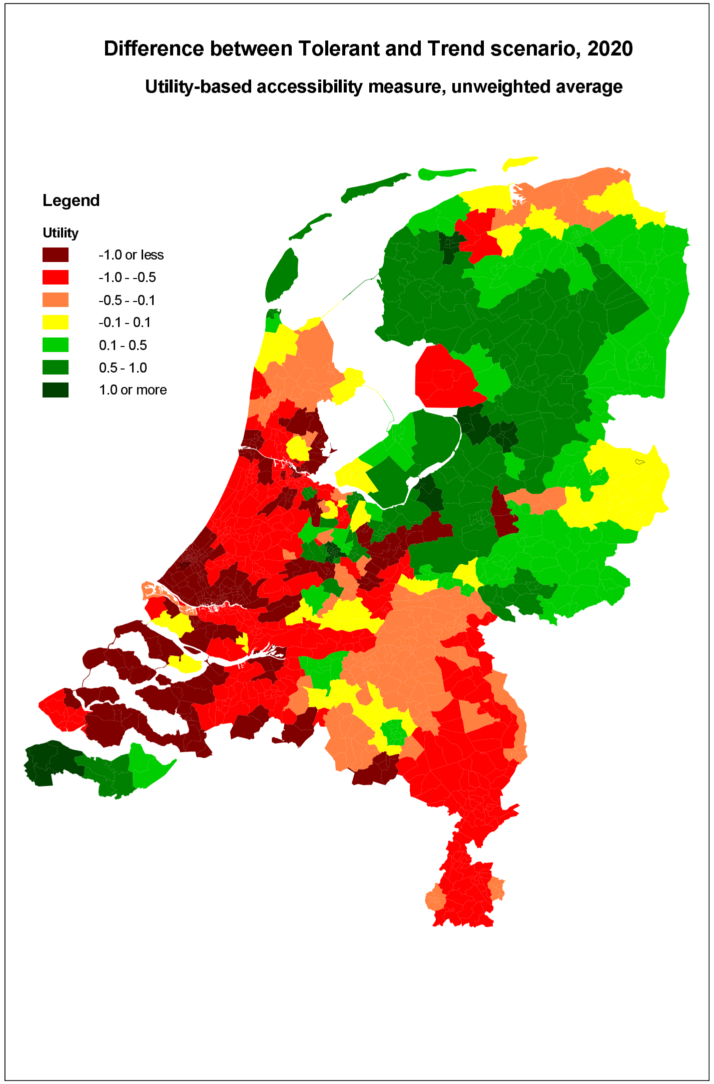

Figure 13.23: Average utility per inhabitant per region, difference between Tolerant and Trend scenarios, 2020.

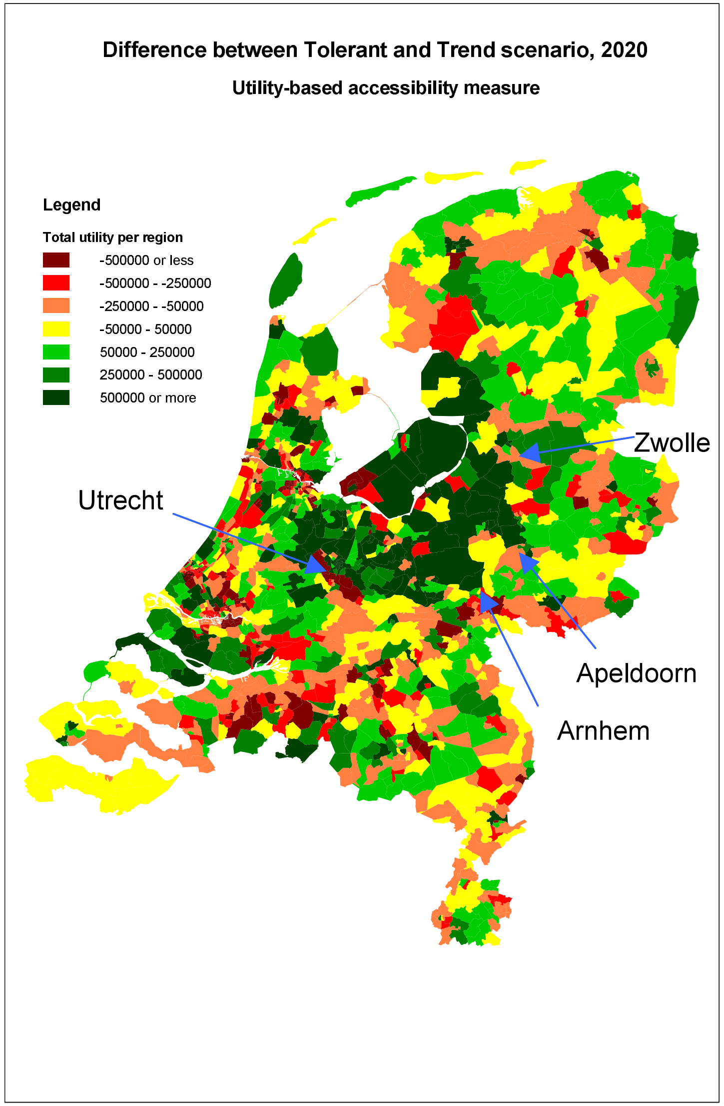

Figure 13.24: Total utility per region, difference between Tolerant and Trend scenarios, 2020.

13.6 Equity impacts of the Trend and Tolerant scenarios

As already described in Section 7, equity has several dimensions and can, for example, be stratified along a spatial, social and economic dimension. In this report, only spatial equity differences between the Trend and Tolerant scenarios can be analysed, i.e. the development of the distribution of job accessibility in space can be analysed. Social and economic equity can not be compared among the scenarios; i.e. for the Trend scenario no land-use data stratifying the population into relevant socio-economic groups (e.g. by education level, income level) is available.

There are several ways of illustrating the spatial equity impacts of accessibility scenarios, e.g. statistical measures, ratios between the “best” and “worst” regions, rank-size distributions, Lorenz distributions and GINI coefficients (see Section 7.3.3). Furthermore, the equity impacts can be analysed for each accessibility measure. Here, the developments of the differences in job accessibility between regions are illustrated by rank-size distributions for the potential accessibility measure and the inverse balancing factor.

Figure 13.25 shows the rank-size distribution of job accessibility by car for 1995 and the Trend and Tolerant scenarios for 2020 according to the potential accessibility measure, and Figure 13.26 according to the inverse-balancing factor.

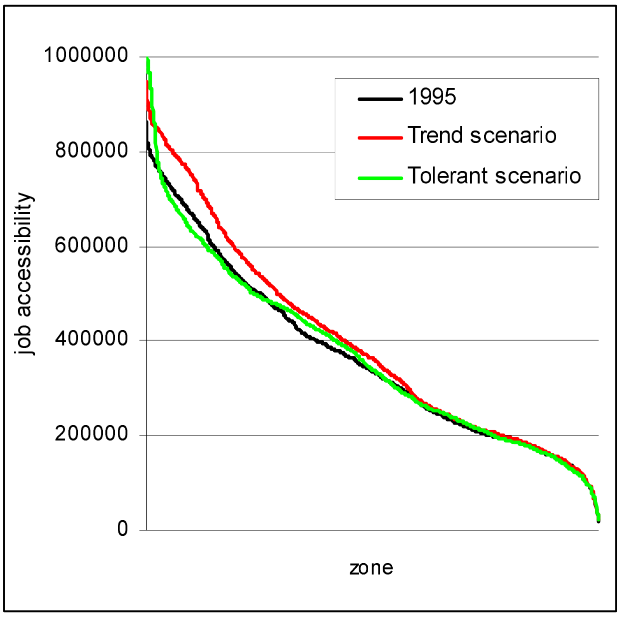

Figure 13.25: Rank-size distribution of job accessibility by car, potential measure, for 1995 and the Trend and Tolerant scenarios for 2020.

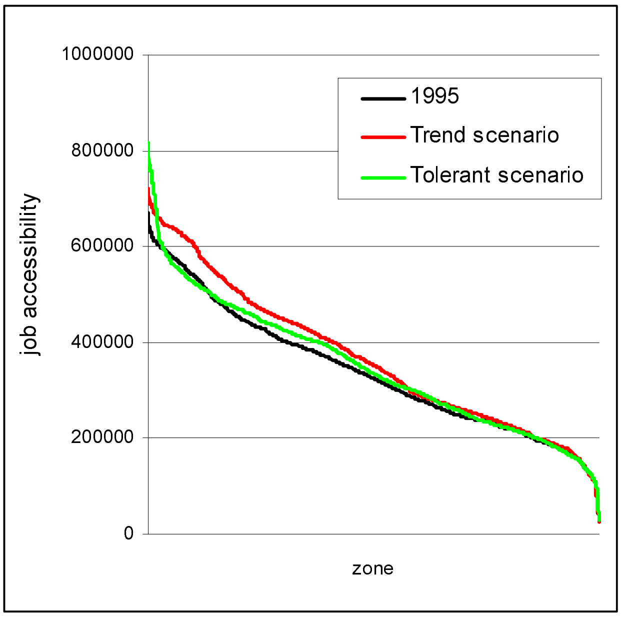

Figure 13.26: Rank-size distribution of job accessibility by car, inverse balancing factor, for 1995 and the Trend and Tolerant scenarios for 2020.

Figure 13.25 shows a large degree of inequality between regions according to the potential accessibility measure: from the most central area (or zone) more than 800,000 jobs can be reached by car in 1995, from the most peripheral area less than 20,000 jobs. Furthermore, spatial inequity increases for the Trend scenario, i.e. the differences between areas with a high and low accessibility level increase. The Tolerant scenario shows an overall decrease in inequality, except for a small number of regions (i.e. in and around Utrecht), which highly profit from this decrease. Figure 13.26 shows that the rank-size distribution of job accessibility according to the inverse-balancing factor is not much different from the potential measure. Thus, the inclusion of competition effects does result in a different conclusion on the spatial (in)equality of regions.

Another equity issue which can be illustrated is the change in the ranking of regions. Figure 13.27 shows the (moving average) rank-size distribution of job accessibility of the Trend and Tolerant scenario compared to the 1995 rank-size distribution of regions, according to the potential accessibility measure, Figure 13.28 according to the inverse balancing factor. Figure 13.25 shows that according to the potential measures, the relative position of regions changes relatively substantial for the Tolerant scenario. This is the result of the relatively substantial land-use changes; i.e. some central regions, which already had a relatively high job accessibility level – the regions in and around Utrecht , profit substantially from the job shift from the Randstad area to the central intermediate region (see also Figure 13.6). Figure 13.28 is similar to Figure 13.27, but the change in the ranking of regions is somewhat less as a result of increased job competition (see also Figure 13.8).

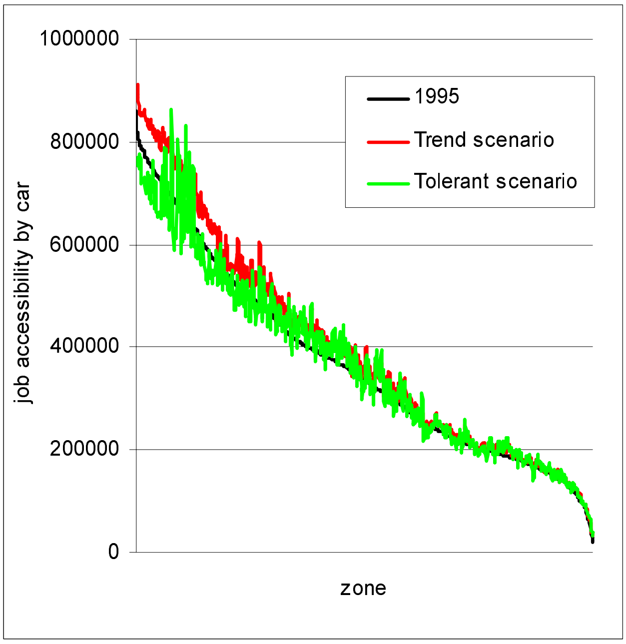

Figure 13.27: Rank-size distribution of job accessibility by car according to the potential measure for the Trend and Tolerant scenarios for 2020, compared to the 1995 rank-size distribution.

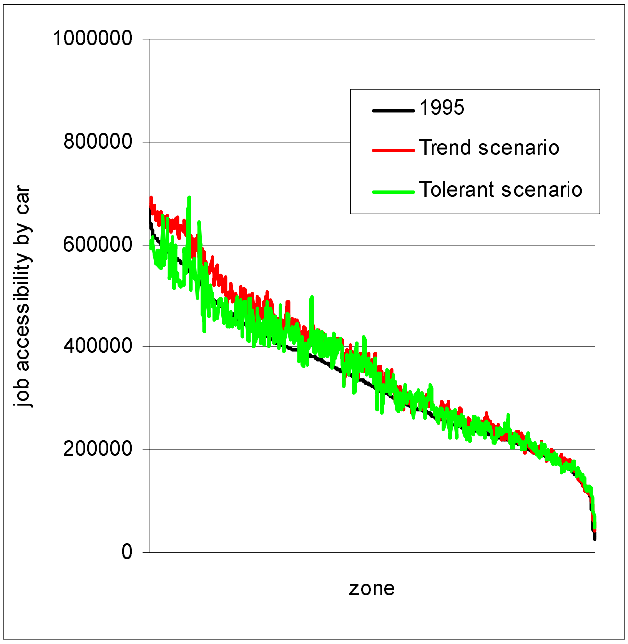

Figure 13.28: Rank-size distribution of job accessibility by car according to the inverse balancing factor for the Trend and Tolerant scenarios for 2020, compared to the 1995 rank-size distribution.

The development of the spatial inequality of regions can also be illustrated for public transport. Figure 13.29 shows the rank-size distribution of job accessibility by public transport according to the potential accessibility measure, Figure 13.30 for the inverse balancing factor.

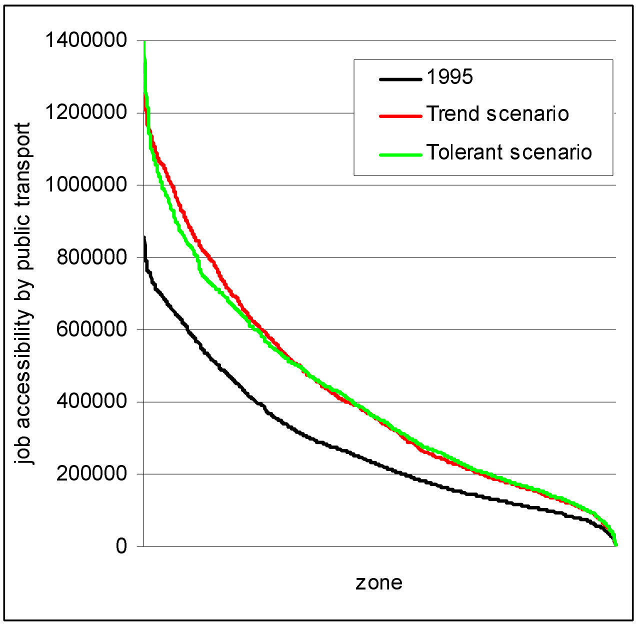

Figure 13.29: Rank-size distribution of job accessibility by public transport, potential accessibility measure, for 1995 and the Trend and Tolerant scenarios for 2020.

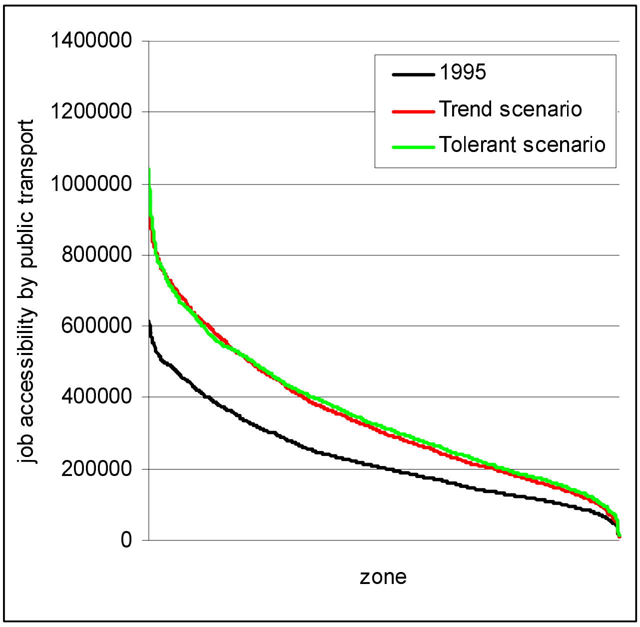

Figure 13.30: Rank-size distribution of job accessibility by public transport, inverse balancing factor, for 1995 and the Trend and Tolerant scenarios for 2020.

Figure 13.29 shows that according to the potential accessibility measure, the spatial inequality in job accessibility for public transport users is very large: from the most central area (or zone) more than 800,000 jobs could be reached by public transport in 1995, from the most peripheral area only about 5,000 jobs. Note that the absolute accessibility value for public transport can not be directly compared to the car mode due to the very different impedance functions used (see also Section 10.2.3). Furthermore, the figure shows that inequality increases for both the Trend and Tolerant scenarios: the areas which have the highest job accessibility level for 1995 (central urban areas) benefit the most in both scenarios – the effect of assumed overall improvement in public-transport travel times. As a result, the absolute increase in job accessibility is highest for regions which were already very well-accessible. Figure 13.30 shows that the rank-size distribution of job accessibility according to the inverse-balancing factor is not much different from the potential measure. Thus, the inclusion of competition effects, also for public transport, does not affect the conclusion on equity.

Figures 13.31 and 13.32 show the development in the ranking of regions for the potential accessibility measure and the inverse balancing factor, respectively. Both figures show the changes in the relative position of regions to be relatively small. Apparently, the land-use developments according to the Trend and Tolerant scenarios have a relatively modest impact on the development of job accessibility by public transport.

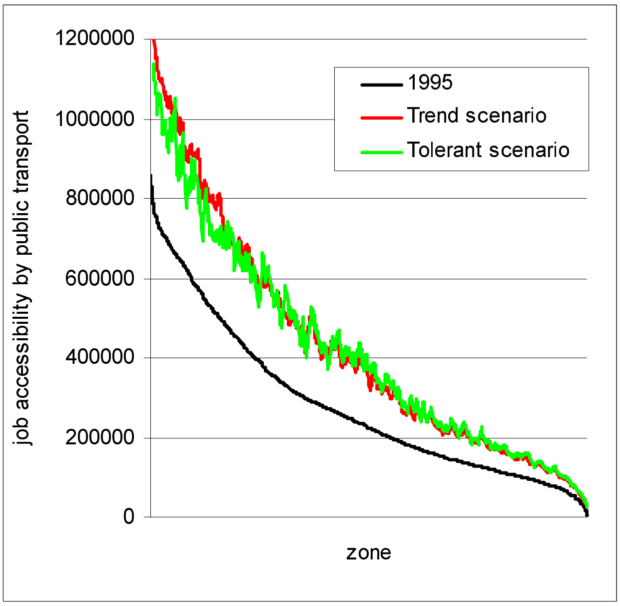

Figure 13.31: Rank-size distribution of job accessibility by public transport according to the potential measure for the Trend and Tolerant scenarios for 2020, compared to the 1995 rank-size distribution.

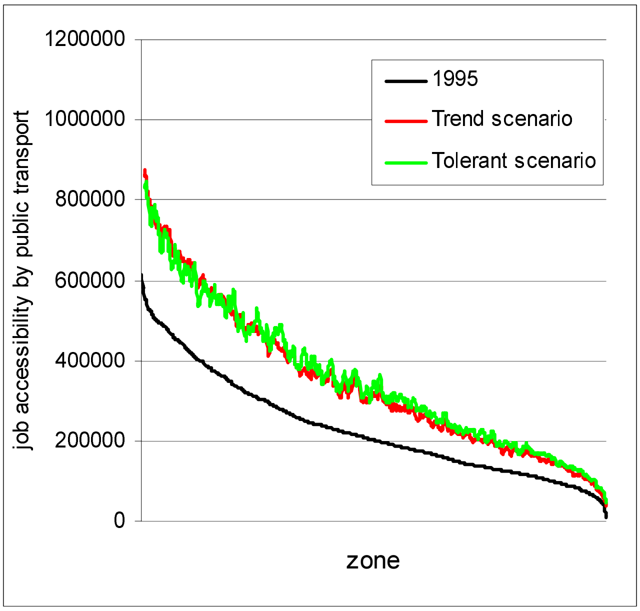

Figure 13.32: Rank-size distribution of job accessibility by public transport according to the inverse balancing factor for the Trend and Tolerant scenarios for 2020, compared to the 1995 rank-size distribution.

13.7 Conclusions

This section has described the development of job accessibility by car for the Tolerant scenario for the 1995-2020 period, according to selected activity-based accessibility measures (i.e. contour measure, potential accessibility measure, Joseph and Bantock's measure, the inverse balancing factor and the utility-based measure). This section will end with several conclusions.

13.7.1 Development of job accessibility and related utility

The development of job accessibility by car for 1995-2020 is the result of different developments: (i) land-use changes (i.e. changes in the number and spatial distribution of jobs and the working population), (ii) transport changes, i.e. travel time changes as a result of (a) development of delays and congestion, and (b) road capacity expansions. For public transport, the development of job accessibility is the result of (a) land-use changes and (b) improved public transport supply.

The contribution of these components to the development of job accessibility by car is analysed using the ***potential accessibility measure.*** The land-use according to the Tolerant scenario (substantial job shift from the western part of the Randstad towards the central middle and eastern regions) have significant impacts on the regional development of job accessibility. That means that, on average, the increase of jobs within reach (assuming no travel time changes) is about 32% (compared to 30% for the Trend scenario). The largest absolute growth of jobs within reach is found on the eastern side of the Randstad (e.g. 70-75% increase for Utrecht). However, the increase of job accessibility as the result of land-use changes is almost fully counterbalanced by increased delays and congestion. The assumed infrastructural improvements have a relatively small impact on the development of job accessibility for the Trend scenario, i.e. average job accessibility increases by about 2%. The net effect is that, on national level, job accessibility by car increases slightly by about 1% in the 1995-2020 period. Thus, the relatively sharper increase in the total number of jobs and the relative increase of jobs at locations easily accessible by car in the Tolerant scenario (compared to the Trend scenario) does not result in a higher job accessibility level by car if no additional improvements in road infrastructure supply are assumed.

For public transport, the contribution of land-use changes to the job accessibility is lower when compared to the Trend scenario (25% compared to 27% growth in the Trend scenario), although total job growth is higher. In conclusion, the relatively stronger processes of national deconcentration and regional suburbanisation in the Tolerant scenario negatively influence job accessibility by public transport.

Compared to the potential accessibility measure, the ***contour measure*** shows, on the national level, a decrease in job accessibility by car and much less increase in job accessibility by public transport. Furthermore, the measure shows an extremely spatially differentiated development of job accessibility. The conclusion for the Trend scenario is thus also valid for the Tolerant scenario: the contour measure shows a regional distribution of accessibility for a certain point in time that is easy to interpret, but the measure is not very capable of describing accessibility developments in time.

On the national level, the ***utility-based accessibility measure*** shows a constant average utility level for car users and a relatively small increase for public transport users for both the Tolerant and the Trend scenarios for the 1995-2020 period. This indicates that the changes in the spatial distribution of jobs and population according to the Tolerant scenario do not, on the national level, result in a very different average utility level, despite regional differences in the utility. The largest increase in total utility is found in suburban regions with an increase in utility as a result of improved job accessibility combined with population growth. Central urban and suburban areas of the large and middle-sized towns in the Randstad Area show a total utility decrease as the result of reduced average utility levels and a population reduction.

13.7.2 Influence of job and labour-force competition on the development of job accessibility

Joseph and Bantock's measure shows more extreme differences between the Trend and Tolerant scenarios than the potential measure and the balancing factor. The number of jobs within reach per working person for the Tolerant scenario sharply increases for the relatively job-poor central middle region (roughly situated between Utrecht, Apeldoorn and Zwolle, except areas where the congestion level is higher) and is substantially reduced for the relatively job-rich central and suburban areas of Amsterdam, Rotterdam and The Hague.

The ***balancing factor*** also shows that job competition in the Tolerant scenario is lower than in the Trend scenario. As a result, job accessibility growth by car and public transport is somewhat higher than according to the potential accessibility measure, and average public transport accessibility is somewhat higher for the Tolerant scenario and for the Trend scenario. In the Tolerant scenario, job competition among car users decreases (i.e. job surplus decreases) in the Randstad, in the western part of the Brabantstad Area, and in eastern and southwestern peripheral regions of the Netherlands. However, the current spatial structure remains dominant, e.g. job competition in the Randstad Area reduces potential job accessibility by about 15-20% for 2020, about 1-5 percentage points less than in 1995. In a number of suburban areas in the central intermediate region (e.g. between Utrecht and Amsterdam and between Utrecht and Zwolle) competition in the labour force increases due to the relative substantial growth of the number of jobs within reach. In these areas, potential job accessibility in 2020 is reduced by about 20-23%; roughly 5-10 percentage points more than in 1995.

In conclusion, there is a significant impact of job and labour-force competition on potential job accessibility. However, the land-use and transport changes according to the Tolerant scenario for the 1995-2020 period do not radically change the spatial distribution job accessibility and related job competition; the current spatial structure of the Netherlands remains dominant.

13.7.3 Effect of socio-economic differences on job accessibility

The development of job accessibility significantly changes if differences between socio-economic groups are accounted for. The potential accessibility measure and the inverse balancing factor show that job accessibility growth is overestimated if the match between workers education skills and job requirements ("occupational match") is not accounted for. In other words, job accessibility growth by car and public transport is about 5-6 percentage points lower if the occupational match is accounted for, resulting in a decrease in job accessibility by car for 1995-2020. This is the result of the growing mismatch between workers' education level and access to jobs with the required education level, especially for highly educated workers. More specifically, average accessibility to jobs requiring a high education level is roughly constant by car and increases by more than 50% by public transport, whereas the total number of highly educated workers increases by more than 75% up to 2020; for low- and intermediate-educated workers, job accessibility increases by 4% by car and more than 50% by public transport, whereas the number of workers increases by more than 10%.

Furthermore, socio-economic developments have a large impact on the utility-based accessibility measure. The increase of average household incomes has a large effect on the utility people derive from the land-use transport system, i.e. average utility derived from job accessibility by car and public transport increases by about 25 to 30%, in contrast to a stabilisation of utility when income developments are not taken into account. This means that if incomes increase, people are willing to travel farther (less sensitive to travel cost), and potential job accessibility and related utility increases. The effect of higher incomes on utility is relatively more substantial than the forecasted land-use and travel-time changes for the 1995-2020 period.

14. Conclusions from the case studies

This section describes the conclusions of Part II, Case Studies, of this report. Several activity-based accessibility measures and a utility-based accessibility measure are used to analyse job accessibility by car and public transport in the Netherlands for the base year (1995) and two land-use scenarios for 2020. The case studies were aimed at analysing the capacity of selected accessibility measures for evaluating accessibility impacts of land-use and transport changes, and related social and economic impacts.

Based on the literature review described in Part I of this report, the following accessibility measures are selected for application:

- A contour measure, estimating the total number of jobs which can be reached within a maximum travel time of 45 and 60 minutes;
- A potential accessibility measure, estimating the potential number of jobs within reach, weighed by their travel time away;
- The accessibility measure developed by Joseph & Bantock (1982), estimating the number of jobs accessible per worker;
- The inverse balancing factor (a_i) of the doubly-constrained spatial interaction model, estimating potential job accessibility, corrected for the interdependent competition effects between jobs and on the working population.
- A utility-based accessibility measure, estimating the utility inhabitants of a location derived from potential accessibility to jobs, using a impedance function for travel cost;

Two land-use scenarios were analysed for the 1995-2020 period:

- A Trend scenario, describing the continuation of (restrictive) land-use policies as described in the Fourth National Policy Document on Spatial Planning Extra and transport policies, as described in the 1999 Transport Infrastructure Plan;
- A Tolerant scenario, in which consumer housing preferences are assumed to determine housing and related employment developments. In this scenario, the same transport policies as for the Trend scenario are assumed.

The accessibility measures use transport data (travel times between zones as impedance) and land-use data as input. The average travel times between origins and destinations (1308 zones) were derived from the Dutch National Model System. The land-use data (i.e. number of jobs (by education level) and the working population (by education and income levels) are derived from national land-use models (the Land Use Planner and Socrates).

The main conclusions of the application of the accessibility measures follow. In general, activity-based accessibility measures are very effective measures for analysing accessibility impacts of land-use transport scenarios, i.e. a change in accessibility may be the result of land-use changes, transport changes, or both. This, however, also makes the activity-based accessibility measures more difficult to interpret than infrastructure-based accessibility measures, e.g. average speed on the road network. This report shows that using the data available, the contribution of land-use changes and transport changes (travel-time changes due to delays and congestion and/or travel-time changes due to changes in the infrastructure supply) to the development of job accessibility can be estimated separately. For the Tolerant and Trend scenarios for the 1995-2020 period, the results show land-use changes and travel-time changes due to increased delays and congestion, as being equally important. Furthermore, on the national level, the contribution of infrastructure expansions to job accessibility growth is relatively small.

The application of the selected accessibility measures shows a trade-off between "common-sense" interpretation of a measure and the capacity to explain accessibility impacts of land-use transport scenarios. See examples below.

- The most simple accessibility measure applied here, the ***contour measure***, has the major advantages of: (a) being very easily interpreted, i.e. the measures shows total number of jobs that can be reached within a certain maximum travel time, and (b) being directly usable to compare accessibility levels between modes. However, the case studies showed that the measure is not very capable of explaining changes in accessibility in time: the measure shows an extreme spatially differentiated picture of the development of job accessibility. The contour measure proved to be very sensitive to travel time changes. This is the result of the (arbitrary) maximum travel time in combination with the absence of an impedance function. As a result, a small change in the travel time may result in the inclusion or exclusion of a job location from the accessibility value of an origin zone;
- The case studies show that the ***potential accessibility measure*** is much more capable of evaluating accessibility impacts of land-use scenarios: i.e. the measure is capable of showing a plausible regional distribution of job accessibility for a given year and for developments in time, thus overcoming the disadvantages of the contour measure by using an impedance function without using an arbitrary maximum travel time;
- A methodological disadvantage of both the contour and the potential measures in analysing job accessibility is that they do not incorporate the influence of job competition. ***Joseph and Bantock's measure*** seems to handle job competition in a relatively simple way; i.e. the measure estimates the number of jobs accessible per working person. However, this measure can essentially not be interpreted as an accessibility measure but as a measure of job competition only: the balance between the spatial distribution of jobs and the working population. The results are thus not easy to compare with the other accessibility measures.
- The ***inverse balancing factor*** overcomes the disadvantages of Joseph and Bantock's measure; i.e. the measure can be expressed as an activity-based accessibility measure and incorporates job competition. The case studies show that job accessibility in central and suburban areas can decrease by 20-30% as a result of job competition among workers and more than double in peripheral areas. However, the land-use and transport changes according to the Trend and Tolerant scenarios for the 1995-2020 period do not radically change the current spatial distribution job accessibility and related job competition; the current urbanisation pattern in the Netherlands remains dominant. The case studies show

> the balancing factor to be very capable of estimating accessibility impacts of land-use scenarios, including competition effects. A disadvantage of the measure is that it is less easily explained than, for example, the potential accessibility measure.

The ***utility-based measure*** estimates the utility people derive from potential job accessibility. This has the disadvantage that the measure: (a) is not easily interpreted, i.e. the concept of utility is related to relatively complex economic theories, and (b) can not be directly compared to other activity-based accessibility measures; i.e. the measure is essentially not a measure of accessibility but of people's valuation of accessibility. The major advantage is that the measure can theoretically be used as a basis for economic evaluations of accessibility, i.e. using the measure as a basis for computations of consumer surplus. The results of the utility-based measure contrast with the potential accessibility measure. Firstly, the bandwidth of utility values is much smaller than for the potential accessibility measure. Secondly, the measure shows diminishing returns; i.e. the marginal benefits decrease as job accessibility further increases. If job accessibility changes at locations with a low accessibility level this results in a relatively substantial utility change, whereas a change at locations with an already relatively high accessibility level, results in a relatively small utility change. Thus, the utility-based accessibility measure suggests that average utility increases more substantially if job accessibility is improved for inhabitants in relatively job-poor areas (e.g. peripheral areas outside the Randstad), in preference to further increasing job accessibility for inhabitants living in already relatively job-rich areas (e.g. central and suburban areas in the Randstad). Note that the utility-based accessibility measures estimated here can not be directly used as an economic indicator (change in consumer surplus or consumer welfare). In other words, the theoretically correct use of utility-based accessibility measures for measuring consumer surplus of a transport project requires a transport model which properly forecasts the combined land-use transport equilibrium, including land-use and transport feedbacks. For measuring consumer welfare, the utility values have to be converted to monetary units by using theoretical research from the literature on economics. Further research is necessary to analyse the added value of using utility-based accessibility measures in economic evaluations (i.e. cost-benefit analysis).

The development of job accessibility significantly changes if differences between socio-economic groups are accounted for. In general, peoples' needs, abilities and opportunities influence accessibility. Here, the application of the potential accessibility measure and the inverse balancing factor clearly shows that job accessibility growth is overestimated if the match between workers' education/skills and job requirements ("occupational match") is not accounted for. Furthermore, socio-economic developments have a large impact on the development of the utility-based accessibility measure, i.e. the forecasted increase of average household incomes has a large effect on the utility people derive from the land-use transport system. Thus, the differentiation of the population according to socio-economic characteristics results in significant changes in average job accessibility and related utility, the result of a more accurate estimation.

In summary, the case studies show that activity-based accessibility measures are very well able to analyse accessibility impacts, satisfactorily incorporate the different components of accessibility (i.e. the transport, land-use, temporal and individual components) and serve as a useful tool for analysing social impacts. The current Dutch practice of evaluating the (infrastructure-based) accessibility impacts of (land-use) transport projects, plans or scenarios can be improved by estimating activity-based accessibility measures, using existing land-use and transport data, and/or models. Utility-based accessibility measures may provide a useful basis for economic evaluations of land-use transport scenarios, but further research is necessary to analyse the added value to existing evaluation methods.

15. Further research

This report presents the first study within the framework of the PhD research programme of the first author, titled "Ecological, Social and Economic Evaluation of Transport Scenarios: An Integral Approach". The programme has been set up to develop, apply and evaluate methodologies for the integral assessment of the anticipated ecological, economic and social consequences of land-use transport scenarios (see Geurs, 2000). The development and evaluation of accessibility measures plays a central role in the research programme. This report has presented an extensive literature study and three case studies, but many additional research issues on accessibility can still be addressed.

Within the framework of the PhD research programme, further research related to accessibility is therefore planned on themes listed below:

- The analysis of accessibility to destinations other than jobs, e.g. nature areas, retail trade, social purposes. This is relevant because home-to-work travel accounts only for a modest part (20-25%) of all travel in the Netherlands.
- The analysis of accessibility to destinations by non-motorised modes (walking, cycling): non-motorised modes account for an important number of trips in urbanised areas in the Netherlands.
- The analysis of more "extreme" land-use transport scenarios, assuming substantially improved (public and/or car) transport infrastructure in combination with relatively large population and employment shifts to (high-density) housing and employment locations near public transport nodes. The relevance of including competition effects in the analysis of job accessibility will, among other issues, be further analysed.

More research also will be conducted to analyse the added value of utility-based accessibility measures in cost-benefit analysis of land-use and infrastructure projects. This report concludes that the theoretically correct use of utility-based accessibility measures for measuring user benefits of a transport project requires a transport model which properly forecasts the combined land-use transport equilibrium, including land-use and transport feedbacks. At the time of writing, the Dutch land-use model Environment Explorer (RIVM, 1998) was undergoing extension at the RIVM with a state-of-the-art transport demand model, estimating passenger mobility (car and public transport) and accessibility at the level of 345 zones (AGV, 2001). This will make it possible to further analyse the value added of using utility-based accessibility measures in the economic evaluation of land-use and infrastructure projects (and plans and scenarios).

Finally, this report points out that the evaluation of non-user values (option values, bequest values) related to transport infrastructure and accessibility has, up to now, been uncharted territory. Further research is planned to analyse non-user values by conducting a Stated Preferences study.

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Appendix 1: Mailing list

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Appendix 2: Estimated impedance functions

Table 1: Parameters for the loglogistic and negative exponential impedance function by trip purpose, mode and socio-economic characteristic for 1995

purpose	mode	socio-economic characteristic	A	B	r squared	N
Loglogistic impedance function						
all	all		-4,360	1,691	0,99	625478
work	car		-6,899	2,326	1,00	51283
work	car	high education level	-7,314	2,354	0,99	12838
work	car	medium + low education level	-6,815	2,333	1,00	37970
work	car	medium education level	-6,372	2,181	0,99	2332
work	car	low education level	-6,842	2,342	1,00	35638
work	public transport	all	-14,208	3,579	1,00	12728
work	public transport	high education level	-15,479	3,784	1,00	4968
work	public transport	medium + low education level	-13,761	3,538	1,00	7628
work	public transport	medium education level	-12,860	3,461	1,00	398
work	public transport	low education level	-13,861	3,555	1,00	7230
business	car		-5,408	1,819	1,00	14355
business	public transport		-10,782	2,521	1,00	1055
shopping	car		-5,472	2,314	0,99	61356
shopping	public transport		-8,526	2,432	1,00	4772
recreation	car		-5,402	1,671	0,99	4251
recreation	public transport		-10,360	2,505	1,00	571
social	car		-5,438	1,958	0,99	50113
social	public transport	all	-9,580	2,296	1,00	5450
Negative exponential impedance function						
work	car	all	n.a.	0,039	0,97	51283
work	car	low income level	n.a.	0,044	0,96	17145
work	car	medium income level	n.a.	0,038	0,97	19285
work	car	high income level	n.a.	0,034	0,97	10581
work	car	all	n.a.	0,016	0,87	12728
work	car	low income level	n.a.	0,016	0,87	5060
work	car	medium income level	n.a.	0,014	0,84	4461
work	car	high income level	n.a.	0,013	0,81	2257

n.a. = not applicable

Source: data taken from the Dutch National Travel Survey, 1995