# EXPLORING THE IMPACTS OF PUBLIC TRANSPORT ORIENTED LAND USE POLICIES, A CASE STUDY FOR THE ROTTERDAM AND THE HAGUE AREA

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## 1. Introduction

In the foreseeable future the continued trend of urbanization calls for a new approach to allow for better joint-use of space and mitigation of undesirable effects. A more integral solution is required and the Ministry of Infrastructure and the Environment of the Netherlands has launched a new program to explore a wider approach to improve accessibility. At the core of the program is an integrated regional approach, to be worked out by national, regional and local stakeholders, including multi-modal, ICT and land-use strategies besides the traditional infrastructure investment measures. The program calls for a better co-ordination between land use and transport measures. For a successful answer many research questions are still to be addressed, among others on valuable design options, stakeholder cooperation, methods to calculate the impacts of integrated strategies and especially comprehensive evaluation measures and procedures.

This paper focuses in particular on the last two aspects, it gives a practical example on how to calculate the impacts of the land use policies on land use and transport, by applying a land use and transport interaction model and secondly the paper discusses the model results for various output accessibility indicators originating from different research disciplines. The research questions in this paper are addressed in the form of a case study for the larger Rotterdam and the Hague area in the Netherlands.

In the study sensitivity analyses are performed for the case study region to get insight in the impacts of land-use policies. The land use policies are oriented to benefit from the existing public transport infrastructure in the region. The sensitivity analysis included origin based policy measures, like additional construction of houses at good accessibility public transport locations, as well as destination based measures, like additional development of office space and jobs near railway stations or the location of higher education facilities near railway stations. In the second part of the study the focus is on mixed strategies, including origin and destination based measures, and the specific public transport oriented land use strategy is compared with a more generic compact city strategy. The scenarios are compared on more traditional transport and accessibility indicators, such as congestion, as well broader accessibility indicators including the impacts of proximity changes as well. Finally a utility based accessibility measure is used to monetarize the broader accessibility indicator as well.

The paper addresses the literature in section 2 and the TIGRIS XL model and accessibility indicators are introduced in section 3. Section 4 describes the study region and policy scenarios and in section 5 the main land-use, transport and accessibility results are presented. Finally section 6 presents the conclusion of this study.

## 2. Public transport oriented land use policies

As subject of research the interaction between land use and transport and mutual influence of policies has a longstanding tradition. In recent years much literature can be found on Transit-Oriented Development (TOD), where high density land-use is combined with easy access to high quality public transport services (Loo, Chen, & Chan, 2010; Olaru, Smith, & Taplin, 2011). The TOD concept includes the mixture of land uses:

residential, employment and retail. Locally the urban design is adapted to enhance access to the public transport network, typically either a commuter rail station or bus rapid transit line. With TOD urban planners aim to reduce the individual car usage and all negative externalities that stem from it (Cervero & Kockelman, Travel demand and the 3Ds: Density, diversity and design, 1997).

Research on the effectiveness of TOD, or other land use policies with a transport objective, often focusses on the usage of transport modes, such as its effect on mode shares (Cervero, Transit-based housing in California: evidence on ridership impacts, 1994), reduction of vehicle miles travelled (Nasri & Zhang, 2014) or the number of transit trips (Sung & Oh, 2011). With measures of potential accessibility, such as job accessibility, a land-use component is included in the analysis (Cervero & Day, Suburbanization and transit-oriented development in China, 2008). A different point of view is considering the effect of TOD on dwelling prices (Kay, Noland, & DiPetrillo, 2014; Mathur & Ferrell, 2013), which would measure all different aspects of location quality: related to transport, land-use and other factors. This research contributes to the literature with a case studying analyzing and evaluation accessibility changes including proximity of land-use policies. The accessibility changes can be expressed in monetary terms as well.

## 3. Methodology

### TIGRIS XL land use and transport interaction model

The calculations for this case study are done by the TIGRIS XL land use and transport interaction model. This model iterates between transport and land-use components, such as housing-, labour-, land- and real estate market, to model how the system evolves over time. The TIGRIS XL model is an integrated system of sub-models addressing specific sectors. The model uses time steps of one year for most of its modules, and the model is a recursive or quasi-dynamic type of model, in which the end state of one time period serves as the initial state of the subsequent time period. The underlying assumption is that the system is not in equilibrium at a certain moment in time; therefore no general equilibrium is simulated within one time step, but that depending on time lags the system moves towards equilibrium. The land-use model is fully integrated with the National transport Model System (NMS) of the Netherlands and the land-use modules and transport model interact, for reasons of computation time, every five years.

The TIGRIS XL model consists of five modules addressing specific markets. Core modules in TIGRIS XL are the housing market and labor market module; these modules include the mutual interaction between the population and jobs and the effect of changes in transport on residential or firm location behavior. Main characteristics are that both the residential location choices and firm location choices are estimated on detailed spatial data sets covering different economic sectors and household types. The model has a multi-level set-up and different spatial scale levels are distinguished, namely the regional level (COROP, 40 regions in the Netherlands) to simulate interregional flows, the municipality level and finally the level of local transport zones of the National Model System (1379 zones covering the Netherlands). Figure 1 presents an overview of the

TIGRIS XL (TXL) model and the main relationships between the modules, for a more detailed description reference is made to Significance (2010) and Zondag (2007).

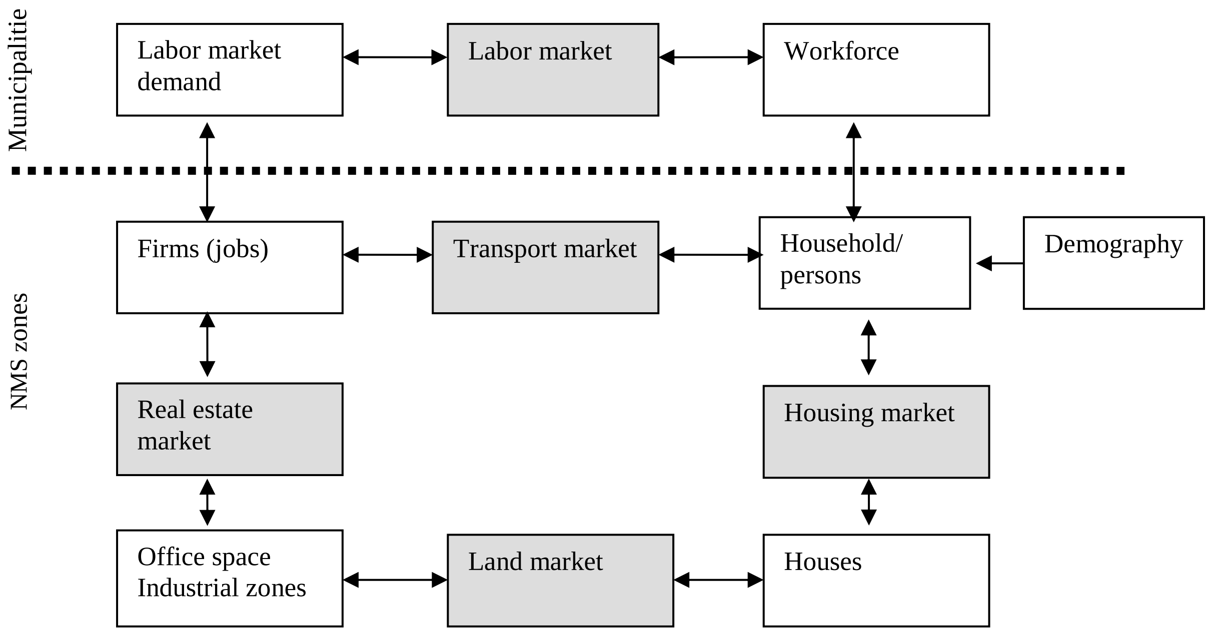


*Figure 1: Functional design of the TIGRIS XL model*

For its demographic module the TIGRIS XL model uses as basis the regional demographic model PEARL (Jong A. de, 2013) of the National Bureau of Statistics and Netherlands Environmental Assessment Agency. The module works bottom-up and the transition processes, such as birth, mortality and changes in household position of the population and households, are at the zonal level. Besides the demographic characteristics the population and household data is enriched with socio-economic information regarding status of employment and household income.

The land and real estate market module processes the changes in land-use and buildings, office space and houses, and addresses both brown field and green field developments. The land and real estate market module interacts with the housing market and labor market module. The module distinguishes the land market, including land regulation policies, and the real estate market addressing the development or restructuring of buildings. The modeling of the changes in land-use depends on the user settings for the level of market regulation by the government varying from a regulated residential land-use planning system to a unregulated residential land market. For its simulation of the real estate market the TIGRIS XL model benefits of the experiences with the Houdini housing market model of the Netherlands (Eskinasi et al., 2011).

**Indicators**

A broad set of output indicators is generated within this study consisting of spatial indicators, such as distribution of population or employment, transport indicators, such as mode split or average distances travelled and accessibility indicators. In this paper we focus in particular on accessibility indicators and their role in the evaluation of land use policies. Originating from different research disciplines, such as transport, geography and economy, a wide variety of accessibility indicators exists. Geurs and van Wee (2004) classify different types of accessibility indicators, in line with this we distinguish here between network indicators, geographical accessibility indicators and/or geographical economic indicators. This study includes an example of all three types of accessibility indicators to analyze the accessibility effects from different perspectives. The discussed accessibility indicators are:

- As *network accessibility indicator* a congestion indicator, expressed as travel time losses on the network, is included.  This indicator is frequently used by the department of transport as output indicator to measure the effectiveness of transport measures. This indicator is also closely related to the rule-of-half evaluation method standard applied to calculate the consumer benefits of travel time changes. The indicator is very responsive to changes in the network especially if bottlenecks are solved, but the indicator only responds indirectly to changes in land use following its impact on travel time losses. Any impact on the proximity of activities is not measured by this indicator;

- A geographical indicator is included to measure both changes in speed and proximity. The indicator consists of either number of population or employment, as measure for the attractiveness of destination, and the distance decay function is described by travel time and estimated on observed travel behavior in the National Travels Survey for the Netherlands. The travel time, included in the indicator in this study, consists of the fastest public transport connection between A en B including access, egress and waiting time. The geographical indicator responds to changes in travel time and frequencies of public transport in the region as well as to changes in the spatial distribution of jobs and population. A disadvantage of this indicator is that a method is missing to transfer the results directly into monetary consumer benefits as part of a CBA. At the moment travel time benefits can be monetarized following the standard approach. For proximity benefits the changes in prices for non-mobile goods, such as houses, might be an option as these changes include all aspects. However simulating these changes in housing prices is not without complexity, covers a wider scope than accessibility and an operational commonly accepted approach is missing;

- As economic-geographical indicator, a so-called logsum indicator measuring changes in utility, is used. In the Netherlands the rule-of-half method is standard used to calculate the consumer benefits. However, in the literature it has been pointed out repeatedly that the rule-of-half gives incorrectly measured welfare effects of land-use policy plans (e.g., Neuburger, 1971) and transport strategies where land uses are forecasted to change as a result of the strategy (Bates, 2006; Geurs et al., 2006; Simmonds, 2004). The logsum indicator is capable of addressing the monetary benefits resulting from speed improvements as well as proximity improvements. The logsum method is therefore well suited to calculate the benefits of accessibility changes as a result of either a transport (generalised cost) change or a land-use change. Land use strategies result in changes for the relative attractiveness of locations and related changes in trip distribution taking place for reasons other than transport cost changes.  An operational advantage of the logsum method is that the discrete choice type of LUTI models, such as TIGRIS XL, can be used to calculate the consumer surplus of land use and/or transport strategies. A theoretical advantage of the logsum indicator is that the estimated demand curves of the model are used instead of a linear approximation as used in the rule-of-half method.

The paper briefly discusses the accessibility effects of the land-use strategies by indicators. Evaluating integrated land use and transport strategies on appropriate measures remains a real challenge in practice as current practice seems strongly focused on transport measures alone. This study aims to present a practical way to include wider impacts like changes in proximity.

## 4. Study area and scenarios

### Study area

The study area is the Rotterdam-The Hague region in the West of the Netherlands. Instead of an administrative region we use a functional region, which is in this case defined as the smallest possible region (in terms of employed population) from which at least 90 percent of the commuting trips to Rotterdam and to The Hague originate. The resulting region comprises 3.6 million inhabitants in 75 municipalities, further divided into 290 zones in the TIGRIS XL model. It is a predominantly urban region, except for the southwestern part. *Figure 2* shows the outline of the study area with railway lines and stations.

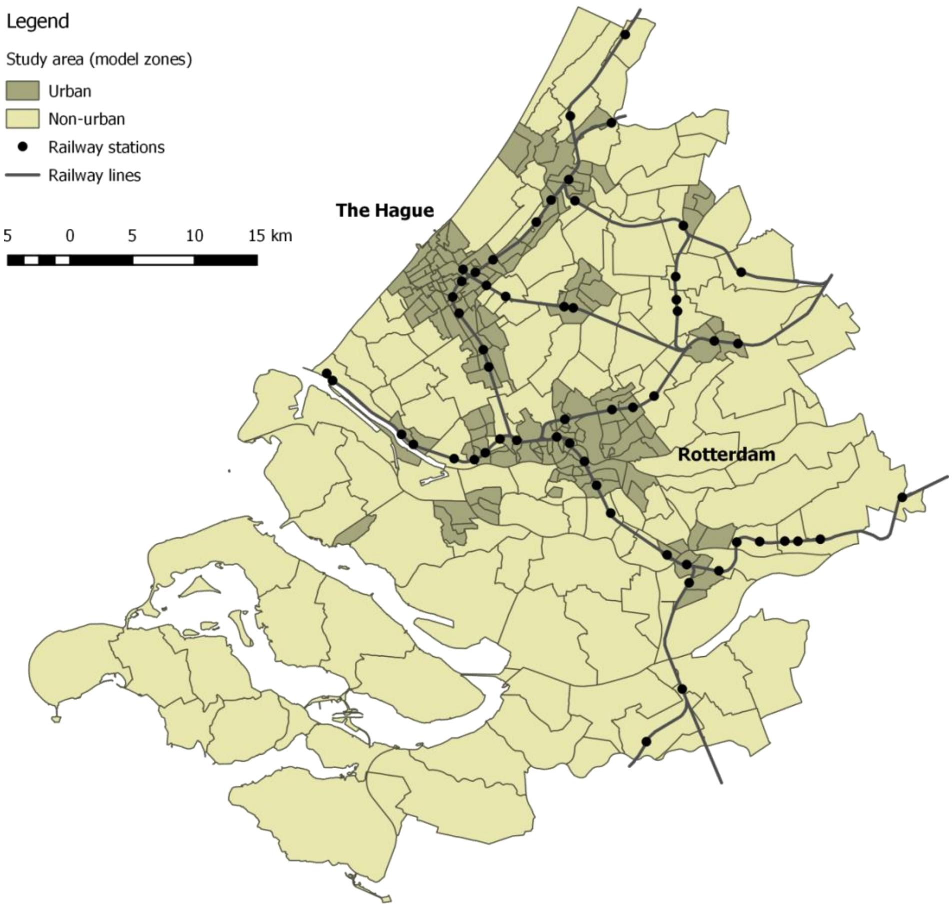


*Figure 2: Study area (situation in 2010)*

**Scenarios**

For the TIGRIS XL model five scenarios are formulated. First of all a reference scenario is developed for the region to compare the influence of alternative policy scenarios. The first two policy scenarios are basically sensitivity tests and allow studying different elements of public transport oriented land use policies separately. A combined policy scenario allows evaluating also the interaction between these land use strategies. Additionally an alternative policy scenario, with increased urbanization without public transport orientation, is included to differentiate the impacts of general urbanization strategies and more specific public transport oriented land use polices. The time horizon of all scenarios is 2030 and within the TIGRIS XL model the scenarios are generated dynamically with time steps of one year. The five scenarios can be described in more detail as follows:

*Reference scenario*: The reference scenario is a moderate scenario, for demographic and economic development, with business-as-usual policies for transport and spatial planning. It follows current trends in demography and socio-economic developments, which includes an increasing degree of urbanization.

*Public transport based housing scenario (housing scenario)*: This scenario tests the impacts of a public transport oriented land use strategy, at the origin location of tours, by influencing the location of new dwellings. Building new dwellings is only allowed in zones with a score for PT accessibility to employment of 400.000 jobs or above in 2010. *Figure* shows the PT job accessibility, with zones that match the criterion for this scenario. The total amount of new dwellings in the study area is kept equal to the number of new dwellings in the reference scenario. At the level of individual municipalities development of new housing is restricted to stay within maximum plausible numbers. The TIGRIS XL model simulates endogenously the location of jobs and the spatial distribution of jobs will respond to new residential locations.

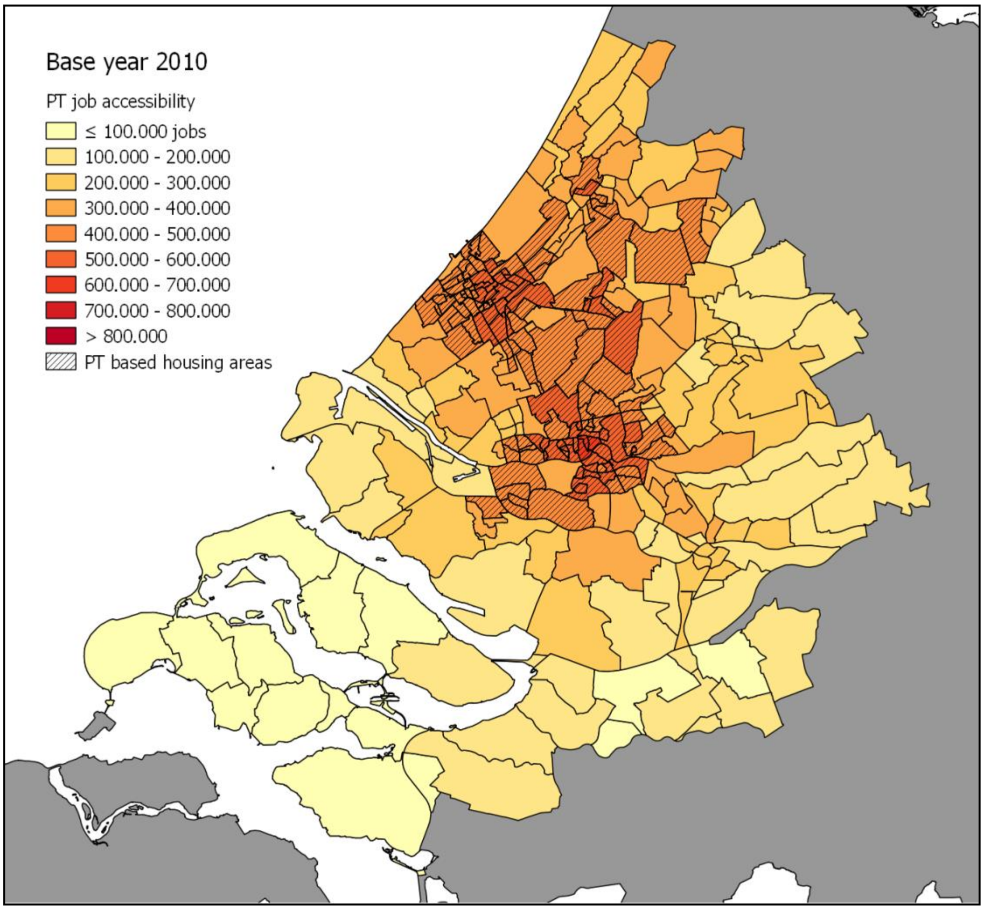


*Figure 3: Public transport accessibility to employment in 2010*

*Rail based employment scenario (employment scenario)*: This scenario test the impacts of a public transport oriented land use strategy, at the destination location of tours, by influencing the location of employment. In this scenario new employment in the service and government sector is concentrated in a selection of zones that are at least partially within 500 meters of a railway station. Large rural zones are excluded from this selection. The TIGRIS XL model calculates the employment endogenously, first at a level of municipalities and secondly on the level of individual zones. The land use strategy in this scenario affects the number of jobs across zones within the municipalities, but at a municipality level the number of jobs is consistent with the reference case. For municipalities that are not within proximity of a railway station, the distribution of employment across zones remains as in the reference scenario.

*Combined public transport oriented land use scenario (combined scenario)*: The Public transport based housing scenario and the Rail based employment scenario are combined into a single land use scenario. At a municipality level urban areas, with good access to public transport, will benefit of additional developments affecting the number of residents and employments. At the contrary more rural municipalities, with lower quality access to public transport, will face a lower population and employment compared to the reference scenario. At a zonal level residential developments are located at well accessible larger public transport locations and jobs are located very closely to existing public transport nodes.

*Compact city scenario*: In the aforementioned public transport based scenarios the distribution of new dwellings over municipalities is modified compared to the reference scenario. An important impact of building at well accessible public transport locations is that the cities receive more new dwellings at the cost of the rural areas. This raises discussion whether a general compact city strategy generates the same results as a more refined public transport oriented land use strategy. The Compact city scenario simulates the result of this redistribution of housing towards the cities without the restriction to zones with a high public transport accessibility. For each municipality the total number of new dwellings is kept equal to the Public transport based housing scenario, but within the municipalities the new dwellings are distributed following the Reference scenario

## 5. Land-use, transport and accessibility results

This section presents the land-use and transport changes as results of the land-use scenarios. A broad set of indicators has been calculated to describe, visualize and evaluate the outcomes of the scenarios. In this paper we focus on accessibility and different type of accessibility indicators. However as a starting point more basic land-use and transport findings will be discussed.

Please note that in all scenarios there have been no changes in the level of service of the public transport system and the aim is to isolate the potential impacts of land-use strategies. It is realized that there are potential synergy effects between land-use and transport policies, meaning that 1 plus 1 is more than two, but these benefits are considered to be outside the scope of this study.

### Land use

Land-use changes can be distinguished by exogenous, part of the scenario input, and endogenous changes as calculated by the model. In all scenarios development of new residential buildings is exogenous what-if type of input and the endogenous module for residential constructions is not used. In the reference scenario the population in the study area increases by 8.9 percent, in the period 2010-2030, and employment is forecasted by 1.8 percent. Both increases are above national average and in combination with a diminishing average household the increase in housing demand is estimated at 200 thousand houses.

In three of the four scenarios namely, the housing-, combined- and compact city scenario, part of the housing demand, around 80 thousand houses, is realized at different location than in the reference scenario. In the housing and combined scenario these houses are realized at good accessible public transport locations, following the geographical accessibility indicator (see figure 3), and in the compact city scenario these houses are more generally developed all over the urban areas. In all scenarios, except the employment scenario, the population in the urban areas is increasing compared to the reference scenario and the distribution of employment is modelled endogenously influenced by the population developments. In the employment scenario the population development is similar to the reference case but in this scenario employment development within an urban area is concentrated at station locations with a maximum distance of 500 m to a train station. Compared to the reference case around 20 thousand jobs are concentrated at station locations from other locations all over the urban area. Agricultural, industrial and logistic jobs are excluded from this concentration strategy.

**Transport: Scenario effects on mode choice**

The land-use developments in all four scenarios have a positive impact on the number of tours by train and other public transport (such as bus, tram and metro) and a negative impact on the number of tours by car. The impact on km travelled by mode is rather similar with an increasing share for the train and a decreasing share for the car (both driver and passenger). The effect on other public transport is more complicated as this mode shows an increase in number of tours but a decrease in average travel distances and as a result also a decrease in the overall number of km travelled by this mode. On longer distances there is a switch from the market share of other public transport towards the train. In the housing-, combined- and compact city scenario more people are living in urban areas with good access to train stations while in the reference scenario other public transport, mainly the bus, plays a more dominant role in the more rural areas. The employment scenario does not assume a change in residential locations and show a positive impact on both the number of tours and km by other public transport.

*Table 1: Effect on mode shares in number of tours compared to reference scenario*

| Scenario | Train | Other PT | Car driver | Car passenger | Bicycle | Walk |
|---|---|---|---|---|---|---|
| Public transport based housing | +2.0% | +1.3% | -0.9% | -0.6% | +0.7% | -0.4% |
| Rail based employment | +1.2% | +0.6% | -0.3% | -0.2% | +0.2% | -0.4% |
| Combined public transport oriented | +3.9% | +1.7% | -1.2% | -0.9% | +0.8% | -1.0% |
| Compact city | +1.8% | +1.1% | -0.7% | -0.5% | +0.5% | -0.6% |

*Table 2: Effect on km mode shares compared to reference scenario*

| Scenario | Train | Other PT | Car driver | Car passenger | Bicycle | Walk |
|---|---|---|---|---|---|---|
| Public transport based housing | +1.6% | -0.4% | -0.8% | -0.3% | +1.1% | -0.6% |
| Rail based employment | +0.8% | +0.5% | -0.4% | -0.3% | +0.5% | +0.1% |
| Combined public transport oriented | +3.1% | -0.3% | -1.4% | -1.0% | +1.5% | -0.5% |
| Compact city | +1.4% | -0.4% | -0.7% | -0.3% | +1.0% | -0.9% |

**Network accessibility measure: Road congestion**

Table 3 presents that concentration of new housing in urban areas and/or around public transport locations, like in the housing, combined and compact city scenario, results in lower congestion both on trunk roads a well as other roads compared to the reference scenario. Reasons are shorter average travel distances and a shift from car to other modes of transport. Furthermore increased residential development in urban areas has a balancing impact on the employment-workforce ratio, which is in general above 1 in urban areas and lower than 1 in rural areas. Misbalances in this ratio are one of the drivers of commuting flows.

*Table 3: Effect on congestion time compared to reference scenario in 2030*

| Scenario | AM peak | | PM peak | |
|---|---|---|---|---|
| | Trunk roads | Other roads | Trunk roads | Other roads |
| Public transport based housing | -1.6% | -8.8% | -1.2% | -5.9% |
| Rail based employment | -0.5% | +4.3% | -0.6% | +5.8% |
| Combined public transport oriented | -1.2% | -5.1% | -3.2% | -2.2% |
| Compact city | -1.7% | -6.5% | -0.6% | -5.2% |

The rail based employment scenario has a negative impact on the congestion on local roads in the study area. The overall impact on congestion in this scenario is the sum of positive and negative impacts. The positive, congestion reducing, impact is the modal shift effect with less car transport. However this impact is less strong than the negative impact of a further concentration of employment. This concentration of jobs, even at locations near railway stations, will attract additional car travel using already highly utilized roads. This negative impact of concentration on congestion in this scenario is stronger than the mode shift impact.

**Geographic accessibility indicator: public transport accessibility**

The geographical accessibility indicator for the accessibility of jobs by public transport will be illustrated for the public transport based housing scenario. Figure 4 compares the accessibility of jobs by public transport between the housing scenario and the reference scenario for 2030.

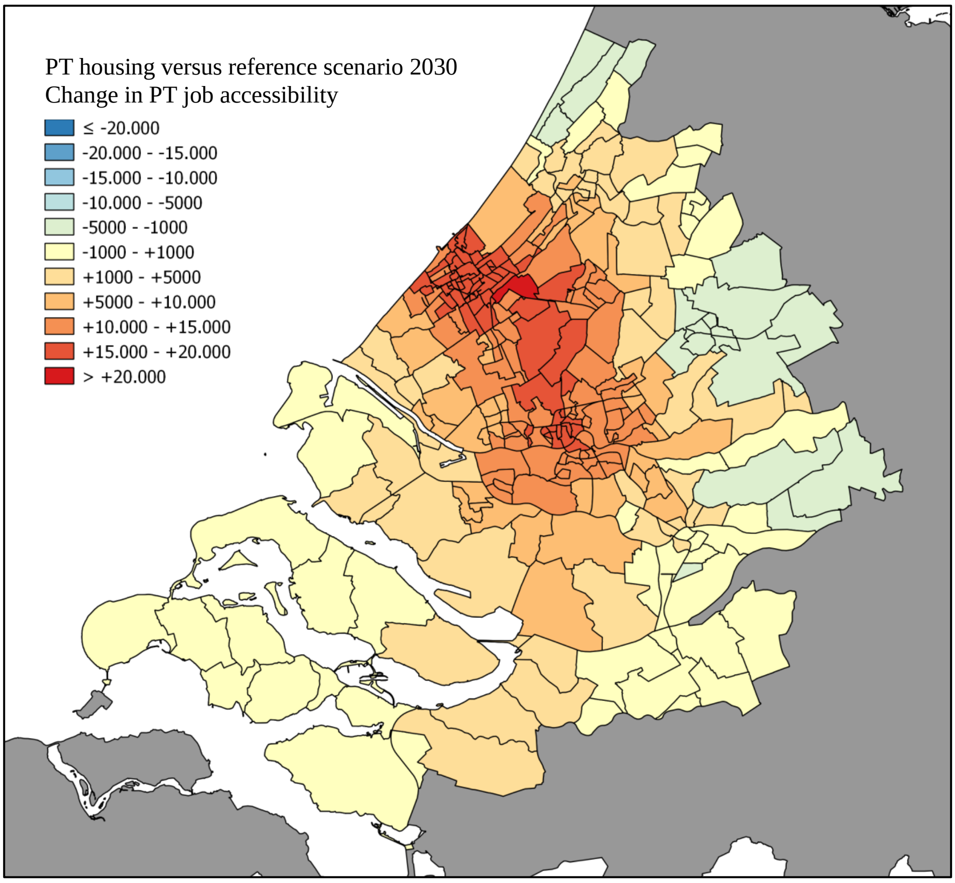


*Figure 4: difference in Public transport accessibility to employment between housing scenario and reference scenario 2030*

The geographical accessibility indicator consists of a travel speed and proximity component. The differences in accessibility between the two scenarios are the result of differences in proximity between the scenarios. The concentration of the development of new houses and associated endogenous response of jobs in well accessible public transport locations has resulted in an improved accessibility for the core area of the study region including The Hague, Rotterdam and the municipalities in between these two cities. Some areas in the fringe of the study region face a decline in accessible. Overall the accessibility of jobs by PT is for most people higher in the housing scenario than in the reference scenario.

**A economic-geographic accessibility indicator: consumer benefits**

The accessibility benefits in monetary terms can be calculated by the so-called logsum accessibility method. The monetary benefits calculated by this method include changes in travel time as well as changes in proximity. It is therefore possible that a land use strategy with modest impacts on travel times can have a substantial impact on proximity and therefore on the accessibility benefits. Table 4 shows for example that the housing scenario, as discussed by the geographical accessibility indicator above, has substantial accessibility benefits. The benefits are primarily resulting from an improved proximity and in addition the reductions in congestion levels have a positive impact as well.

*Table 4: Logsum accessibility benefits compared to reference scenario (mln. € per year, 2010 price level)*

| Scenario | Commuting | Business | Other | Total |
|---|---|---|---|---|
| Public transport based housing | 69 | 17 | 42 | 129 |
| Rail based employment | -4 | -1 | -2 | -7 |
| Combined public transport oriented | 73 | 24 | 67 | 165 |
| Compact city | 48 | 8 | 20 | 76 |

The table presents that three of the four scenarios have substantial accessibility benefits (including proximity) in monetary terms. Comparing these three scenarios indicates that a more tailor-made land use policy, oriented at public transport locations, have additional benefits above a generic compact city strategy. Further the combined scenario demonstrates that a mixture of functions has additional benefits above the focus on one aspect. The employment scenario shows that too much concentration of one function can result in negative accessibility benefits, even if this activity is concentrated at a well accessible location.

Logsum accessibility measures are also capable of presenting the results by population segments. It is therefore possible to focus on the impact for specific groups who might benefit or suffer from a certain policy strategy. As an example shows table 5Table the results of the combined public transport scenario for three selected segments who might benefit strongly of PT strategies, namely: students, workers not owning a car and elderly. All three show, as expected, positive accessibility effects for commuting, business and other tours.

Table 5: Logsum accessibility benefits for selected person types, Combined public transport oriented scenario compared to reference scenario (mln. € per year, 2010 price level)

| Scenario | Commuting | Business | Other | Total |
|---|---|---|---|---|
| Student | 4 | 2 | 18 | 25 |
| Working, without car | 23 | 4 | 6 | 33 |
| Elderly | 1 | 2 | 10 | 12 |
| All person types | 73 | 24 | 67 | 165 |

## 6 Conclusions

The paper demonstrates that the conclusions regarding the effectiveness of the land use policies are very much dependent on the type of indicators included in the evaluation.

The main results of the land use scenarios are that modest positive results are calculated for the mode shift towards the public transport modes in combination with a modest reduction in average travel distances. Regarding congestion the mixture is more complex and origin oriented and combined strategies result in reduction of the congestion levels for the region. However, the sensitivity analysis for concentration of jobs at station locations results in less car km but an increased congestion due to additional traffic on already congested roads. But most prominent results are the substantial accessibility benefits (including proximity) in monetary terms of the mixed land-use strategies. The analysis also indicates that a more tailor-made land-use policy, oriented at public transport locations, have additional benefits above a generic compact city strategy. Finally the paper demonstrates that the impacts will be different for various socio-economic population segments.

The message to policy makers is that land-use strategies are a valuable instrument to influence accessibility within a region. However to evaluate the effectiveness of land use policies it is needed to complement the existing accessibility indicators with accessibility indicators measuring proximity as well. This study presents an example of how such ambition can be realized in practice by applying an operational model and indicators.

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