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# Adapting spatial conditions to reduce car dependency in mid-sized 'post growth' European city regions: The case of South Limburg, Netherlands

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## ABSTRACT

Defining Car Dependency (CD) as a lack of travel choices to daily destinations, this paper explores how possible changes in the spatial context of a post-growth, mid-sized urban region can affect the conditions for CD. In the most rural parts of the region distances to schools and shops will exceed walking and biking distances. Distances to work will increase on average. With the bicycle and e-bicycle fewer jobs will be accessible, although the e-bicycle shows greater reach than public transport. Despite the population and job decline, more jobs will be accessible by car, as a result of current investments in road infrastructure. This is enhanced by the ongoing development of economic centers along the highways, resulting in a growing mismatch between the rail system and the spatial economic structure of the region.

We developed policy scenarios to explore spatial conditions for reducing car-dependence within the region. Intensifying land uses along the axes of public transport has a limited effect in a shrinking region. Introducing direct and fast public transport connections to the existing economic centers however does have effect. We tested two transport policy scenarios, one based on improving Inter City (IC) rail services on the existing rail network and one based on creating Bus Rapid Transit (BRT) services on the existing highways. The IC- scenario makes more jobs accessible outside the current daily urban system, while the BRT- scenario intensifies relations within the region. With regards to CD 'three worlds' seem to be emerging in this medium-sized, 'post growth' region. Rural areas (10–15% of the population in 2030) are increasingly becoming completely car dependent, suburban areas (65 –75% of the population) are offering travel choices to daily amenities, but increasingly becoming more car dependent in relation to jobs, and central urban areas (15–20% of the population) are providing travel choices to amenities as well as jobs, but only under the condition of improving the regional public transport system.

## 1. Introduction

Adapting cities and regions to facilitate car use is not only a technical issue, it has also made society heavily car dependent, increasing its vulnerability to adverse changes in social, economic, environmental or other spheres (Jeekel, 2013; Wiersma et al., 2016; Dennis and Urry, 2009; Shyi-Min, 2016; Lu, 2015). In the fields of policy and research this has led to the question of how to reduce dependency on cars. Several authors have analyzed the driving forces of car dependency (CD). Some, such as Jeekel (Jeekel, 2013) and Harms (Harms, 2008), see the car as an answer to the needs of 'modern life': increasingly complex activity patterns, tight time schedules, multi-purpose trips etc. In other words, the car is seen by these authors as an essential component of the 'mobility capital' which modern societies demand of their members, or what has been termed 'motility' (Kaufmann et al., 2004). Others, notably Handy (Handy, 1993) and Urry (Urry, 2004), while not denying this need for motility, argue that, because of the car's specific characteristics, like low capacity and high speed, and requirements, like parking space and road infrastructure, it has caused a 'cycle of CD', i.e. the increasing dispersal of residential areas, amenities and economic activities, making car use a necessity, not an option. In other words, it is not the requirements of modern life but the spatial conditions co-determined by increasing car use that make society car dependent (Wiersma et al., 2016).

The following question arises: Can we change the spatial conditions of our cities and regions to reduce car dependence, and can we even somehow reverse this cycle of dependence? Considerable research examines the relation between spatial context and car use (Newman

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and Kenworthy, 1999; Kenworthy and Laube, 1999; Wegener and Furst, 1999; Van Wee et al., 2009; Bagley and Mokhtarian, 2001; Litman and Laube, 2002). Spatial features advocated to reduce car use include compact cities, high residential and employment densities, mixed land use, availability of public transport, transit-oriented development and others.

A first observation with respect to these studies is, however, that car *use* is not necessarily related to car *dependency*. Sometimes people choose to use a car, even though alternative transport modes are available. Conversely, in many cities policies are introduced to discourage car use and promote alternative transport modes like cycling and public transport, in spite of unfavorable spatial conditions, like dispersal of jobs and amenities. CD needs to be defined more rigorously. Jeekel (Jeekel, 2013) and Jones (Jones, 2011) distinguish real (objective) car dependency from emotional (subjective) car dependency. Subjective car dependency can be a matter of attitudes, habit or just of lack of information about alternative transport modes, but objective car dependency is simply having no acceptable alternative in terms of travel time and costs (Jones, 2011; Golob et al., 1979). This distinction is important, because in light of the discussion on the risks of car dependency, it is the availability of alternatives that matters – more so than whether or not these alternatives are used. Following Jeekel (Jeekel, 2013) we describe car dependency as the situation in which for a trip there is no alternative transport mode available (or only a greatly inferior alternative).

Second, many studies assume that the desired changes in the spatial context can occur from planning decisions about new developments, for example by planning new developments close to existing transit, so-called transit-oriented development (TOD), or by creating increasing densities within existing cities (Rogers, 1997; Girardet, 2004; Suzuki et al., 2013; Janssen-Jansen and Smit, 2013). However, in that respect we need to distinguish between 'growth' and 'post-growth' environments. Growth environments, mostly found in big cities and metropolitan areas in developed countries and especially in the emerging economies in Asia, Africa and Latin America, are experiencing population and job growth and will need space for expansion. New developments can significantly change their spatial context. Post-growth environments, on the other hand, are experiencing population and employment stabilization or even decline, with stabilization in some parts causing further decline in other parts of the region. In these environments the potential for introducing substantial changes in the spatial context is greatly constrained. In particular, in large parts of Europe, mid-sized urban regions are increasingly facing post-growth conditions. As most people in Europe live in mid-sized urban regions (Giffinger and Meyers, 2007), this is a particularly relevant context. Little research has been conducted on how changes in the spatial context of mid-sized, post-growth European areas can affect car dependency. Our study seeks to fill this gap.

We will examine the following research questions: How does the current spatial context, i.e. the combined pattern of land use and transport, shape conditions for CD in mid-sized, post growth European regions? What is the potential for change of this context in the coming decades, and which policy measures could be effective for reducing CD?

In Section 2 we will address the choice of the case, our definition of CD and research methods. In Section 3 we will present our findings, followed by the conclusions and reflections in Section 4.

## 2. Case, definitions and research method

### 2.1. Case study

Our study focuses on South Limburg, a mid-sized and post growth urban region in the south of the Netherlands (see Fig. 1). Like many European urban regions it is polycentric, with no dominant node (Grünfeld, 2010). This causes complex, multi-directional, daily mobility patterns, much stronger than in monocentric cities of comparable size.

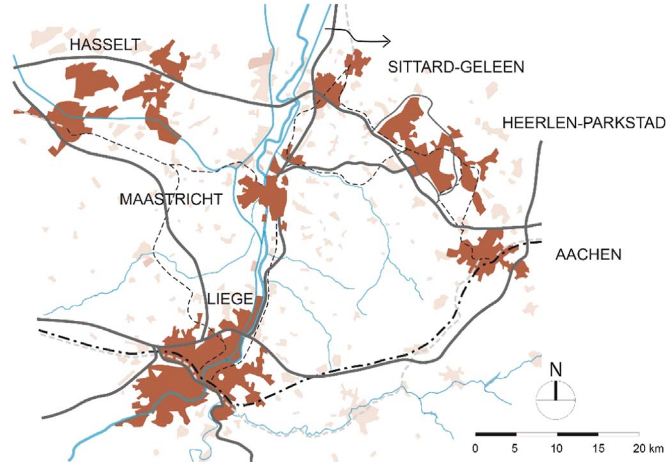


**Fig. 1.** South Limburg, cross-border cities and the network of highways and railways.

South Limburg is an urban region with a population of about 610,000 inhabitants, expected to decrease to 575,000 in 2030. There are three mid-sized cities: Heerlen and Sittard, former mining centers with a diffuse and spread out urban pattern, and the compact historic town of Maastricht. Of these cities Maastricht is expected to stabilize in population at around 120,000, mainly due to the growing student population. The other two are expected to shrink. Across the national borders the cities of Hasselt, Liege, and Aachen are situated within 30 km of Maastricht, potentially being part of the daily urban system of the region. Although to date cross-border commuting has been restrained by cultural and institutional barriers, in this study we have assumed that the cities of Aachen and Hasselt (250,000 and 90,000 inhabitants respectively) will increasingly become more integrated in the daily urban system of South Limburg in the coming decades. Regional amenities and knowledge jobs are traditionally found in the inner cities, but in the past decades they increasingly have also been located in economic centers near highway exits with no rail access in the periphery of the urban areas, thus creating a mismatch between the rail system and the economic structure of the region. Average population densities per municipality vary between 1,000–2,500 people per square kilometer in urban areas, 500–1,000 in suburban areas, 250–500 in semi-rural and below 250 in rural areas.

### 2.2. Defining CD

As stated in the introduction, CD is related to the lack of adequate alternative transport modes to the car. This can be seen as a form of (or lack of) accessibility, by Geurs and Van Wee (Geurs and Van Wee, 2013) described as 'the extent to which land use and transport systems (1) enable groups or individuals to reach activities or destinations by means of a combination of transport modes at various times of the day; and (2) allow companies, public facilities and other places of activity to receive people, goods and information at various times of the day'. However, as Geurs and Van Wee (Geurs and Van Wee, 2013) point out, accessibility has not only a spatial but also a temporal component (i.e. when is accessibility needed) and an individual one (commuters, traveller for the purpose of a social visit, etc.). With regards to constraints in the availability of adequate alternative transports modes to the car, Jones (Jones, 2011) distinguishes 'structural constraints', 'hard-wired' into the existing land use and transport system and 'situational constraints', being person or trip specific, e.g. transporting people with mobility restrictions or large and heavy items. In principle, for a large part of these trips one does not need to own a car and can rent one or share one when needed (Cervero et al., 2006; Baptista et al., 2014). On the other hand, for daily trips like commuting or bringing children to school, renting a car is in most cases no option (Cervero et al., 2006; Baptista et al., 2014). People who have daily returning mobility patterns and are subject to the above mentioned 'structural constraints' will need a car on a daily basis and tend to own it. The evidence shows that once people own a car, they tend to use it also for trips where a choice is possible (Van Acker et al., 2010; Harms, 2003). In this study this group, needing a car on a daily basis, having no transport alternative available, is the one considered to be CD. A final point is on what basis a transport alternative to the car can be considered acceptable. While there are many factors at play (Van Acker et al., 2010) in our developed, affluent societies, acceptable travel time is a key factor (Bertolini and le Clercq, 2003; Van 't Hart, 2012). In light of the above, we further refined our definition of car dependency as 'the situation in which there is no – or only a greatly inferior – alternative transport mode available in terms of travel time for trips to daily destinations'. We distinguish two types of daily destinations: daily amenities and jobs.

### 2.3. Measuring accessibility

#### 2.3.1. Accessibility of daily amenities

Considerable research has been done on the accessibility of daily amenities for the Netherlands as a whole (Wiersma et al., 2016; Steenbekkers and Vermeij, 2013; Centraal Bureau voor Statistiek). It appears that at present in the Netherlands generally taken daily amenities are located within walking or cycling distance of homes, even in rural areas, and thus do not contribute to CD. However, this could change in the future due to the disappearance and/or spatial concentration of amenities following the shrinking of the population. We will use data from the municipalities of South Limburg in order to get a view of these possible changes.

#### 2.3.2. Accessibility of jobs

For job accessibility there is no univocal relation between travel time and distance. While the former shows some stability, the latter is much more varied (Mokhtarian and Chen, 2004). Research in the Netherlands shows that between 1985 and 2008 the average distance between home and work has increased by 1,5 times, up to 17 km, while travel time increased by 1,2 times, reaching almost 30 min one way (Kennisinstituut voor Mobiliteitsbeldeid KiM, 2010). Based on these findings, in order to explore the level of CD in relation to jobs we will compare the accessibility of jobs by different transport modes within 30 min of travel time, door to door. Alternative transport modes to jobs are bicycle, electric motor aided bicycle (*e*-bicycle) and public transport (we assume walking is rarely a serious option for this type of travel). Based on the observation that people in the Netherlands are prepared to travel 45 min by public transport (Centraal Bureau voor Statistiek), we also considered 45 min by public transport as an acceptable alternative for a car trip of 30 min. To make these computations, we used the multimodal transport model of the Province of Limburg. This is a gravity based model, which allows for comparison of how many people can reach jobs by different transport modes within a given travel time. This transport model is based on a database of the road network, open street map, and the existing timetables of public transport. Travel times by car were calculated for the morning peak period, and include effects of possible congestion. Travel times for public transport include waiting time and time needed to travel to and from the station. An additional 'transfer penalty', due to the more than proportional negative perception of time spent transferring between different public transport services, was not included in the model. This accessibility analysis was carried out using a potential accessibility measurement with a distance decay or impedance function, i.e. closer opportunities are weighed more strongly than more distant ones. The travel time of 30 min indicates the turning point in our impedance functions; where a job is weighted precisely as one job. Jobs that can be reached within less than 30 min are weighted proportionally higher than one, and jobs that are further away than 30 min are weighted proportionally less than one.

#### 2.3.3. Accessibility of economic centers

We will first explore how many people can reach jobs in the main economic centers in the region by different transport modes, assuming that the companies and amenities situated there are more regionally oriented. The Structural Plan for South Limburg (Gedeputeerde Staten Limburg, 2013) identifies 22 centers with a regional or even national importance, including cross-border centers, each having different spatial conditions for CD. We distinguished 'red' centers, within 500 m of local railway stations or 1 km of InterCity stations (IC stations), and 'blue' and 'green' centers, not within reach of railway stations but within 500 m from an highway exit or trunk road. Blue centers are multi-functional campuses, with education, research, business services or health care functions, and green centers are mono-functional industrial parks.

#### 2.3.4. Travel choices from homes to jobs

Having an insight in the accessibility by different modes of economic centers, however, does not give us a clear insight in how this relates to the differences in the levels of CD in urban, suburban and rural areas. Therefore, we will also compare travel times by different transport modes from residential areas to jobs. We call this 'travel choice' from homes. The 'travel choice score' indicates the car dependency of a residential area by showing the number of jobs accessible by public transport or bicycle, compared to the number of jobs accessible by car within the same travel time. We made a separate analysis of urban residential areas, defined as being located in cities and within 1 km from an IC station.

### 2.4. Job accessibility scenarios

We have explored the possible changes in land use and transport network up to 2030. First, we have identified the 'autonomous' changes, based on expected demographic developments and effects of current investments in infrastructure. We call this the 'business as usual' (BAU) scenario. In addition, we developed 'policy scenarios', showing measures that aim to realize more travel choices to daily destinations. These scenarios explore the maximum of changes conceivable within the current policy framework of a shrinking region: no new developments or major investments in infrastructure; trying to avoid housing and job vacancies in some areas while accepting them elsewhere; and trying to optimize the use of existing infrastructure. These scenarios were developed in consultation with local policy-makers. We distinguished Transit-oriented Development (TOD) and Development-oriented Transit (DOT) scenarios (Janssen-Jansen and Smit, 2013). The TOD scenario focuses on changes in the land use pattern to make land use more consistent with the existing public transport network (similar to 'adaptive city' in Cervero (Cervero, 1996). The DOT focuses on adapting the public transport network to the existing land uses (similar to 'adaptive transit' in Cervero (Cervero, 1996)).

#### 2.4.1. Changes in land use (TOD)

We will describe the current (2008) distribution of populations and jobs and their possible redistributions under a BAU scenario (2030), using socio-economic data obtained from the Province of Limburg. To explore the changes needed to shape spatial conditions for less CD, we developed a TOD (2030) scenario concentrating jobs in cities and current red centers (see definition above). In this scenario we foresaw a stabilization of the number of jobs in central cities and station areas, which would create vacancies in other areas within the same total number of jobs under the BAU scenario (2030). Trying to persuade or tempt people to move their residence to central urban areas might be more difficult, as in many cases they are emotionally and socially attached to their current surroundings as well as financially tied to their homes, especially as increasing vacancies may slash home values. However, following the current policy goals of the Province of

Limburg, we assumed in the model a concentration of an additional 4000 people in central residential areas**,** resulting in additional decrease in other areas. This figure is based on the potential building programs in inner city areas in South Limburg. The implementation of this scenario would require strong policy, but will be in accordance with the Structural Plan for South Limburg (Gedeputeerde Staten Limburg, 2013).

#### 2.4.2. Changes in the transport network (DOT)

We identified the current transport network (2008) and the network with improvements on road infrastructure and public transport underway (BAU scenario 2030) and analyzed its effects on the accessibility of jobs by all transport modes, including the potential use of the e-bicycle using the existing road network. We also added a 'RAIL' scenario, an existing long term plan to improve the rail network, especially cross-border connections (Gedeputeerde Staten Limburg, 2013). The plan enjoys strong political support but the implementation funds are currently lacking. To further improve the competitiveness with the car in daily commuting we added two scenarios: (1) the 'IC+ scenario', improving the RAIL scenario by adding extra IC services to the red centers (raising frequencies from 2 to 4 per hour), in this way shortening average waiting and travel times, but with necessary transfers to blue centers; and (2) the 'BRT scenario', supplementing the RAIL scenario by introducing bus services using the existing highway system, with direct access to the existing blue centers (4 per hour), thus avoiding transfers to these centers.

## 3. Findings

### 3.1. Possible changes in the distribution of jobs and population in South Limburg

Table 1 shows the distribution of the population, divided in central urban areas within 1 km from an IC station (with more than 2500 inhabitants/km$^2$), urban and suburban areas further than 1 km from an IC station (with 500–2500 inhabitants/km$^2$), and semi-rural and rural areas (with less than 500 inhabitants/km$^2$). It appears that while the population in South Limburg shrinks from 610,000 inhabitants in 2008 ('current situation') to 575,000 in 2030 as a result of autonomous changes ('BAU'), its distribution doesn't change substantially – even in the TOD scenario, which foresees a policy-driven concentration of the population in central urban areas.

Table 2 shows the distribution of jobs in the different land use scenarios. In all scenarios only about a half of the jobs in South Limburg are situated in economic centers. This means that improvements in the network of railways and highway infrastructure directly affect the accessibility of only half of the jobs. Approximately 50% of this half have direct rail access (red centers), while the other half have direct highway access (blue and green centers). In the BAU scenario (2030), which describes the autonomous changes, the share of jobs in blue centers increases. The policy-driven TOD scenario, concentrating jobs in station areas and inner cities, would however result in a 7% shift of jobs toward these centers. Currently as well as in 2030 there appears to be a mismatch between the rail network and the location of economic centers.

**Table 1.**
Distribution of population in the different land use scenarios.

| | *Central urban areas* | *Suburban areas* | *Rural areas* |
|---|---|---|---|
| ***2008*** *(current)* | *17%* | *62%* | *21%* |
| ***2030*** *(BAU)* | *17%* | *63%* | *20%* |
| ***2030*** *(TOD)* | *18%* | *62%* | *20%* |

### 3.2. Accessibility of amenities in 2030

A comprehensive study on the situation of the inhabitants of the villages in the Netherlands (Bertolini and le Clercq, 2003) shows that even in small remote villages in the Netherlands, a supermarket and a primary school are provided within an average distance of 1 km, which can be considered an acceptable distance for walking or cycling, and thus an acceptable alternative for the car. This is confirmed by data from Statistics Netherlands (CBS) (Centraal Bureau voor Statistiek). It should be noted however that only residents of large towns, suburban and urban areas have a choice between several shops and schools within walking distance (Wiersma et al., 2016; Centraal Bureau voor Statistiek). In some rural areas in South Limburg the average distance to shops (large supermarkets) is over 1 km (possibly too long to walk), but still below 2.5 km (considered an acceptable bicycle distance). Since 2008 this figure has remained more or less stable (Centraal Bureau voor Statistiek). Although, due to shrinking of the population and the general upscaling of retail, the number of shops is still decreasing, the pattern of larger supermarkets is not expected to change significantly. This result has strongly been influenced by policy choices ensuring an even distribution of primary services over the past decades. For instance, since the 1960s the Dutch national government banned the development of large shopping malls outside existing urban centers. This policy is not expected to change significantly, at least for the time being. However, as the population is not only declining, but also aging, this is expected to lead to the disappearance and/or spatial concentration of primary schools, thus increasing the average distances to schools in the periphery over 1 and in some cases over 2,5 km. This will affect an expected 10–15% of the total population (Centraal Bureau voor Statistiek; Van Til et al., 2007; Public Result, 2015).

The overall picture of accessibility of amenities shows that people living in the thinly populated peripheral areas (10–15% of the population) will become more CD, especially in relation to primary schools. However, it seems that, given the average densities in a mid-sized post-growth region, there still will be enough support for reaching an array of daily amenities within an average distance of 1 km for 85–90% of the population.

### 3.3. Accessibility of jobs in economic centers

#### 3.3.1. Accessibility of jobs in centers by different transport modes

Measuring the catchment area around economic centers of 30 min travel time by different transport modes gives an indication of their multimodal accessibility. To explore the possible effect of improving public transport on the accessibility of jobs in centers we distinguished the following DOT scenarios:

- Transit 2008 30 and 45 min: Number of inhabitants reaching jobs in centers in 30, respectively 45 min, current situation
- Transit 2030 BAU 30 and 45 min: Number of inhabitants reaching jobs in centers in 30, respectively 45 min, following the autonomous development of jobs and population
- Transit 2013 RAIL 45 min: Number of inhabitants reaching jobs in centers in 45 min, as a result of existing plans for improving rail services.
- Transit 2013 BRT 45 min: Number of inhabitants reaching jobs in centers in 45 min, as a result of introducing BRT on highways
- Transit 2013 IC+45 min: Number of inhabitants reaching jobs in centers in 45 min, as a result of doubling the frequency of Intercity-services.

The TOD scenario is not shown here, because the shift in the distribution of the population towards urban areas from 17–18% has no substantial effect on the accessibility of centers.

Fig. 2 shows that the car is by far the most competitive transport mode for accessing economic centers, in both the current (2008) and

**Table 2.**
Distribution of jobs in the different land use scenarios.

| | *All centers* | ***Red centers*** *(station areas and inner cities)* | ***Blue centers*** *(peripheral campuses)* | ***Green centers*** *(industrial areas)* |
|---|---|---|---|---|
| ***2008*** *(current)* | *47%* | *24%* | *15%* | *8%* |
| ***2030*** *(BAU)* | *50%* | *23%* | *18%* | *10%* |
| ***2030*** *(TOD)* | *56%* | *31%* | *16%* | *9%* |

future (2030) situations, even when allowing for 45 min travel time for public transport, compared to 30 min for car. It also shows that within 30 min travel time the second best transport mode is the e-bicycle. The RAIL scenario, combined with IC+ or with BRT, shows more or less the same total effects.

Fig. 3 shows that relative to the situation in 2008 in the BAU (2030) scenario the position of the car improves, public transport more or less stabilizes, but bicycle and e-bicycle fall, meaning that in 2030 fewer people can reach centers within 30 min travel time by bicycle or e-bicycle than in 2008. The decrease in the population density could explain this result. However, more people can reach the centers by car, caused by current improvements in the road infrastructure. It also shows that in the RAIL scenario, combined with BRT or IC+, substantially more people (20% more) can reach the centers by public transport, compared to BAU (2030).

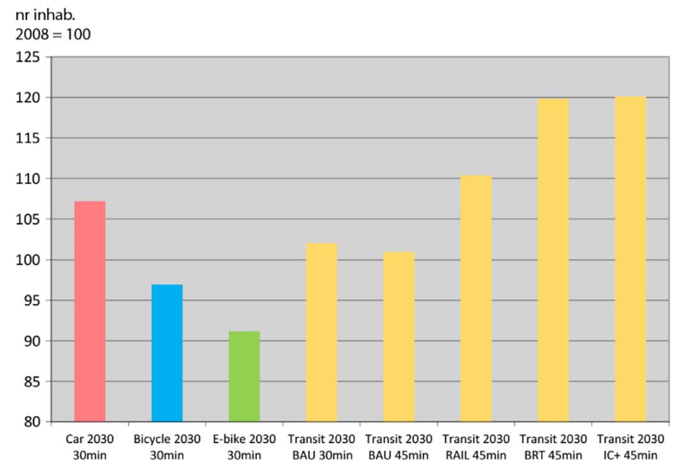


**Fig. 3.** Accessibility of centers in BAU (2030), and in RAIL, BRT and IC+(2030) scenarios: number of inhabitants that can reach centers by different transport modes in 30 or 45 min, 2008=100.

### *3.3.2. Accessibility of jobs in centers, per type of center*

Figs. 2 and 3 showed the average accessibility of all centers. We also analyzed the effect of the scenarios on the different types (red, blue and green) of centers.

Figs. 4 and 5 show that blue centers, with campuses and regional amenities outside urban areas profit most from the BRT, and red centers, in the inner cities near station areas profit most from the IC+. Furthermore, from our catchment area studies (not shown here) it appears that in the BRT scenario the blue centers are more accessible to people within the region of South Limburg, while in the IC+ scenario the red centers are more accessible to people living in the central urban areas of the cross-border city of Hasselt.

While the multimodal accessibility of the centers was shown in the previous sections, we examine here the 'mirror image', the travel choices from residential areas. It appears that the travel choice score (i.e. the percentage of jobs accessible by public transport relative to car) of all residential areas in relation to the accessibility of jobs in centers (left side of Fig. 6) in the BAU scenario is about 45%, and can rise to a maximum of about 50% in the BRT scenario. However, for people living in urban areas, shown on the right side of Fig. 6, the scenario with the highest travel choice score is the IC+ , in which the score increases from about 70% in the BAU scenario to a maximum of almost 90% in the IC+ scenario. From our isochrone studies (not shown here)

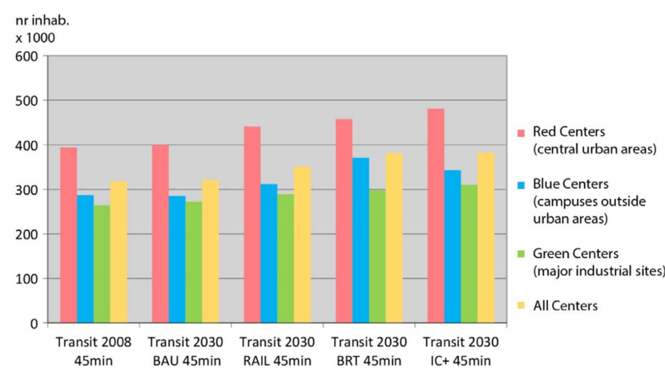


**Fig. 4.** Accessibility of centers in scenarios: absolute number of inhabitants (in 1000's) that can reach centers by public transport in 45 min, per type of center.

it appears that this increase in the number of accessible jobs in economic centers in the IC+ scenario is also partly affecting people living in the cross-border urban areas. The BRT scenario on the

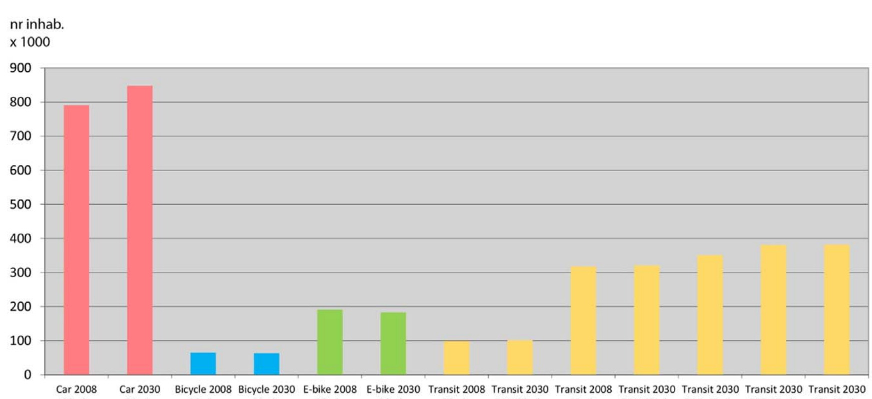


**Fig. 2.** Accessibility of centers Current (2008), BAU (2030) and scenarios RAIL, BRT and IC+(2030): number of inhabitants (in 1000 s) that can reach centers by different transport modes within 30–45 min.

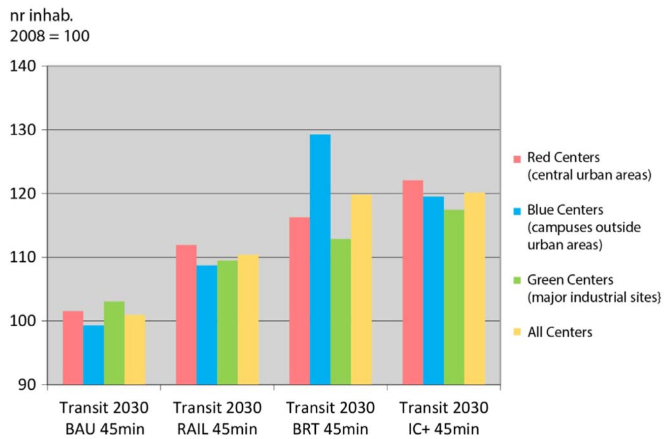


**Fig. 5.** Accessibility of centers in scenario's: number of inhabitants that can reach centers by public transport in 45 min, per type of center, 2008=100.

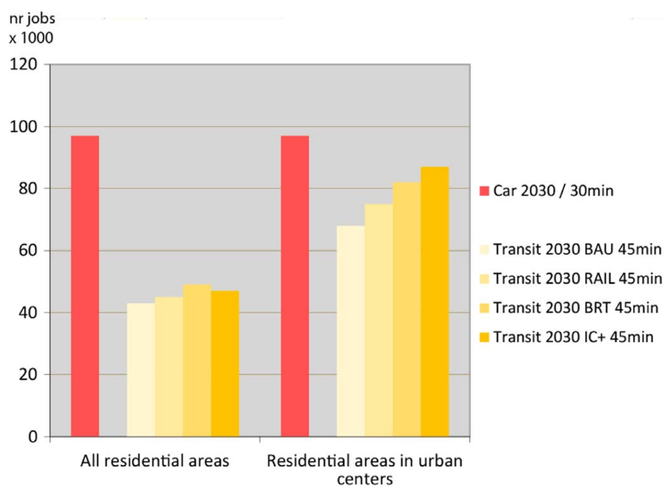


**Fig. 6.** Number of jobs in 1000's, accessible in centers from all residential areas and from urban residential areas within 30 min by car and 45 min by public transport in scenarios 2030.

contrary mostly benefits people living in South Limburg, in urban, but also some suburban areas in the proximity of blue centers.

### *3.4. Possible changes in the travel choices from residential areas*

While the multimodal accessibility of the centers was shown in the previous sections, we examine here the 'mirror image', the travel choices from residential areas. It appears that the travel choice score (i.e. the percentage of jobs accessible by public transport relative to car) of *all* residential areas in relation to the accessibility of jobs in centers (left side of graphic 6) in the BAU scenario (Transit 2030 45 min) is about 45%, and can rise to a maximum of about 50% in the BRT scenario. However, for people living in urban areas, shown on the right side of the graphic, the scenario with the highest travel choice score is the IC+: the score increases from about 70% in the BAU scenario to a maximum of almost 90% in the IC+ scenario. From our catchment area studies (not shown here) it appears that this increase in the number of accessible jobs in economic centers in the IC+ scenario is also partly affecting people living in the cross-border urban areas. The BRT scenario on the contrary mostly benefits people living in South Limburg, in urban, but also some suburban areas in the proximity of blue centers.

## 4. Conclusions and reflections

### *4.1. Conclusions*

In this paper we explored the current and the possible future spatial conditions for car dependency (CD) in mid-sized, post-growth regions, with South Limburg as a case study. The region's population decline has two effects in relation to CD. In areas with low densities, villages and semi-rural areas in its periphery, the economic basis for maintaining daily amenities decreases, leading to their likely disappearance and/or concentration. Average distances here are expected to exceed 1 km and even 2.5 km in the future, the recognized comfortable walking and cycling distances respectively, especially for schools. This increases the CD in relation to daily amenities, affecting 10–15% of the population. However it seems that in urban as well as suburban and some rural areas, about 85–90% of the population, in 2030 there will be still enough economic support for maintaining a pattern of daily amenities within an average range of 1 km.

A second effect due to the declining population is that fewer people can reach economic centers and fewer jobs can be reached from residential areas within 30 and 45 min. The current improvements of the highway system will mitigate this demographic effect to some extent, giving more people access to jobs by car, partly from outside the region. Although current planned improvements to regional public transport are quite substantial, e.g. some cross-border rail projects, public transport will become less competitive in 2030. And although the e-bicycle has a potential to make people less CD, showing better performance than public transport against cars within 30 min of travel, the change in spatial conditions described above (increasing distance between homes and jobs) will also make its use less favorable.

It appears that currently as well as in 2030 about 25% of the jobs in South Limburg are found in multimodal locations, directly served by rail and highway; about 25% at highway locations without rail access; and 50% elsewhere, without adequate regional accessibility. The TOD strategy, aiming at concentrating homes and jobs at transit-oriented locations, seems to have only a modest effect in a mid-sized, post-growth environment. We also tested two DOT scenarios adapting public transport network to land use patterns, both aimed at offering more travel choices from urban residential areas to economic centers. One was based on improving IC services on the existing rail network and one on creating BRT services on the existing highways. We found that in both scenarios, in central urban areas travel choices related to jobs in economic centers can rise from 70% to almost 90%, meaning that out of 10 jobs accessible by car in 30 min, 9 are accessible by public transport in 45 min, door-to-door. This means that DOT as a strategy can have a significant effect in offering travel choices to jobs, at least in central urban areas. The IC+ scenario improves the accessibility of centers which are already served adequately by public transport, but also improves access to urban areas outside the current daily urban system of South Limburg (e.g. the central urban area of the cross-border city of Hasselt), thus extending the daily urban system geographically. The existing economic centers and campuses outside city centers (situated next to highways) would however benefit less from this scenario. In contrast, the BRT scenario, adding bus services on highways, directly linked to the campuses, would improve the accessibility by public transport of these areas in a substantial way, with the existing rail system still serving the central urban areas. In contrast with the IC scenario, it improves the connections within the existing daily urban system, instead of extending it geographically.

It should be kept in mind that the model does not include a 'transfer penalty'. Recent research shows that this penalty, expressed in travel time, in train-bus transfers can be on average about 20 min (Schakenbos, 2015). Seen from this point of view, the BRT scenario, which in combination with the RAIL scenario gives direct access to all economic centers, seems the best alternative for the car in terms of experienced travel time. On the other hand, research also shows that most people prefer traveling by train or light rail to traveling by bus within the same travel time (Bunschoten et al., 2012).

In conclusion, it seems that in terms of CD we can distinguish 'three worlds' emerging in the post-growth, mid-sized European region:

1. Rural areas increasingly becoming completely car dependent (in South Limburg 10–15% of the population in 2030),
2. Suburban areas offering travel choices to daily amenities, but increasingly becoming more car dependent in relation to jobs (65–75% of the population in 2030), and
3. Central urban areas providing travel choices to amenities as well as jobs, but only under the condition of improving the regional public transport system (15–20% of the population in 2030).

The main policy implications, derived from this study, appear to be:

– The e-bicycle has a potential to reduce CD, showing better performance than public transport against cars within 30 min of travel.
– The TOD strategy, aiming at concentrating homes and jobs at transit-oriented locations, seems to have only a modest effect in a mid-sized, post-growth environment.
– DOT, improving public transport to economic centers, can have a significant effect in offering travel choices to jobs, at least in central urban areas.
– The IC- scenario makes more jobs accessible outside the current daily urban system, while the BRT- scenario intensifies relations within the region.

### *4.2. Reflections*

#### *4.2.1. The 'system' of alternative transport modes*

In terms of travel time, it seems that within 30 min travel time public transport could be replaced by bicycle and e-bicycle as an alternative to the car. Of course, travel time is not the only motive for mode choice, but the still rising popularity of the bicycle in Dutch towns and the growing demand of bicycle parking near stations question the current concept of regional public transport systems as a hierarchy of trains and light rail serving urban areas with local buses serving as feeders. In many cases the latter are not faster than the bicycle while requiring additional mode transfers. In terms of travel time and costs a policy which facilitates the use of the bicycle or e-bicycle as feeder for a high quality public transport network directly serving the regional economic centers could be a more effective alternative for the car than the hierarchical system of trains and local buses.

#### *4.2.2. Conditions and actual behavior*

In this paper we have indicated the potentials of a high quality transport network, distinguishing two scenarios and indicating the number of people potentially benefiting from these investments. However, this potential benefit does not demonstrate the economic viability of these alternatives. People who have a reasonable travel choice don't necessarily make this choice. The actual use of public transport is heavily dependent on disincentives for car use. In that respect a rail-based transport system, as described in the IC+ scenario, with central urban areas as destination, profits from restraints on car use in these areas. However, as shown in our findings, it doesn't substantially improve the accessibility of the peripheral centers, which are not only economic centers but also locations for important regional amenities like hospitals and vocational training institutions. The second scenario, introducing BRT along the highways and giving direct access to the peripheral centers, profits less from restraints on car use, due to the current ample and free parking there. But if these areas are developed into full-fledged urban areas, with mixed use and quality of public space, and combined with parking restrictions, the competitiveness of BRT would increase.

#### *4.2.3. Potential and actual accessibility*

We explored the spatial conditions for CD at an aggregated level, describing the average accessibility of all jobs by all inhabitants by different transport modes in the region. Furthermore, we described the potential accessibility (what people can access) rather than the actual accessibility (what people do access, as e.g. revealed by their mobility patterns). Of course not everyone has the same accessibility needs, and fulfilling them might not require the full range of potential accessibility options. For instance, research shows that commuters with lower education levels live on average less than 15 km from their work (Van Roon et al., 2011). The e-bicycle could be an acceptable alternative for the car within 30 min in these cases and would provide a better alternative than public transport in terms of travel time. Furthermore, in the urban areas of Maastricht, Heerlen and Sittard-Geleen, 50–70% of residents commute within their own city, making the bicycle an attractive alternative (Vaessens and Knoors, 2015). Although further research is required, it seems thus that in urban and many suburban environments across the region the bicycle or the e-bicycle could function as a basic alternative to the car for most trips – amenities as well as jobs. On the other hand, two groups seem to be become increasingly CD in their daily accessibility needs: (1) commuters and students living more than 10–15 km from their jobs or schools located on highway locations without adequate public transport and (2) people living in rural areas (10–15% of the population). For the first group it seems to be possible to provide regional public transport as a reasonable alternative to the car, at least in central urban areas, and under the condition of improving public transport as shown in the scenarios. For the second group to avoid CD the only – and rather draconian - alternative seems to be to move to these more urban areas. This underscores the importance that in an urban region at least the urban areas offer the possibility of a choice for a car-independent lifestyles if the wish or the need arises.

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