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How to build an alternative to sprawl and auto-centric development model through a TOD scenario for the North-Pas-de-Calais region? Lessons from an integrated transportation-land use modelling

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Abstract

This paper discusses results of an integrated land use and transport modelling, carried out for the territory of the French region of North-Pas-de-Calais using the software Tranus. The interest of this research was to simulate, test and evaluate impacts of a Transit Oriented Development regional plan, using the LUTI modelling tool. Therefore were analyzed evolution of transport demand modal share and dynamics of real estate market and of localization choices of population and activities. TOD is a model of urban development that promotes high quality, mixed and multi-functional densification, located in proximity of transit nodes and corridors, with priority to non-motorized mobility and with the aim to reduce land consumption and car dependency. Multiple TOD examples can be found at urban and metropolitan scale, with different characteristics depending on the socio-economic and territorial contexts, while rarer are interventions at a regional scale. Therefore this research aim to analyze the application of a TOD regional plan, applied to a specific group of regional railway nodes and corridors, selected for their TOD potential. Results showed that some rail corridors initially selected, clearly confirmed their TOD potential and that TOD effects are more evident in areas with good basic levels of attractiveness and of economic dynamism. Furthermore, if policy of densification clearly contributes to concentrate residential demand in urban zones and to limit urban sprawl, further incentives has to be organized in favor of transit use. More interesting effects are in fact found by simulating transit integrated tariff policies between regional train and bus services, as well as interventions discouraging car use, in addiction to TOD urban configurations.

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Keywords: Integrated land-use and transport modelling; Transit Oriented Development; Tranus; urban sprawl; car dependency.

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1. Land use and transport integration

Consider changes in land use and transport, as a phenomenon that influences each other it is a sufficiently shared principle, which requires a coordinated and integrated approach. Factors of generalized transport costs are related to land use strategies (density, functional mix and urban design quality (Wegener and Fürst, 1999) can influence car possession rate, average distance travelled, congestion, costs of transport infrastructure, accidents rates, pollution, equity and social inclusion levels (Litman, 2012a), but this interaction actually occurs in both directions (transport also influences urban development), in a continuous, bidirectional and circular way (Wegener, 2004), constantly evolving, with mutual interferences and dependencies. However this correlation is difficult to define. Factors involved are always different in each context, stimulating a diverging debate on the relevance of this interaction (Giuliano, 1995). D. King (2011) considers urban development a factor that promotes transport systems development, while Levinson (2007) affirms that urban development must necessarily follow a primitive form of transport network (river, natural valleys or harbors, etc.), giving rise to a process of centrifugal and centripetal forces, which act differently in function of territorial contexts. Therefore land use factors affect mobility and transport, especially if considered in cumulative and synergy terms (Litman, 2012a). Urban density is inversely proportional to average travel time (Newman and Kenworthy, 1989), mainly in multifunctional urban configurations (Cervero and Kockelman, 1997), while concentration of employment in urban centres implies an opposite effect. Balance between residences and activities location appears to have positive effects on commuter flows (Wegener and Fürst, 1999) and on the amount of non-motorized mobility (Cervero, 1989). Greater functional diversity and urban accessibility for pedestrians enhances a reduction in car use for trips to shopping and services, as well as greater transit regional accessibility influences modal commuting choices (Litman, 2012a). Several studies (Litman, 2012; Ewing and Cervero, 2010; Handy et al., 2010) consider also connectivity as a factor that affects average distance travelled and modal share of non-motorized modes, as well as average speeds and levels of congestion (Ewing and Cervero, 2010). Anyway Litman (2012b) admits that to accurately predict impact of transportation planning policies on land use dynamics is extremely difficult. Effects can indeed be very slow over the time and dependent on fluctuations of economic, social and environmental cycles (Still, 1995; Michael Wegener, 1999). Accessibility (L'Hostis and Conesa, 2010) is also a crucial factor (Wegener and Fürst, 1999), because it contributes directly to increase attractiveness and to accelerate the development of urban areas (Hansen, 1959).

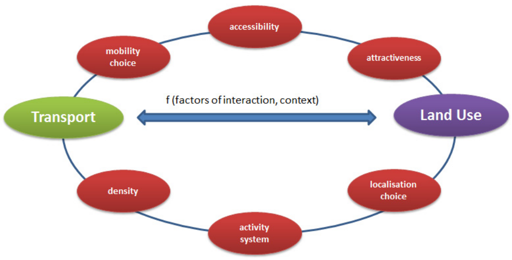

Fig. 1. Factors of interaction between Transport and Land Use (F. Lo Feudo, 2014).

Massive car diffusion, at the beginning of last century, has greatly influenced and oriented land use and transport planning policies especially in Western countries. Pedestrian and transit city was replaced by the automobile city, which promotes urban sprawl, energy consumption (Crozet, et al., s.d.) and car dependency. This led planners to operate primarily to make road traffic more pleasant and comfortable. This strategic direction, driven by a "fear of congestion" (Mangin, 2004), led to an underestimation of land use effects and impacts of car dependency (Dupuy, 2011; Urry, 2003; Newman and Kenworthy, 1999). The "model of car society" (O.P. Dubois-Taine, 2010)) is a lifestyle mainly based on accelerated and uncontrolled exploitation of non-renewable energy resources (Robert, 2009; Massot and Orfeuil, 2007) and encouraged by some unbalanced industrial, economic, energetic and land use policies (automobile industrial was intensely supported by western governments, with financial incentives and huge investments in road network (Handy, 2002), that encouraged low density and fragmented land use (VTPI, 2010)).

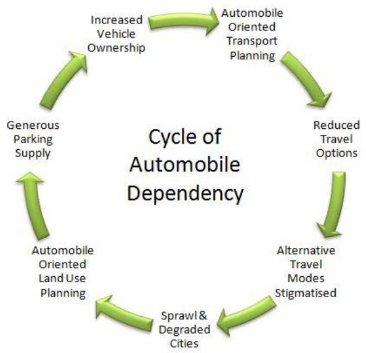

Fig. 2. The cycle of automobile dependency. (Heran, 2001; O.P. Dubois-Taine, 2010).

Many authors shared for that reason the notion that a completely car oriented mobility system is no longer sustainable (Melia, 2009)) and that negative effects caused by an excessive car use bring into a vicious circle (”spiral of car dependency”) (O.P. Dubois-Taine, 2010; VTPI, 2010), in which car creates problems involving the need to use car to avoid them (Heran, 2001). This is the opposite of a "balanced" transport model, where multi-modal and transit oriented mobility, with high levels of accessibility (VTPI, 2010), is encouraged (Litman, 2002). Therefore, trying to not fall into the anti-car rhetoric (Leysens, 2011), it can be argued that car oriented planning policies tend to favor more dispersed urban and regional development (Litman, 2012b), while transit and non-motorized oriented planning strategies stimulate a less dispersed and more compact land use development. The aim of this work is therefore to propose an integrated approach (related to transport and land use), to simulate and evaluate effects of a Transit Oriented Development at a regional scale.

2. Transit Oriented Development

Transit Oriented Development (TOD) (Calthorpe, 1993; Chorus and Bartolini, 2011; Litman, 2012a; Cervero, 1998; Dittmar and Ohland, 2004) tends to integrate transport and land use policies, to promote compact and intense urban configurations, characterized by lower land consumption and greater densities (Cervero, 2011).

TOD principles aim to improve quality and efficiency of a multi-modal transit supply, in order to contrast urban sprawl, pollution and car dependency (Dupuy, 2011; Nuzzolo, 2012; Dittmar and Ohland , 2004; Cervero, 2006; Conesa , 2012; Zooneveld and Ortuno Padilla, 2012), to stimulate economic development (Pharoah and Apel, 1995) and increase liveability in proximity of transit access points (Wegener and Fürst, 1999).

It is a concept that derives mainly from reflections of "New Urbanism" movement (CNU, 2013), and develops principles of Smart Growth theory. H. Dittmar and G. Ohland (2004) also note as TOD basically refers to principles previously proposed in the concepts of Garden City (Howard, 1898) and of Linear City (Soria y Mata, 1894). It is therefore recommended a quality, compact, dense, mixed and integrated urban development (Nuzzolo, 2012; Chorus and Bartolini, 2011), located near railway stations or transit access nodes and with priority for non-motorized mobility (Nuzzolo, 2012; Litman, 2012a). It is not, however, a simple adjacent development, limited to isolated points (Wulfhorst, 2011), but diffused in a corridor or network and strategically designed (Cervero, 2011).

Fig. 3. Scales of TOD. (F. Lo Feudo, 2014).

However several factors can represent a barrier to TOD implementation. Political, institutional and operational obstacles (Rietveld and Stough, 2004), as well as cultural and territorial context diversities (Hine, 2005), lack of dynamism in land and property market and difficult to attract and involve private investors (Douglas, 1997), can avoid success of TOD. Even if the exact size of their catchment area is not determinable, Nuzzolo (2012) defines TOD interventions as a "tool to increase the use of the rail network" and to regenerate urban areas around stations, while others affirm that TOD can generate phenomena of land and real estate property value capturing, generating also, increased tax by municipalities (Papa, 2009). This may be paradoxically less attractive for private investors (Zooneveld and Ortuno Padilla, 2012), which tend to be more interested in profitable investments on marginal land, usually cheaper and already car-connected. Time factor is also decisive. Interventions of regeneration of degraded areas, not inserted into an organic territorial strategy, should be extremely time-consuming than interventions on vacant lots or blocks. Finally some specialists observe that a people and equity based (Rojas, 2012) approach is needed, mainly oriented to increase opportunities for disadvantaged categories (access to jobs and to urban functions and resources) (Irvine, 2013), through affordable housing policies (Litman, 2013) and high transit accessibility levels. Hence most significant innovations introduced by TOD are in the adaptation of land use and transport integration principles to complexity of contemporary cities, to create an alternative to the car-oriented model. The speed of modern transport systems reduces perceptions of time-space relationships and increase average travel distances (even if daily transport time budget remains substantially constant (Zahavi, 1974)). TOD therefore acts in such complexity, on urban design, on strategic and operational transport planning, on land use governance and promoting a more social and shared lifestyle, characterized by more sustainable mobility practices. Hence in this research TOD principles are applied to a group of railway nodes and corridors of the French region of North-Pas-de-Calais, selected for their TOD potential. Land use and transport integrated (LUTI) modelling tool is then used to simulate impacts and effects of these interventions.

3. Integrated land-use and transport modelling to support strategies and policies of territorial development

Reproduction of interaction between transport and land use represents an extremely interesting subject for modellers and specialists of simulation methods.

"*Land Use and Transport Integrated models are a representation theorized and formalized to analyse a territory in its spatial economic and social aspects*". (Laurent, 2012)

Wegener (1995) individuated three main methodologies used to address this issue: the stated preference method, based on direct interviews to investigate possible changes in location and mobility choices, consequent to changes in the characteristics of transport system and land use; the revealed preferences method, based on observations of users behaviours changes in different contexts; the mathematical method, based on the simulation through mathematical models and algorithms, of mobility and location choices (Lefévre, 2009; Wegener, 1995). A weakness of the first method is casualty and uncertainty of answers about behaviours related to unknown situations. The second method, which can provide reliable and accurate results, can investigate only current situations and therefore gives no indications of future time horizons. Mathematical methods can extend the simulation to future scenarios and to unknown situations, in addition to offer quantitative and therefore verifiable results (Lefévre, 2009; Wegener, 1995).

''*Mathematical models are the only method by which the effects of individual determining factors can be analysed by keeping all other factors fixed*''. (Wegener, 1995)

Especially three main approaches are individuated (Lefévre, 2009; Wegener and Fürst, 1999):

- A geographical and sociological approach based on the theory of Darwinian evolution and oriented to study the eco-socio-spatial dynamic at an urban level. These methods provided qualitative results and do not to simulate the interaction between transport and land use.
- A micro-economic approach based on the Lowry (1964) theory of spatial interactions and oriented towards the study of interrelationships between transport and land use, but with a homogeneous representation of space, generally mono-centric.
- An operational approach that does not rely on a specific theory, but includes the urban transport modelling systems (four-step model), the discrete choice models and land use and transport integrated models.

Urban transport modelling systems are used to predict transport demand, so they simulate user's trip selection process (purpose, transport mode and path choice). The four-step model is the most common transport demand model, corresponding to a sequence of decision-making choices: emission, generation, distribution of demand, modal choice and path selection. For this type of modelling, land use data should be added exogenously (Lefévre, 2009). The discrete choice model is based on McFadden (1973) theory of random utilities. It represents a development of classical transport models (de la Barra, 2013), as introduced a random element, analysed through probabilistic models (Logit and Probit) (McFadden, 1973). The integrated land use and transport modelling approach can be instead synthesized in combining transport demand forecast functions and estimation of land use dynamics, then simulating their reciprocal influences.

As part of the basic theory of land use and transportation model we can distinguish an operational approach based on the theory of spatial interactions (Lowry, 1964), or on the theory of entropy maximization (Wilson, 1970), in which land use models are designed to study the relationship between different activities, based on the analogy with Newton's gravitational theory and with physical principles of entropy maximization. Another approach refers to econometric input/output models (Leontief, 1941), as the Tranus model (de la Barra, 1989). The entire structure of these models is based on integrated economic models where transport demand is obtained as a function of economic relationships. These models can simulate effects of transport policies on various socio-economic and territorial components and require a large amount of data.

In general LUTI models approaches (Wilson, 1997; Wegener, 2004) depends on how system evolution is examined and analysed. Static models study a variable in a fixed period of time, keeping unchanged other system variables, while quasi-dynamic models explicitly simulate the evolution of the system, considering different reference periods. Others quasi-dynamic models are based on maximization of the utility function (Tranus) and on various transformation processes that influence consumption of space and activities. The implementation of these models requires input data referred to land use and transport network, not often totally available. A. G. Wilson (1997) considers in effect reproductive capacity of reference data, one of the most important characteristics of a LUTI model. Several researchers as F. Laurent (2012) note that LUTI modelling can be applied to investigate problems and questions of urban and transport developers and planners, thanks to its potential and capacity of spatialization and of temporal decomposition of user's behaviours and of territories functioning factors. This type of modelling can provide a comprehensive and inclusive analysis, especially during the decision-making process, looking at the location of specific services, resources or activities, as well at the individuation of strategic development configurations. However, the basic complexity in the conception and implementation of models and the need of a specialized and multidisciplinary approach produces an engineering problem of temporality, reproducibility and sharing among researchers and modellers about objective and modelling questions (CERTU - PST Rhône-Alpes, 2011). The structure of land use and transport integrated models can be vector-based or matrix-based (de la Barra, 2013). In the first case attributes about population, employment and land use, are represented as vectors. These vectors are used to estimate O/D matrix of transport demand, which in turn are characterized by transport mode and affected to the network. This approach contains an aggregation problem (de la Barra, 2013) between O/D matrix and land-use model, which remains in a vector form.

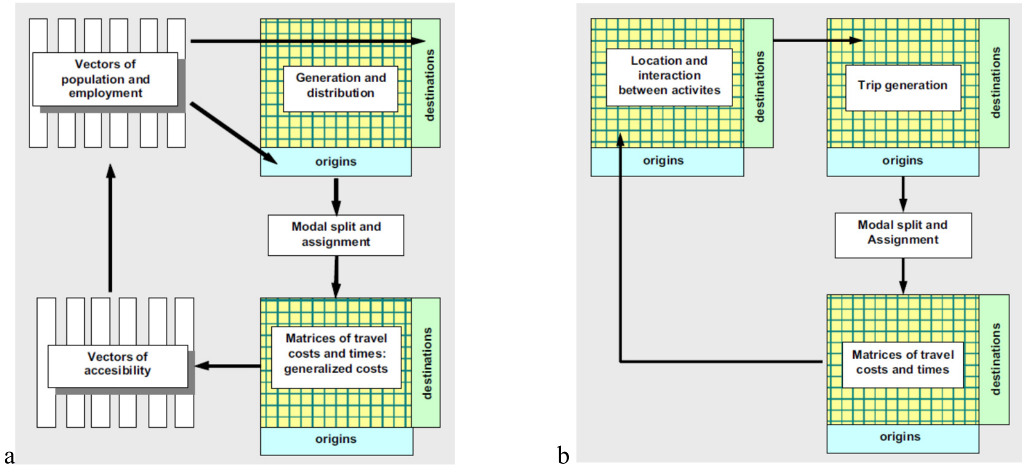

Fig. 4. (a) Vector-based structure of LUTI models; (b) Matrix-based structure of LUTI models (T. de la Barra, 2013).

The matrix-based approach has as theoretical basis the input-output model, where economic flows, become transport flows, keeping the matrix form. Then from the O/D and transport disutilities matrix, data can return to the land use model in a matrix form, avoiding the aggregation problem of the vector-based approach (de la Barra, 2013).

The input-output model of Leontief (1941) divides the regional economic system in sectors and provides that products of an industry can either be used as input for induced productive sectors or consumed by final demand (which may include population, exports investments, etc.) (Wilson, 1974). Exogenous inputs (raw materials, financial capital, public subsidies, etc.) arrive from outside the regional economic system (Wilson, 1974). On this basis inputs are divided into produced and primary inputs, while outputs in intermediate and final demand (de la Barra, 1989). Intermediate demand represents the amount of output of a generic production sector, demanded by production of an induced sector (de la Barra, 1989). Once completed the iterative calculation and obtained convergence, the input-output model provides the amount of regional production that is required to meet total consumption demand (de la Barra, 1989). This matrix to matrix structure can be also found in the mathematical formulation of the Tranus software, used for this work, giving more consistency to the model (Lefévre, 2009).

3.1. Choice of the LUTI modelling software: Tranus

Tranus was considered the most appropriate and consistent approach to test potentiality and applicability of Transit Oriented Development (Calthorpe, 1993; Cervero, 1998; Bartolini, et al., 2009) and Rail Oriented Urbanism (L'Hostis, 2009; Leysens, 2011) policies, at a regional scale. It is open source software, with a direct online support provided by its creators and with a multi scalar configuration. It integrates several different theoretical approaches in a single structure, related to transport and land use, and is primarily based on a nested logit multinomial modelling (de la Barra, 1989). The Tranus model is a spatial input-output model, aggregated and based on equilibrium between supply and demand, in function of price and time (CETE Normandie Centre, s.d.), that works in according to the theory of random utility, based on the maximization of a utility function. It includes a transport model (to allocate transport demand, define modal split and congestion), an activity model (to simulate location and interaction between activities) and an interface module that simulates their interactions. Tranus model is composed by zones, transport categories and activity sectors. For each zone values of production and demand, for exogenous and induced sectors, imports and exports, production constraints, costs of consumption and equilibrium prices are defined. Transport model is characterized by type of users and trip purpose categories, allowing assigning demand to a multi-modal and spatial network. The interface model is represented by the input-output matrix, which can reproduces economic flows, transforming them into transport flows and then calculates costs and transport disutilities that will influence activity model in following simulation times. In summary data to enter in Tranus regards location of activities and population and their mobility behaviours. Actors and sectors are located in function of changes in accessibility and land prices, which in synthesis depend on level of attractiveness of each zone.

"*The model is essentially a large set of nested multinomial logit demand equations embedded in algorithms to accomplish equilibration*." (Johnston and de la Barra, 1998)

Another fundamental characteristic of Tranus is the inclusion of a substitution logit model. Each activity and population group can choose between a range of different location alternatives (types of land use and real estate typologies) (Johnston and de la Barra, 1998) and preferences are defined for each alternative. Tranus further provides a different method of representation of the transport network. J.Anes, T. de la Barra and B. Perez developed a *dual graph* method, in which links represent road sections and nodes represent intersections. Connections and transfers within each node are transformed into internal links. In this way definition of complex networks characterized by turn restrictions and multiple transfers (Anez, et al., 1996) results more simplified (Modelistica, 2013). The implementation of multiples future simulation scenarios, containing assumptions about transport and land use changes, can provide results about residential and activities location in the study area, evolution of land prices and distribution of transport demand.

4. Hypothesis, data, general structure and implementation of a Tranus model for the French region of North-Pas-de-Calais.

Tranus model for the French region of North-Pas-de-Calais was designed primarily to analyse, simulate and evaluate the interaction between transport and land use, with a multi-scalar approach and to evaluate effects of a regional Transit Oriented Development plan. Proposals of concentrate future urban development near some corridors and nodes of the regional rail network, match strategic perspectives of regional planning documents (Schéma Régional des Transports et des Mobilités (2013b); Schéma Régional d'Aménagement et de Développement Durable du Territoire (2013a); Contrat Etat-Région (2007)), oriented to contrast urban sprawl, natural land consumption and car dependency.

Hence some rail corridors have been identified as potentially able to accommodate urban and transport planning interventions, following TOD principles. In these selected zones, an assumption of progressive urban densification and improvement of transit supply, as well as the application of policies of integrated transit tariff and of discouragement of car use, was simulated in a time horizon of 16 years (2009-2025). The objective is to evaluate effects on residential and activities location dynamics and on modal repartition of transport demand. The existing regional rail infrastructure is indeed considered, in regional strategic planning documents, as a key element on which to build future regional development, following principles of environmental and energy sustainability, economic growth and quality of life.

For all zones of the model will therefore analysed results and trends in future times, based on observed data of 2009, related to several transport and land use parameters.

The modelling process consists of numerous steps that incorporate each other, interdependently. General objective and assumptions are firstly defined, specifying zoning and indicators of interest. However, all these modelling choices are strongly dependent on data availability. The zoning replicates the existing regional administrative organization, with 16 urban zones, representatives of major regional conurbations. To reflect the real economic and social dimensions of considered urban zone, data (population, employment, land use and land prices) of main cities were combined with those of minor adjacent municipalities, functionally and geographically connected to each main city (agglomeration effect).

Fig. 5. Insertion of a rail station district in the urban fabric. (Lo Feudo, 2014).

Each of 16 urban zones is actually an aggregation of two or more municipalities, except in the case of the municipality of Lille (institutional capital of the region, epicentre of regional economic activity and mobility system), that was analysed in a more disaggregated way, creating 1 zone for Lille and 21 zones related to the more representative municipalities (by size and population density) of Lille metropolitan area (Lille Metropole Communitè Urbaine – LMCU). To take account of the rest of regional population were also identified 15 zones, corresponding to municipalities included in major regional employment areas (Employment Zones according to the classification proposed by INSEE[1]), and each gravitating around a specific main city. 14 TOD zones were also identified, after a previous classification of all regional rail stations, by type and level of integration with the surrounding urban structure. Among five types of spatial urban conformations around stations (Nedellec, 2010), three types have been identified as most likely to receive TOD interventions (integrated, bi-cephalous, fragmented), then some strategic rail corridors have been identified.

To take account of the cross-border nature of the region, 7 external zones and an O/D exogenous matrix, representing external and crossing trips, were defined. An exogenous O/D matrix was also introduced to take account of trucks traffic flows in the region. All mobility data were obtained from the Regional Mobility and Trips Survey (Enquete Régionale Mobilité et Déplacements - ERMD) (Conseil Régional NPDC, 2010).

According to available and accessible statistical data, regional population was classed in households groups, in function of their socio-professional category and average annual income. Based on data provided by the last official population census of 2001 (INSEE) and its subsequent amendments made in 2009, three categories of households were defined: high, medium and low income households (HIH, MIH, LIH). For each household category, was introduced a corresponding transport category, related to *home-work* and *home-service* trips. In addition, two transport categories have been created to define external trips (trips with origin or destination outside of the study area) and trucks traffic flows.

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[1] Formally defined by the French National Institute of Statistics (INSEE) as "geographic areas in which the majority of employees live and work and or production activities find the essential labour force needed to cover their work offer".

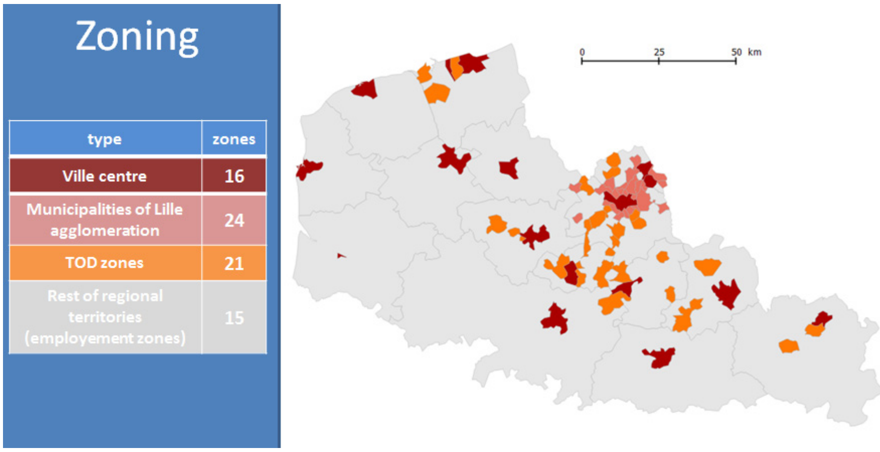

Fig. 6. Zoning of Tranus model for North-Pas-de-Calais.

For the calculation of parameters of value of travel time and of value of waiting time, used to reproduce mobility choices of each transport category, was used the method proposed by the mathematical Tranus guide, provided online (*www.tranus.com*) (Modelistica, 2013). Referring to parameters of Trip Generation Rate, initial values were set according to specifications of the ERMD (Conseil Régional NPDC, 2010), representing a starting point for the calibration procedure. Some assumptions about transport modes preferences and penalties by transport categories were also defined (High Income households prefer cars while medium income households have a more balanced set of preferences and Low income households prefer transit modes). These values are actually important parameters to adjust during the calibration phase. It should be considered in fact that initial estimated values are referred to total trips, while Tranus model considers only inter-zonal trips, excluding all internal trips of each zone (for this reason walk and bike trips are not considered in modal share outputs). Transport operator types were also defined (car, urban bus, suburban bus, tramway, subway, regional railway, high speed railway, bicycle, pedestrian, trucks) and a Time Factor parameter, which is the reference time for modelling, was set as 3 (referring to the three rush hours for home-work trips: 6:00h to 9:00h A.M.). Even for calculation of energy related parameters, the method proposed by the mathematical Tranus guide was used. The basic parameters used in this calculation are for each transport mode: average energy consumption per km travelled and energy cost per unit of distance.

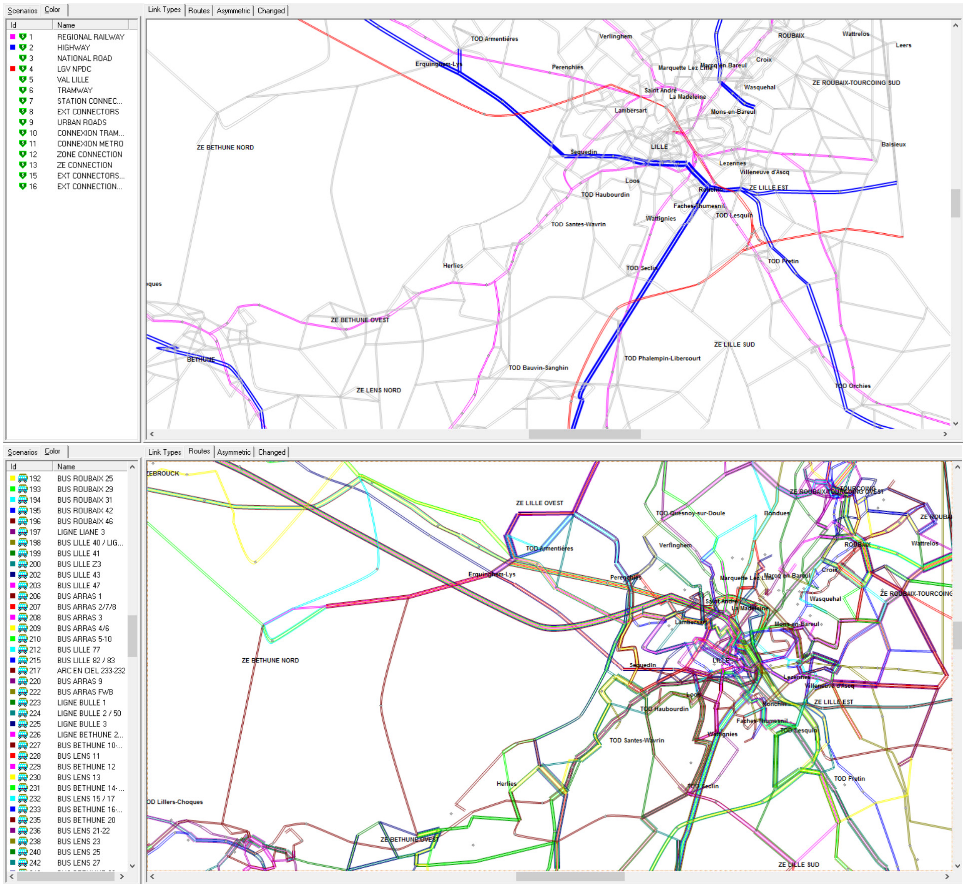

Fig. 7. Two screen shots from Tranus with the representation of the transport network and the transit supply.

The matrix of transfer costs between operators was also defined, to represent monetary cost of transfers between transport operators and to further represent tariff integration policies. Was then charged the entire regional transit supply at 2009 (reference period for the base scenario), composed by regional and national rail lines, urban and suburban buses and urban tramway and subway lines, with correspondent specific operational parameters (frequency, passenger capacity, speed, energy consumption, etc.).

Sectors corresponding to different production activities and types of land use were then defined, using data provided by the SIGALE system (Geographic Information System of North-Pas-de-Calais) and by INSEE. In particular were introduced two exogenous activities sectors (industrial and construction sector and agriculture sector), for which resources needed to production come from outside the study area, and two endogenous/induced activities sectors (public tertiary and service tertiary), for which resources needed to production come from exogenous sectors. For each of these sectors Tranus needs number of jobs, by sector and zone. Finally 6 types of land use were created, corresponding to almost all regional urbanized land, with the exception of hospitals, schools and transport infrastructures: residential land; continuous dense or mixed urban land; collective land; rural residential land; activity land; empty land (brownfield); TOD land (high levels of densities and of transit accessibility). Moreover in the case of residential, collective, rural and activities land, two sub-sectors corresponding to urban and rural levels of densities were defined, in order to specify the particular urban configuration of each zone. For these different types of land use, data of available surface for each zone and type of land were loaded into the model. Besides to calculate price of land has been applied a procedure that, from average sales prices per unit of area, provides the corresponding monthly payment of a mortgage based on the total selling price (VPM function on

Excel). To reproduce land market in Tranus is in fact preferable to use monthly rental prices than sale prices. In detail the estimation of land prices was performed using data provided by the website *www.meilleursagents.com* (a notarial real estate database available online and implemented by all French notarial offices).

The Intersector section is finally the core part of the model and defines the interface between transport and the land use models and thus all relationships and interactions between different activities and land use sectors. In this particular case sectors can interact as follows:

- Activity sectors can "consume" labor force (jobs, classed by average income and socio-professional category), as well as some types of land (activity, collective, mixed land), generating respectively home-work flows and activities location dynamics;
- Household categories can "consume" endogenous activities sectors (tertiary) and some land types (residential, mixed, collective, rural land), generating respectively home-service flows and residential location dynamics.

"*The amount of inputs that a production unit of a sector requires from another sector is determined by a demand function. The Tranus model includes options like: a fixed demand (the equivalent of technical coefficients in an input-output model), a variable demand (elastic) and the ability to specify substitutes. Land is a typical example of a substitute, when different types of land are present in the system, such as low density, high density, industrial, commercial land, etc*." (Modelistica, 2013)

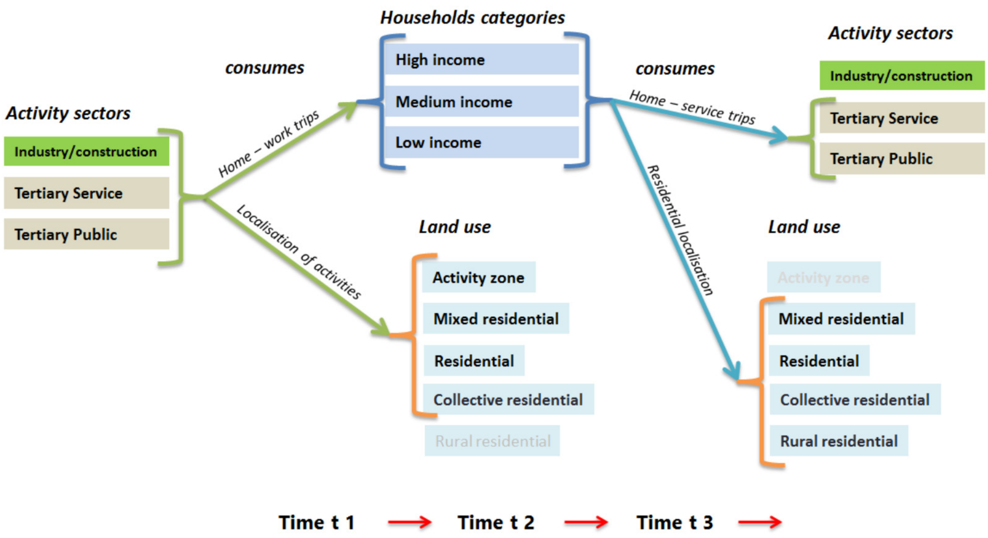

Fig. 8. Representation of interactions between sectors in the Tranus model for North-Pas-de-Calais.

For non-transportable[2] sectors (where demand function changes depending on price), in addition to estimation of elasticity, which defines the relationship between price and consumption, a maximum and minimum amount of input consumed on average by each unit of demand categories (population or economic activity) must also be defined, taking the form, for land consumption, of the inverse of density. Even in this case land use substitution preferences, by land demand categories, were defined (Low income households are more sensible to land prices variations in

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[2] "Transportable sectors may be consumed in places different to those in which they were produced. [...] A typical example of a non-transportable sector is land or buildings; these must be consumed in the same place where they are produced". (Modelistica, 2013)

their localization choices, than medium and high income households). These indicators related to land use are estimated considering the base scenario situation and during the calibration process had some adjustments (especially minimum and maximum amount of input required and substitutes penalties). All previous assumptions about the structure of the model are in fact used to implement a base scenario in which the objective is to simulate and reproduce real observed data. The model then provides three different scenarios of simulation, with a time horizon of 16 years and considering 2009 as base period.

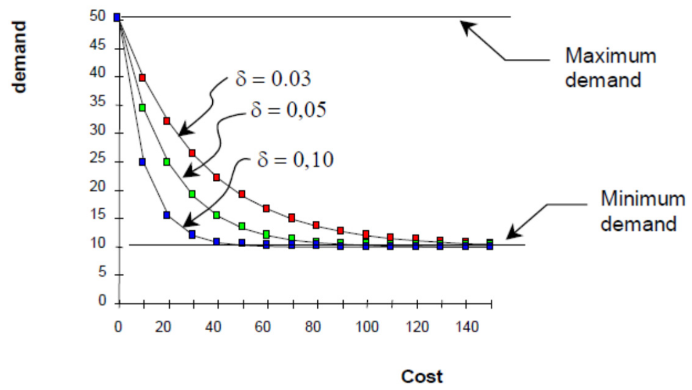


Fig. 9. Examples of Tranus demand functions with different values of elasticity δ (Modelistica, 2013).

The first simulation scenario (scenario A), is a “nothing changed/trend” scenario without changes in characteristics of transport system and land use. This scenario is also useful to compare results with those of scenarios dedicated to the simulation of TOD policies. Once the base scenario results calibrated, it can be argued that the model reproduces correctly (with an acceptable error) observed data and is possible to proceed with future scenarios. Calibration is the most complex, difficult and time loosing step of whole modelling activity, in which experience and expertise results decisive. It consists in adjusting some values and indicators, not empirically estimable, with an iterative trial and error activity. In this specific case calibration process was accomplished through the direct support of Professor Tomàs de la Barra and of the whole team of Modelistica, as part of a visit of research in Caracas (Venezuela) on 2013.

“*Calibration is not simple, due to the large number of calibration variables, which are internal to the model, that is, are inputs to other sub-models. Because of the model's complexity, calibration cannot be judged by a single goodness-of-fit statistic and must be done judgementally, looking at many fits. Calibration can take weeks of effort.*” (Johnston and de la Barra, 1998)

In Tranus the objective is to achieve convergence in an iterative process of calculation of prices, flows and variables related to production. Simmonds (1994) individuated difficulties related to the calibration process as the most important disadvantages of LUTI models like Tranus. In Tranus calibration is not automated and allows modifying some parameters through some adjustment factors. In detail, once introduced values of production, land prices and transport flows, the output of the calibration process is a series of adjustment factors (shadow prices), which must respect a convergence factor previously fixed (Dutta, et al., 2012). Shadow prices are actually correction factors that are added or detracted to modelled prices, for a fixed number of iteration, in order to reach convergence with observed data. They can also supply to the usual lack of reliability and precision of land prices estimation.

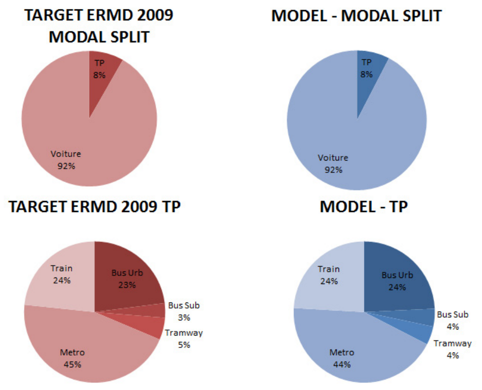


Fig. 10. Transport system calibration results (in red observed data and in blue modeled data).

"*It was found that, if during calibration, TRANUS converges, and then with a high probability the calibration process is verified. Moreover, a weak correlation was found between the inputs and the outputs of the calibration process*." (Dutta, et al., 2012)

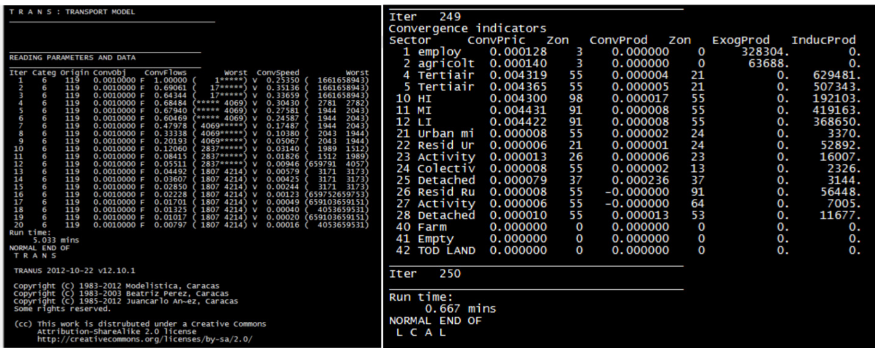


Fig. 11. Tranus output that confirm convergence (with a convergence factor of 0.001) of transport and land use models.

Was therefore implemented a scenario B referred to the implementation of a TOD Regional Plan, which provides in selected TOD zones, interventions of gradual urban densification and transit supply improvement. From this second scenario was also developed a scenario C, which provides further interventions discouraging car use, such as introduction of highway tolls and of an integrated tariff system between regional rail and bus services.

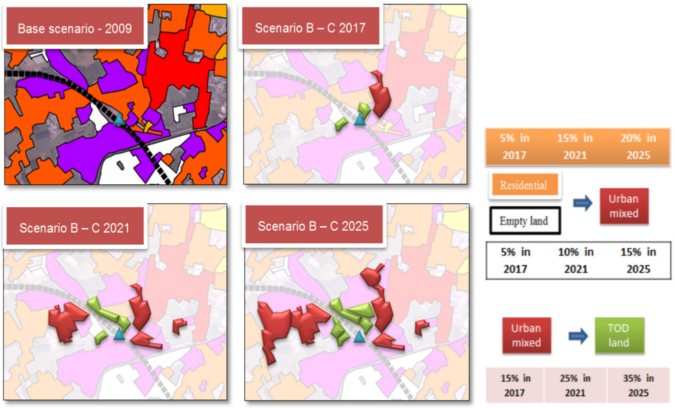


Fig. 12. Qualitative representation of densification around stations, proposed in scenario B and C. Example of Saint-Amand-les-Eaux).

Table 1. Consumed Land and hypothesis of evolution of consumed land in TOD zone of Saint-Amand-les-Eaux

		Urban Dense	Residential	Empty Land	TOD Land
Consumed Land [ha]	2009	36	442	42	0
	2013	36	442	42	0
	2017	51	420	40	9
	2021	127	357	36	32
	2025	204	286	31	71
Evolution of land consumption [ha]	2009	0	0	0	0
	2013	0	0	0	0
	2017	+15	-22	-2	+9
	2021	+76	-63	-4	+23
	2025	+77	-71	-5	+39

5. Results and modelling lessons.

Tranus allows evaluating several parameters and indicators about transport system and land use evolution in the study area. The main interest is to see if interventions of urban densification and transit supply improvement (TOD), simulated in selected rail corridors and stations (TOD potential zones), contribute to contrast urban sprawl and car dependency. As previously described, three scenarios (A, B and C) with a time horizon of 16 years (2009 - 2025) have been implemented. Results show that without specific actions and policies, an intensification of urban sprawl would be observed, especially in Lille metropolitan area and in urban central area of the region, surrounding cities of Lens, Bethune, Douai and Valenciennes.

Interventions of multifunctional urban densification simulated in scenario B show a reversed trend. Residences and activities, hence households and jobs are in this case mainly located nearby TOD zones, even more distinctly in scenario C (Fig. 13 and 14). In fact in maps that show households and jobs growth during simulation periods, it can be clearly seen how in scenario A most of growth is located in rural zones, perceived more attractive than urban and

TOD zones, indicating an intensification of urban sprawl. In scenario B and C jobs and households growth is, at the contrary, more concentrate in TOD zones, demonstrating an increase of attractiveness of mixed, dense and transit well-connected areas. In maps related to land prices evolution can be also seen how TOD interventions allow improving the value of land in TOD zones, mainly because of the increasing attractiveness and hence landing demand for these zones (Fig. 15).

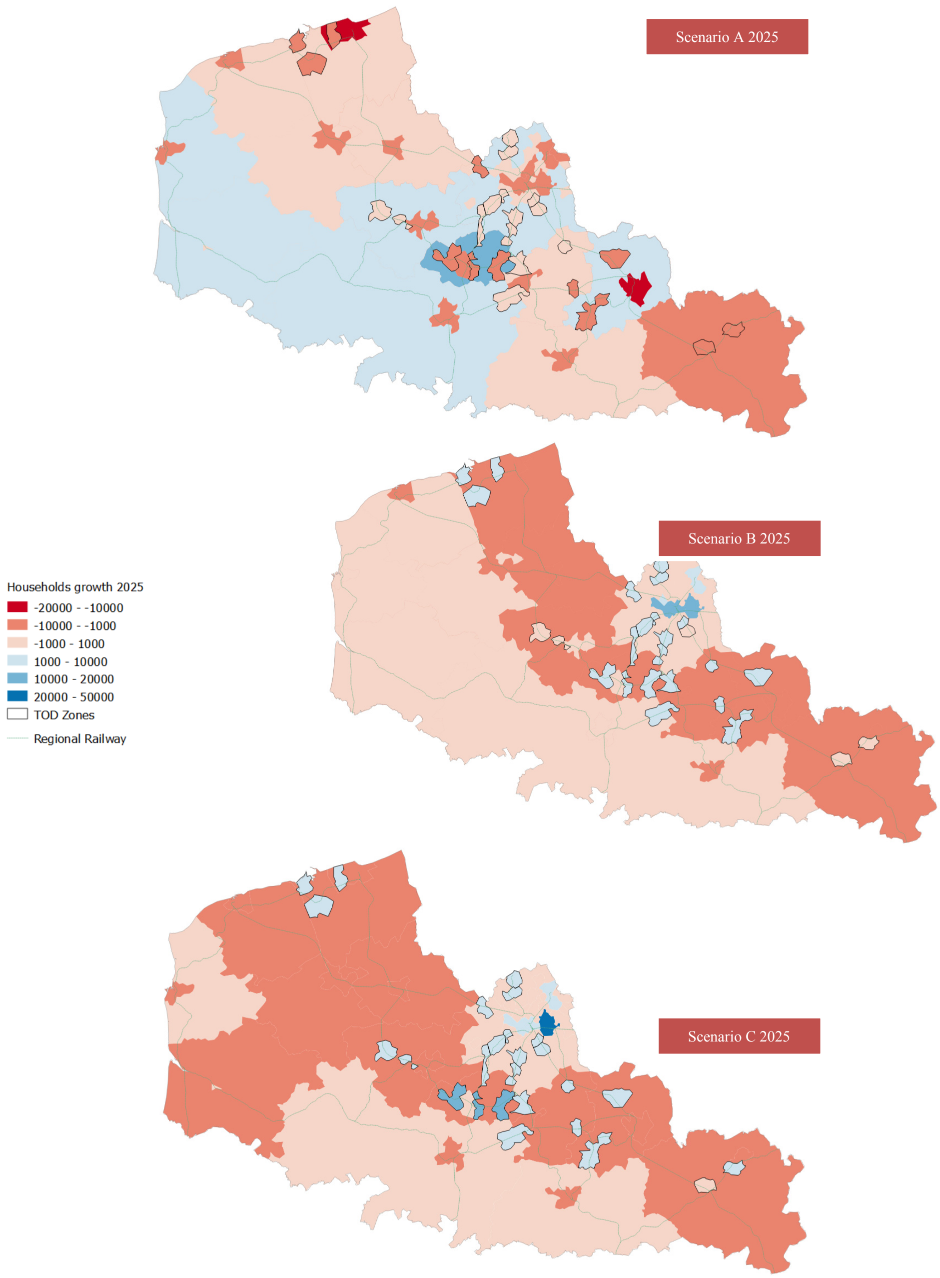


Fig. 13. Households growth in 2025 for scenario A, B and C.

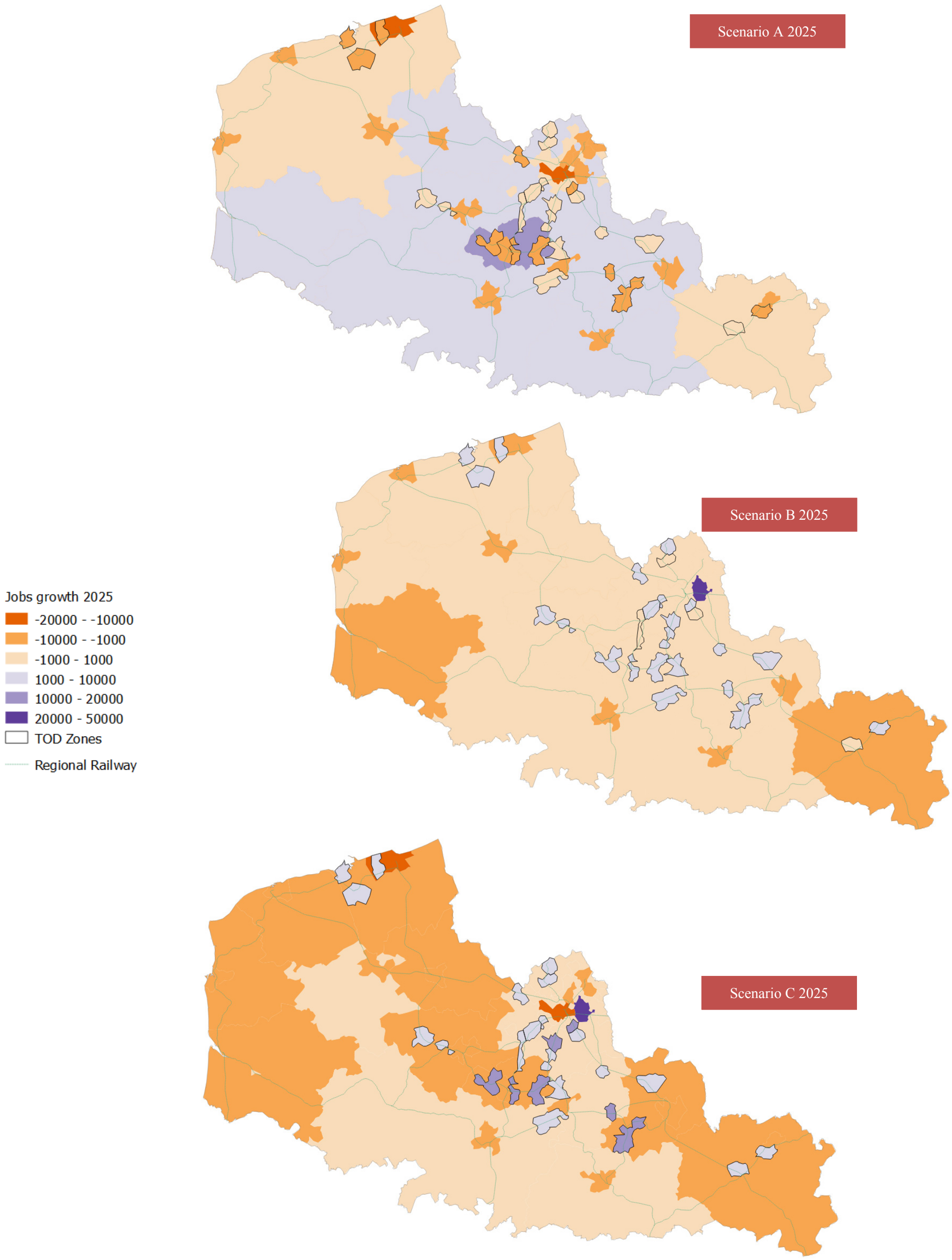


Fig. 14. Jobs growth in 2025 for scenario A, B and C.

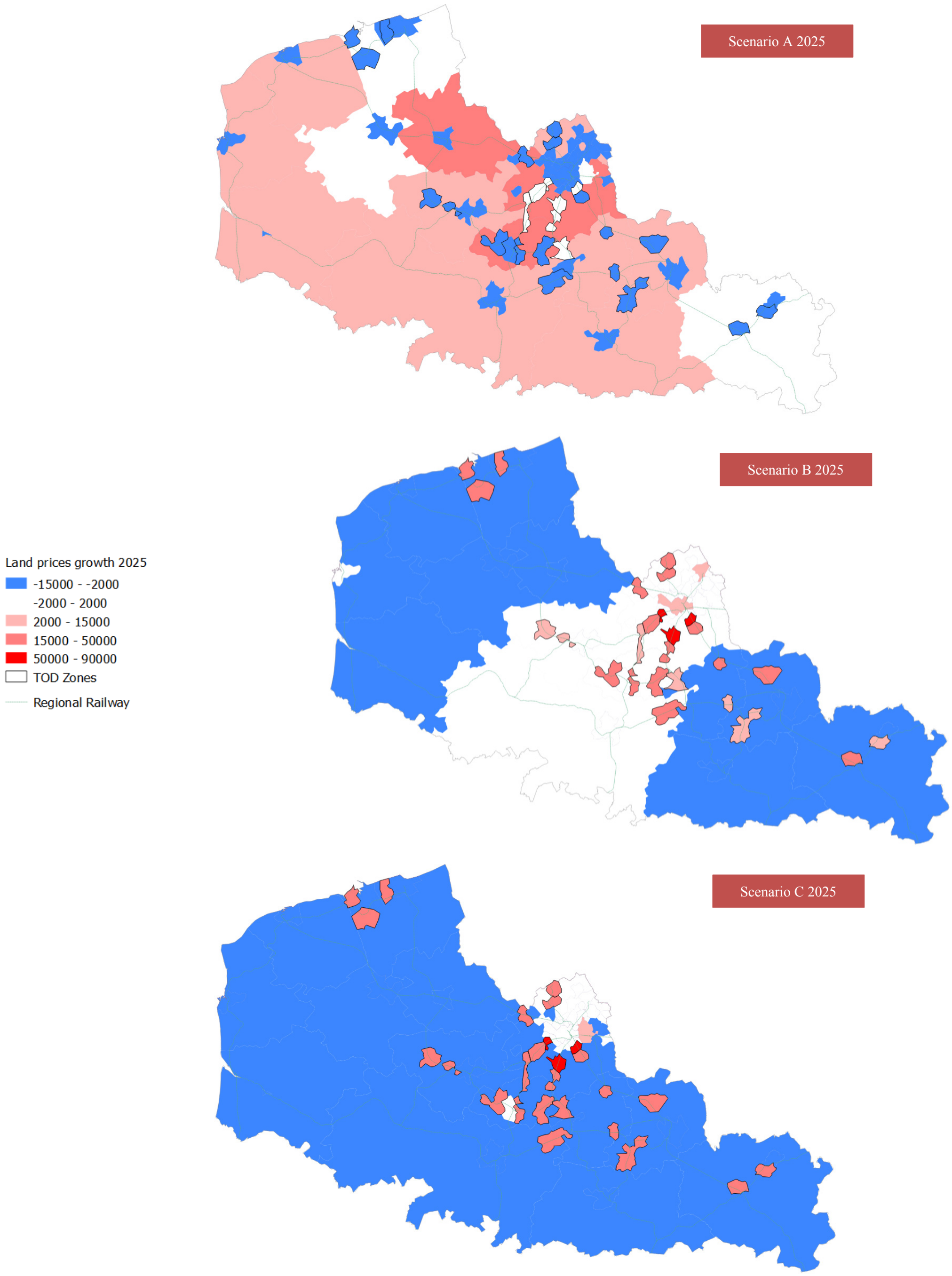


Fig. 15. Land prices in 2025 for scenario A, B and C.

Looking to Tranus outputs related to total land consumption rates, can be also seen that after the introduction of TOD policies, rural and detached land consumption remains constant, even decreasing for high income households, in contrast with urban mixed land consumption, that generally increase for all demand sectors (Fig. 16).

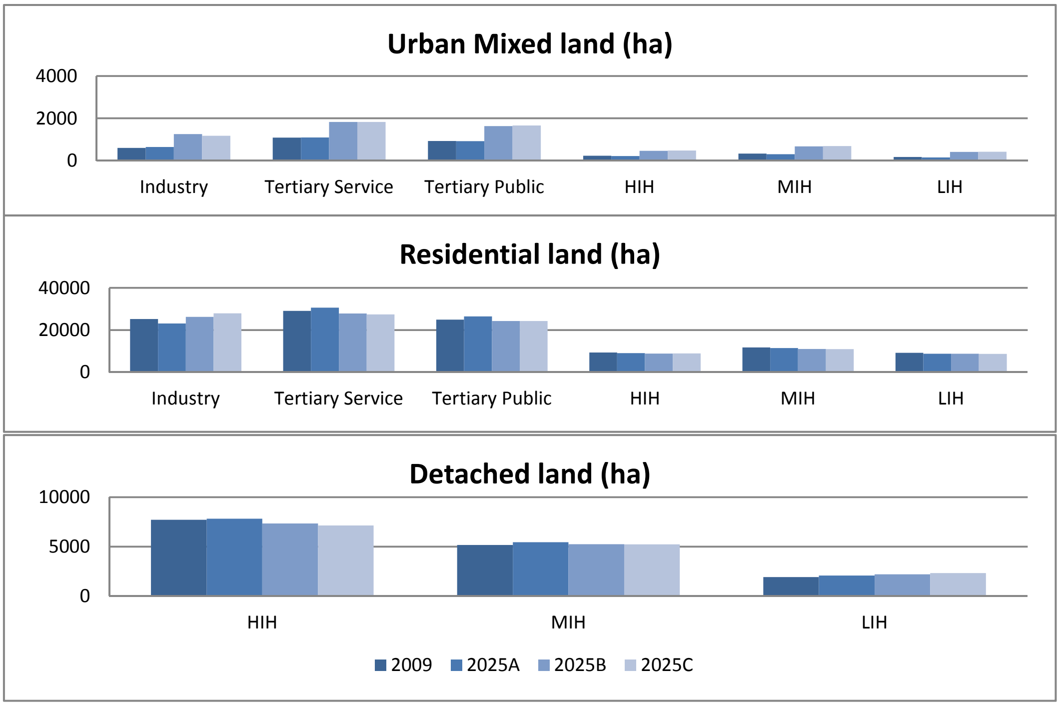
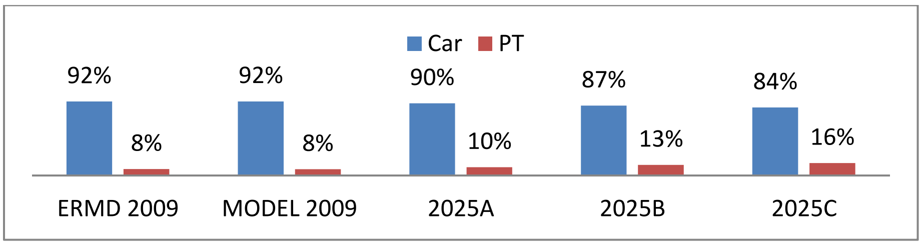
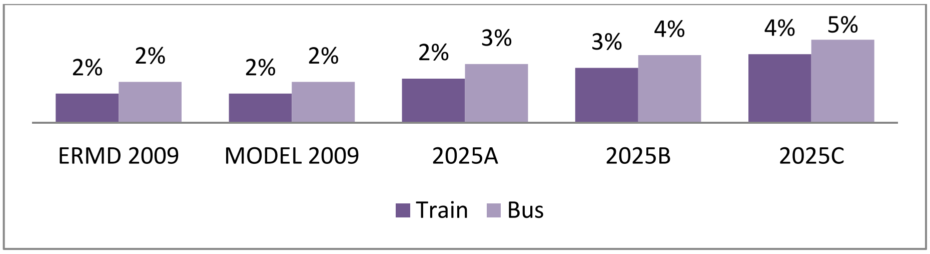


Fig. 16. Urban mixed, residential and rural/detached total consumed land.

Considering transport results the main interest was to analyze the evolution of modal share between car and transit and how TOD policies (scenario B), linked to integrated tariff and highway tools introduction (scenario C), could affect transport demand distribution. Anyway it should be specified that results are referred only to motorized trips, because Tranus simulates only inter-zonal trips (from zone to zone) and not intra-zonal trips (each zone internal trips). Moreover this assumption results unfavorable to verify hypothesis of TOD, because does not allow to consider mobility of proximity (active mobility), usually the most positively affected in TOD interventions. In particular scenario C results the most favorable referring to transit modal share (Fig. 17a and 17b).



a



b

Fig. 17. (a) Evolution of transport demand modal share (for motorized trips). (b) Evolution of transport demand modal share for trains and buses.

These data can be better analyzed if disaggregated in function of different territorial scales of the model. Best results can be found in municipalities of Lille metropolitan area (LMCU) and in urban zones, with a positive effect also in TOD zones. In general for all types of zones, transit modal share is almost doubled in scenario C (Fig. 18).

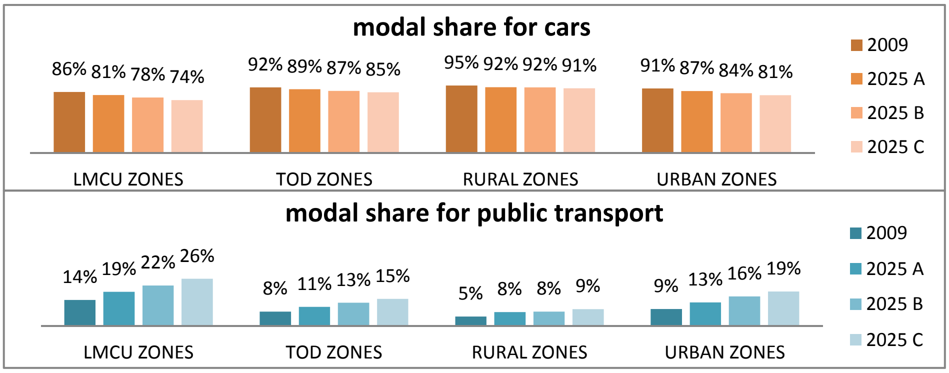


Fig. 18. Transit and car modal share results par zoning type.

Looking total trips data evolution, by train and bus (Fig. 19), can be seen a reduction in rural zones from scenario A to scenario B and C, because of the general reduction of total transport demand (due to migration of population and jobs in urban and TOD zones as showed in Fig. 13 and 14), confirming the trend of urban sprawl reduction after TOD policies application. It can be also observed how TOD zones have the greatest increase of trips by bus and trains in scenario C.

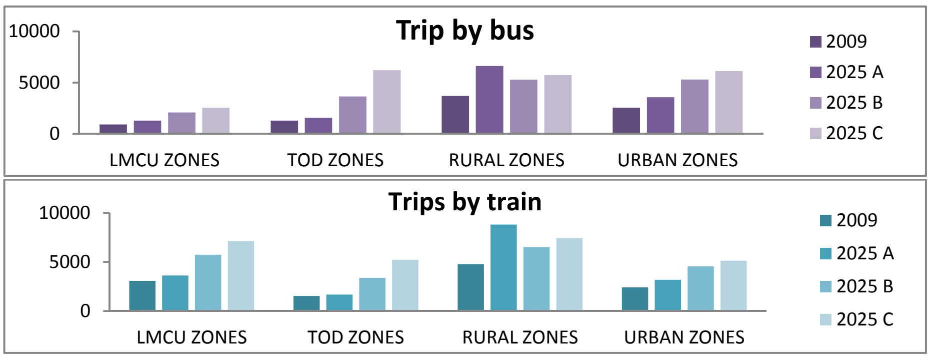


Fig. 19. Total trips by train and bus par zoning type.

Transport results for each TOD zones are then showed, referring to modal share (Fig. 20). Most interesting results can be found in TOD zones of Haubourdin, Seclin, Ostricourt, Santes-Wavrin and Phalempin-Libercourt and in general in rail corridors starting from Lille to Lens, Douai and Béthune. All these zones are in effect situated in the urban central area of the region, which is the most populated urban conurbation near the Lille metropolitan area. In addition these corridors are also located on the axis between Lille and Paris, characterized by important transport flows and then more reactive to transit service improvements.

Anyway there are some TOD zones, like in particular the TOD zone of Armentiéres, where transit modal share decreases in the last scenario (the most favorable to transit use). To check the reason of this unexpected tendency, Tranus outputs related to road network's level of service evolution, were analyzed. As shown globally, level of service of road network has a relevant improvement in scenario C (Fig. 21). If we consider the specific case of Armentéres TOD zone, it can be therefore argued that the important road congestion reduction of highway A25 in scenario C (Fig. 22), in addition to the strong car accessibility of this zone, especially to Lille metropolitan area, induces a regrow of car attractiveness and therefore of car use. The same occurrence can be found in correspondence of the TOD zone located in the south of Valenciennes (Denain Somain, Bouchain), where in scenario C highway section of A2, that connects the TOD zone with Valenciennes (north) and Cambrai (south), is completely de-congested and characterized by the maximum service level (Level A, not colored) (Fig. 22).

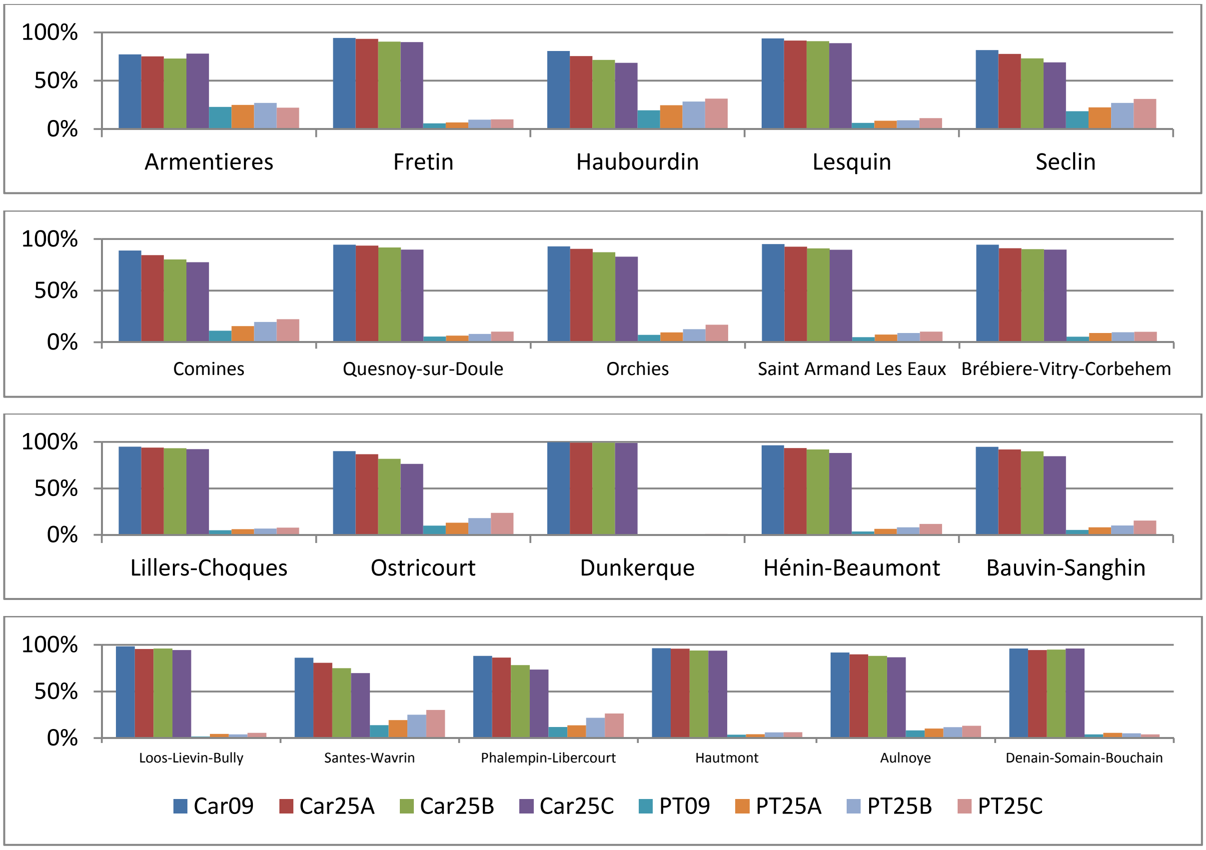


Fig. 20. Modal share between car and public transport for TOD zones.

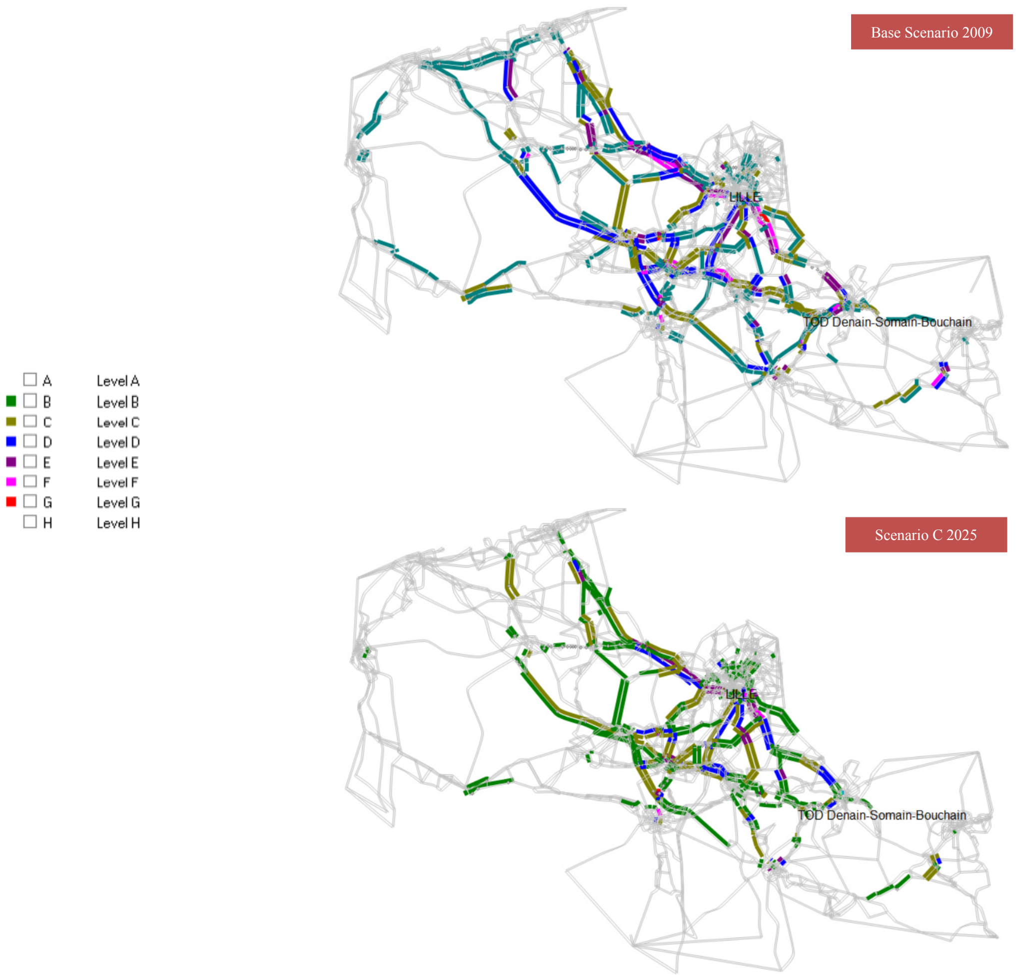


Fig. 21. Level of service (Tranus output) of regional road network, in base scenario (2009) and scenario C (2025).

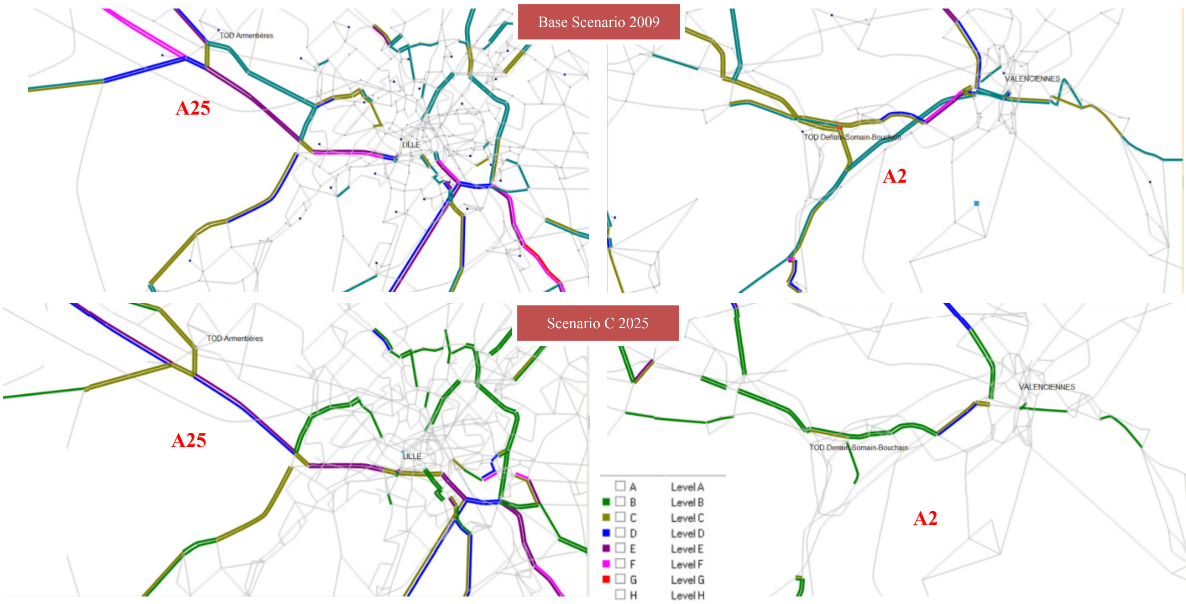


Fig. 22. Level of service (Tranus output) for highway section of A25 near Arméntieres and of A2 between Valenciennes and Cambrai, in base scenario (2009) and scenario C (2025).

6. Conclusions

In this paper results of a land use and transport Tranus model for the French region of North-Pas-de-Calais are presented. Positive effects, expected from the application of TOD policies in some selected rail corridors and stations (for their TOD potential), are confirmed by results. Scenario A demonstrates how land consumption and car dependency would increase without the application of specific contrasting policies. Scenario B and C confirmed that TOD policies help to concentrate urban development and activities near transit corridors, inducing higher transit use (even if not as much as expected for rail mode). Best results are referred to rail corridors located between Lille, Lens and Douai. Moreover rail corridors located between Lens and Bethune and in the south of Valenciennes also confirmed their TOD potential and capacity to attract households and jobs.

In the case of TOD zone of Armentiéres and Denain-Somain-Bouchain was instead found that in the scenario C, the progressive highway congestion reduction, due to the increase of transit modal share, induces a regrow of car attractiveness in these zones, because of the strong connection to the road network. This result could stimulate some new considerations about effects of transit use incitatory policies that don't consider a progressive road capacity reduction. It can be therefore concluded that TOD policies effects are largely more evident in contexts where a general economic and productive dynamism and a basic transport and land demand are present. This is the case of rail corridors above-mentioned, with best results in transit modal share after TOD interventions, which are located in the central urban area of the region and on the way between Lille and Paris. The increase of transit use induced by TOD policies appears however to be largely more incisive if linked with actions oriented to limit car use (scenario C: transit tariff integration; highway tools).

Finally Tranus confirms its capacity to model land use and transport interactions in multi scalar and regional networks, but also its strong complexity. Main difficulties are related to the conception of starting hypothesis, to data collection and to calibration. Tranus also needs a solid multidisciplinary approach and a not irrelevant working time for implementation, calibration and outputs analysis.

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