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Improving speed and frequency in the European rail system

Impact on accessibility and welfare

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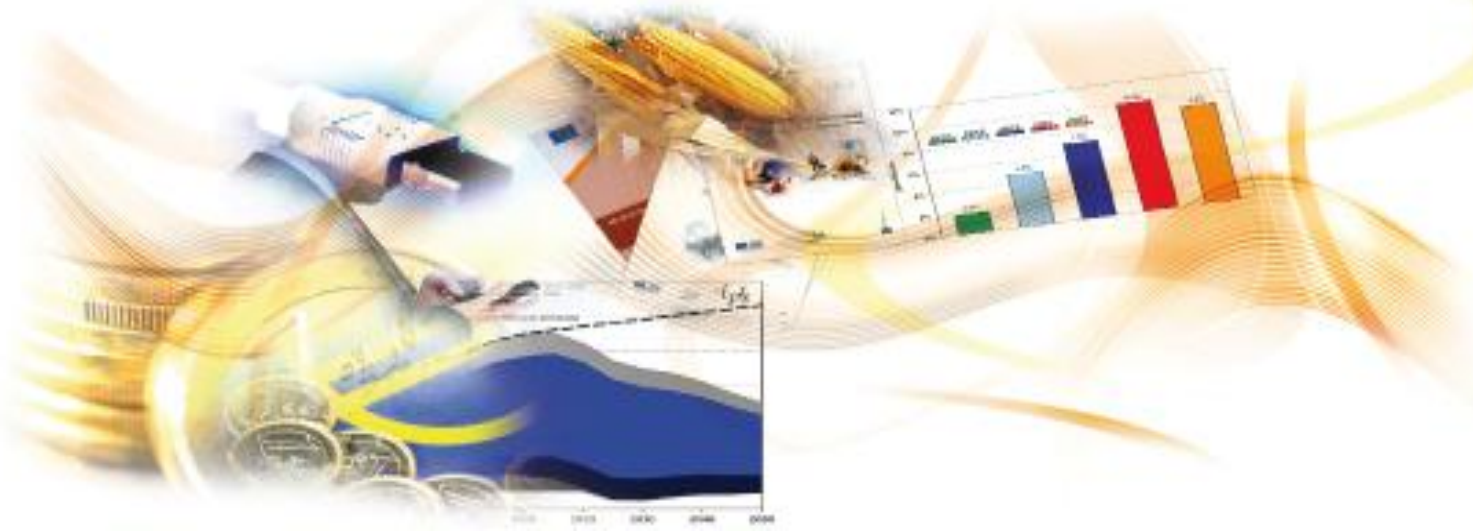

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Abstract

The report addresses passenger rail transport and its main purpose is to evaluate if and to what extent, reductions of the travel times or increases in train frequency in the European Railway System may lead to an increase in accessibility for users and a reduction of costs, resulting in an increase of consumer's surplus. Various scenarios considered. Two scenarios simulating increases of all speed to 90 km/h and 200km/h, one scenario assuming a decrease to 45 km/h and a scenario of increasing train frequency by 20% have been tested. The results provide insight into which parts of the rail network can provide higher benefits to the users through the improvement of quality of service.

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1. Introduction

It is widely accepted that "*transport infrastructure endowment influences competiveness of a Region; the provision of investment in transport infrastructure entails positive effects on productivity and growth, even if on the other side, heavy infrastructures (as railway lines) could affect negatively on the environment*" (5th Cohesion Report, 2010). The importance of transport networks for regional development has been demonstrated, among others, in the recent TIPTAP ESPON project (see Final report, 2013), which analyzed the territorial impacts of transport policies at NUTS3 level using the TRANSTOOLS model. In particular the TIPTAP project analyzed different scenarios and estimated the economic benefits from new infrastructure projects.

Building on the findings from the TIPTAP project, the JRC has explored the potential impact of improvements of the passenger rail network in particular, in order to evaluate how these could potentially improve accessibility for EU regions and increase welfare.

This report summarizes the results of the model simulations carried out in order to estimate the potential impacts of changes in the speed and frequency of rail passenger services across the EU. The simulations assumed a change in the quality of service on the whole network that would correspond to theoretical radically different speeds and frequencies. Four different scenarios were tested: two scenarios simulating increases of all speeds to 90 km/h and 200 km/h, one scenario assuming a decrease to 45 km/h and a scenario of increasing train frequency by 20%. The results provide insight into how the demand for passenger rail transport would react and where the higher benefits and costs in terms of accessibility and welfare gains can be expected. This information, in turn, can be useful for the prioritization of investment needs and the identification of parts of the rail passenger market where new demand may be generated.

2. Methodology

The impact of increasing speed or frequency on the EU rail network was simulated using the rail network of the TRANSTOOLS model. TRANSTOOLS provides a detailed network for passenger rail (see Figure 1) and includes an assignment module, Traffic Analyst[1], which allows the model to capture changes in route choice as a result of the changes in speed and frequency. The impacts on total transport demand and modal shift were simulated through linking TRANSTOOLS with model T (see Annex 2). The data on demand between origins and destinations at NUTS 3 level (ie provinces) is based on the ETISPlus[2] 2005 demand data. The post-processing analysis was carried out with utilities developed in Matlab, while the results for each zone (at NUTS3 level[3]) have been reported in easy-to-read ArcGIS maps.

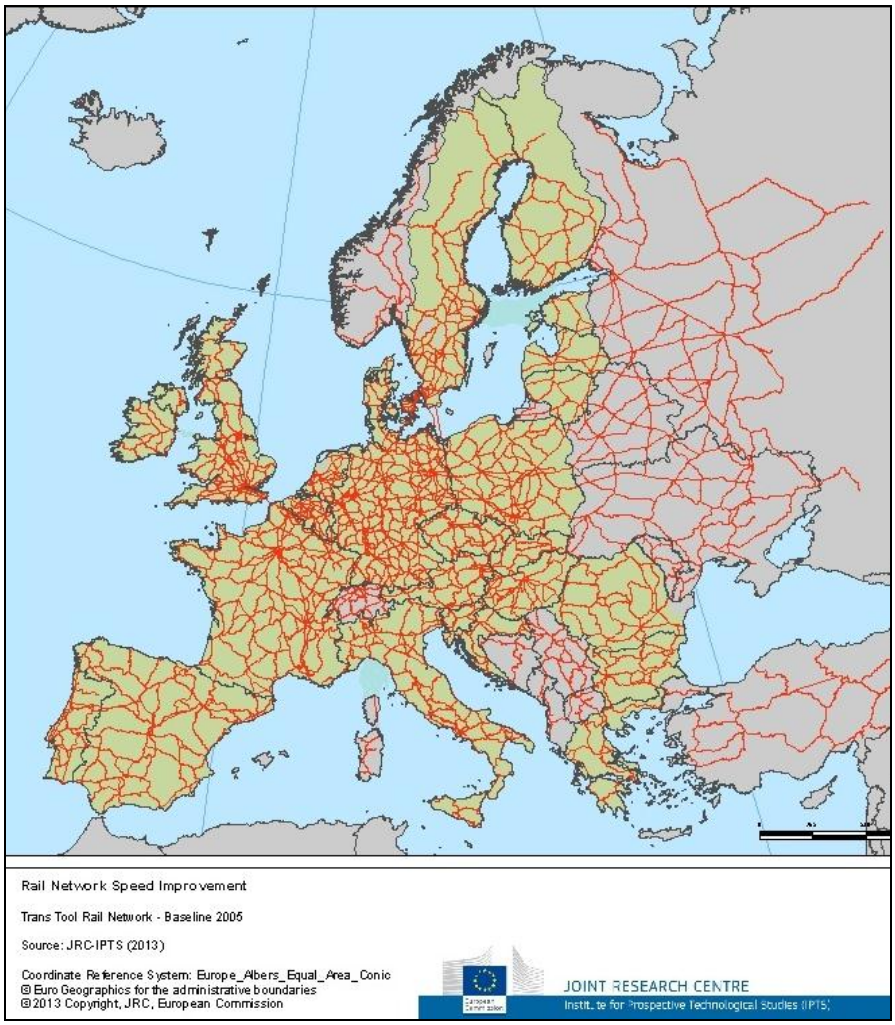


Fig. 1: Trans Tools Rail Network

[1] Commercial assignment tool developed by Rapidis (for more information see www.rapidis.com)
[2] ETISplus is a FP7 Project (European Transport policy Information System) on data collection for transport at EU level. For more information see www.etispus.eu
[3] The EU NUTS regional classification system is described in http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction)

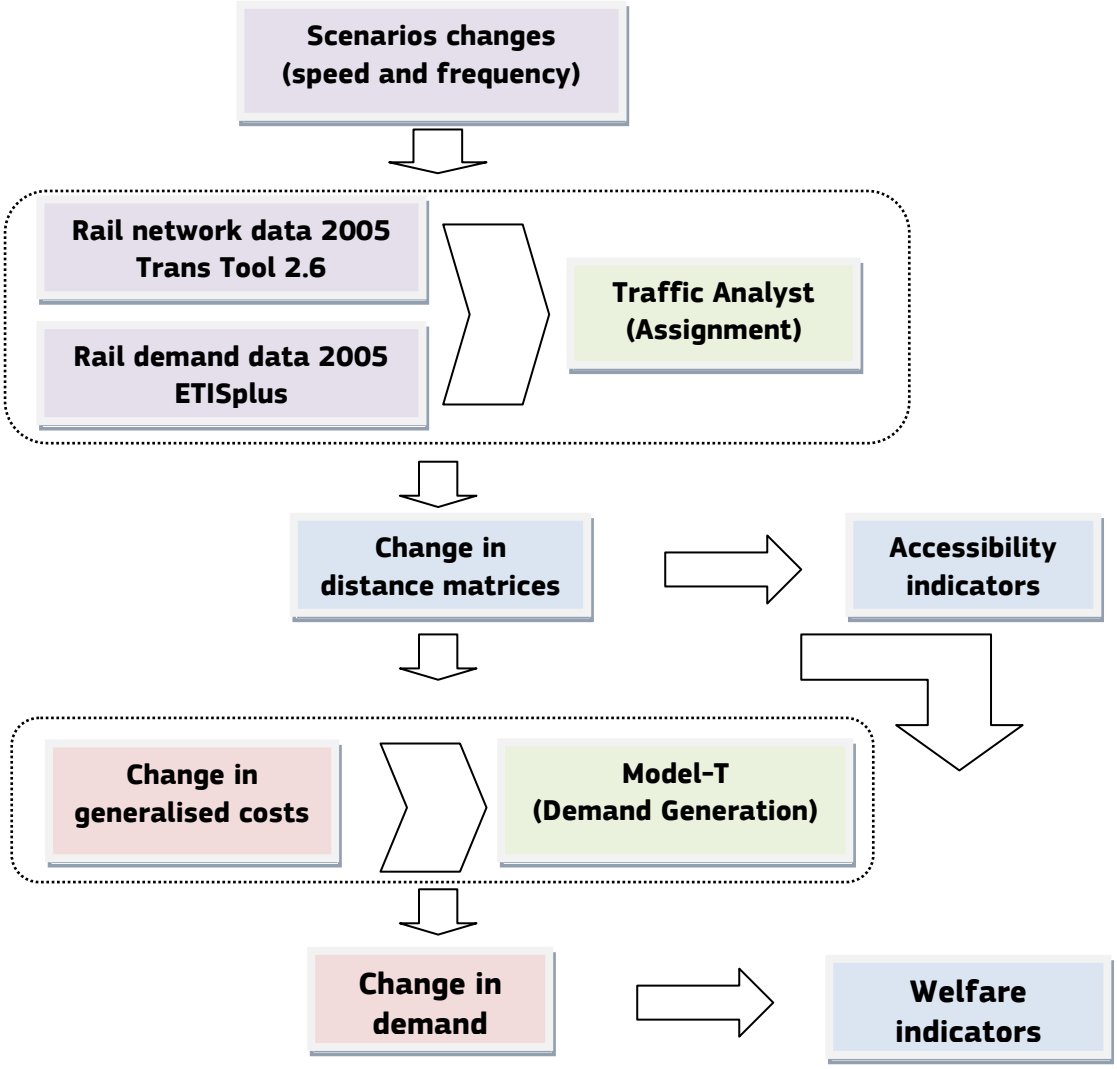


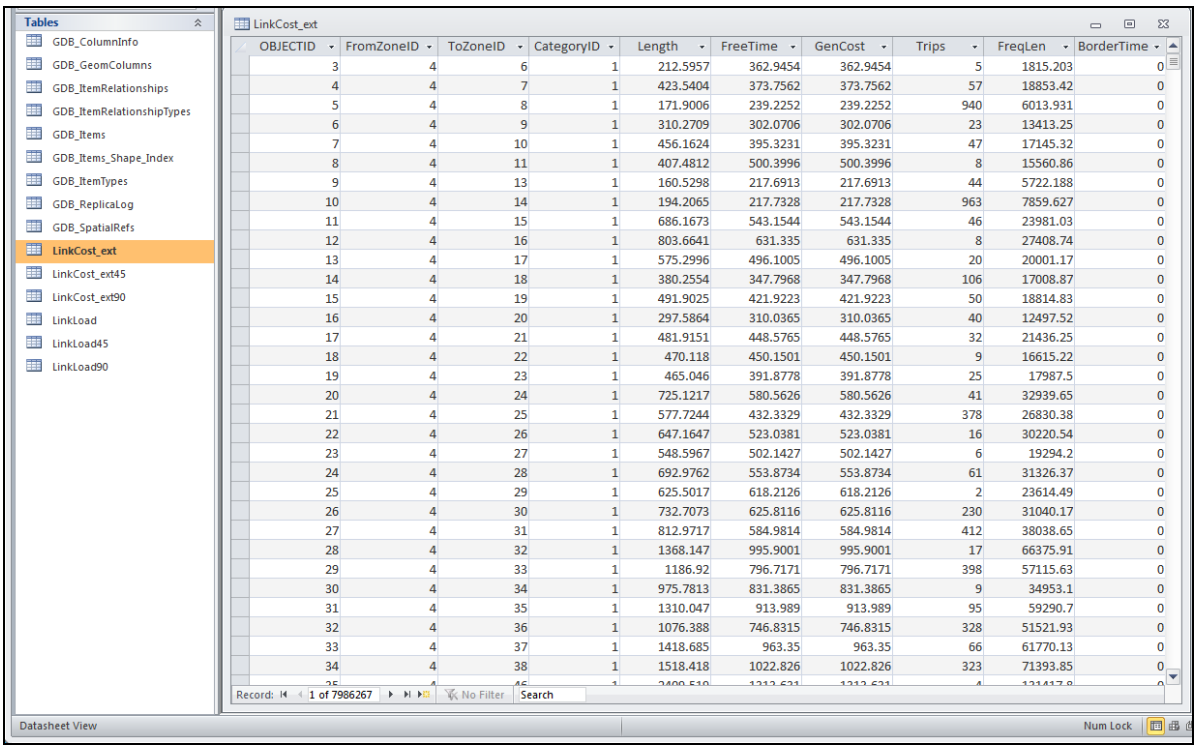
Figure 2: Flowchart of methodological steps

Figure 2 describes the flow of the simulation process and the main results delivered in each step. All simulations were carried out staring with the introduction of a change in the speed or frequency of passenger trains on the TRANSTOOLS rail network. The four scenarios were implemented by changing speed or frequency as follows:

- Scenario 200 km/h: Link speed increased to 200 km/h, for all links that currently have a speed lower than 200 km/h. For links with current speed higher than 200 km/h (high speed trains), no changes were introduced.

- Scenario 90 km/h: Link speed increased to 90 km/h, for all links that currently have a speed lower than 90 km/h. For links with current speed higher than 90 km/h, no changes were introduced.
- Scenario 45 km/h: Link speed decreased to 45 km/h, for all links that currently have a speed higher than 45 km/h. For links with current speed lower than 45 km/h, no changes were introduced.
- Frequency increase: Frequency of all train is increased by 20%.

The combination of TRANSTOOLS with the model T demand module was run for all four scenarios using the ETIS+ demand matrices and the updated rail networks reflecting the changes in speed or frequency. The first major step in the simulation consists of performing route assignment (with Traffic Analyst) using the new speed or frequency assumptions. The outcome of the assignment phase consists of new traffic volumes on each link and, most important, an update table of generalized costs and trip duration (''LinkCost_ext'' matrix, table 1)



OBJECTID	FromZoneID	ToZoneID	CategoryID	Length	FreeTime	GenCost	Trips	FreqLen	BorderTime
3	4	6	1	212.5957	362.9454	362.9454	5	1815.203	0
4	4	7	1	423.5404	373.7562	373.7562	57	18853.42	0
5	4	8	1	171.9006	239.2252	239.2252	940	6013.931	0
6	4	9	1	310.2709	302.0706	302.0706	23	13413.25	0
7	4	10	1	456.1624	395.3231	395.3231	47	17145.32	0
8	4	11	1	407.4812	500.3996	500.3996	8	15560.86	0
9	4	13	1	160.5298	217.6913	217.6913	44	5722.188	0
10	4	14	1	194.2065	217.7328	217.7328	963	7859.627	0
11	4	15	1	686.1673	543.1544	543.1544	46	23981.03	0
12	4	16	1	803.6641	631.335	631.335	8	27408.74	0
13	4	17	1	575.2996	496.1005	496.1005	20	20001.17	0
14	4	18	1	380.2554	347.7968	347.7968	106	17008.87	0
15	4	19	1	491.9025	421.9223	421.9223	50	18814.83	0
16	4	20	1	297.5864	310.0365	310.0365	40	12497.52	0
17	4	21	1	481.9151	448.5765	448.5765	32	21436.25	0
18	4	22	1	470.118	450.1501	450.1501	9	16615.22	0
19	4	23	1	465.046	391.8778	391.8778	25	17987.5	0
20	4	24	1	725.1217	580.5626	580.5626	41	32939.65	0
21	4	25	1	577.7244	432.3329	432.3329	378	26830.38	0
22	4	26	1	647.1647	523.0381	523.0381	16	30220.54	0
23	4	27	1	548.5967	502.1427	502.1427	6	19294.2	0
24	4	28	1	692.9762	553.8734	553.8734	61	31326.37	0
25	4	29	1	625.5017	618.2126	618.2126	2	23614.49	0
26	4	30	1	732.7073	625.8116	625.8116	230	31040.17	0
27	4	31	1	812.9717	584.9814	584.9814	412	38038.65	0
28	4	32	1	1368.147	995.9001	995.9001	17	66375.91	0
29	4	33	1	1186.92	796.7171	796.7171	398	57115.63	0
30	4	34	1	975.7813	831.3865	831.3865	9	34953.1	0
31	4	35	1	1310.047	913.989	913.989	95	59290.7	0
32	4	36	1	1076.388	746.8315	746.8315	328	51521.93	0
33	4	37	1	1418.685	963.35	963.35	66	61770.13	0
34	4	38	1	1518.418	1022.826	1022.826	323	71393.85	0

Table 1: ''LinkCost_ext'' matrix – Scenario Do-Nothing, Baseline 2005

2.1. Accessibility analysis

Regarding the accessibility analysis, for each alternative scenario (speed decreased at 45 km/h, or increased up to 90 and 200 km/h as described above) the characteristics of the network (input data) have been changed and the ALL-OR-NOTHING assignment module (with generalized cost depending only on the travel time and on the border time where significant) has been run, evaluating the new travel times between each couple OD.

A different procedure has been utilized only for the 'frequency increase' scenario which assumes an increase by 20% of the frequencies of trains on the whole railway network. Although the ETISplus data (inputs) provide the frequencies on each link of the network, the utilized ALL-OR-NOTHING assignment module does not consider these frequencies in the calculation of the generalized cost, nevertheless it returns in the ''LinkCost_ext'' matrix (see tab. 1) a FreqLength value (frequency per length) for each couple of origin and destination.

To take in account the frequency of services, a post-process data analysis has been implemented in Matlab based on the results of the assignment for the baseline scenario (2005).

In practice, the travel time is assumed to be equal to the sum of the time on board plus a waiting time (depending on the frequency)[4]:

$$t_{travel} = t_{onboard} + t_{waiting}$$

Assuming that the travel on board will not change (the analysis has hypothesized only increase in frequencies, not improvements in infrastructures or trains), variations in travel time correspond to variations in waiting time (and so in frequency):

$$\Delta t_{travel} = \Delta t_{onboard} + \Delta t_{waiting} = \Delta t_{waiting}$$

In particular, considering the waiting time as half of the head time (so half of the inverse of the frequency):

$$t_{waiting} = \frac{1}{2} * headtime = \frac{1}{2} * \frac{1}{freq}$$

and introducing an increase of 20% in frequency for each couple O/D gives:

$$\Delta t_{travel} = \Delta t_{waiting} = \frac{1}{2} * \left(\frac{1}{freq_{2005}} - \frac{1}{1.2 * freq_{2005}} \right) = \frac{1}{2} * \left(\frac{1}{freq_{2005}} - \frac{5}{6 * freq_{2005}} \right) = \frac{1}{12} * \frac{1}{freq_{2005}}$$

[4] For the frequency and the travel on board, it was considered the total length and time for each couple of origin and destination provided in the ''LinkCost_ext'' matrix, so including also the effects of the connectors.

Reassuming, based on the results of the ALL-OR-NOTHING assignment for the baseline scenario (2005), it has been evaluated in Matlab for each couple of origin and destination the variation in travel time that could correspond to an increment of 20% of frequency.

The topics of accessibility and potential accessibility indicators have been widely treated in the scientific literature (Schürmann et al., 1997; Wegener et al., 2002; Spiekermann and Neubauer, 2002, Geurs et al., 2001, Salze et al., 2011) and also in various European documents (e.g. ESPON projects, Cohesion reports, etc.). Accessibility could be defined as ''the amount of effort for a person to reach a destination'' or ''the number of activities which can be reached from a certain location'' (Geurs et al., 2001); this report considers three different types of indicators, founded on the concepts of potential and daily accessibility.

Potential accessibility is based on the assumption that the attraction of a destination increases with size, and declines with distance, travel time or cost. Destination size is usually represented by population or economic indicators such as GDP or income. Accessibility to population is seen as an indicator for the size of market areas for suppliers of goods and services; accessibility to GDP as an indicator of the size of market areas for suppliers of high-level business services (ESPON, 2007). *Potential accessibility is a construct of two functions, the activity function representing the activities (or opportunities to be reached) and the impedance function representing the effort, time, distance or cost needed to reach them* (Wegener et al., 2002); it can be analyzed for different transport mode:

$$A_{im}(t) = \sum_j W_j(t) * F(c_{ij}(t))$$

where $A_{im}(t)$ is the accessibility of zone *i* by mode *m* (rail in our analysis) in year *t*, $W_j(t)$ is the activity to be reached at zone *j* (we have considered the population of the destination *j*) and $F(c_{ij}(t))$ is the impedance function depending from the generalized cost (c_{ij}) of reaching area *j* from area *i*; the attraction term sometimes (not in this study) is weighted by an exponent α greater than one (W_j^{α}) to take account of agglomeration effects. Summarizing, A_i represents the total of the activities reachable in *j* weighted by the ease of getting from *i* to *j*.

Regarding the impedance function, it has long been understood that the interaction between locations declines with the increasing disutility (distance, time, and costs) between them. *In general, the perception and valuation of the distance between an origin and a destination differ according to transport modes, purpose of trips, characteristics of the household and of the destination* (Geurs et al., 2001); in the present report we focused on rail mode, on the population of destination and on tree different purpose of trips (business, work/commute, non-work) even if the reported results are referred only to their total.

Several forms of distance decay (or impedance) function have been used in past accessibility studies; this study considers five different shapes depending on travel time (disutility):

- A negative exponential function $F(t_{ij}) = e^{-\beta t}$ with β=0.005;
- A generalized logistic function dropping to almost zero after four hours (representing a potential daily accessibility indicator, i.e. the total population that can be reached from the region *i* within a certain time or cost limit, in this case 4 hours), with equation:

$$F(t_{ij}) = \frac{1}{\left(1 + e^{-\alpha(t-t_0)}\right)}$$ with α=-0.03 and t_0 = 150 minutes;

- An *'ad hoc'* function dropping to zero after four hours (see the following figure)
- A generalized logistic function dropping to almost zero after five hours, with equation $$F(t_{ij}) = \frac{1}{\left(1 + e^{-\alpha(t-t_0)}\right)}$$ with α=-0.025 and t_0 = 180 minutes;
- An *'ad hoc'* function dropping to zero after five hours (see the following figure);

For ease reading and understanding, the following chapter 3.1 will report only the results in potential accessibility using the negative exponential function, while all the other obtained results are reported in the Annex.

The following figure reports the above described impedance functions, to better analyze and compare the shapes and the differences among of them.

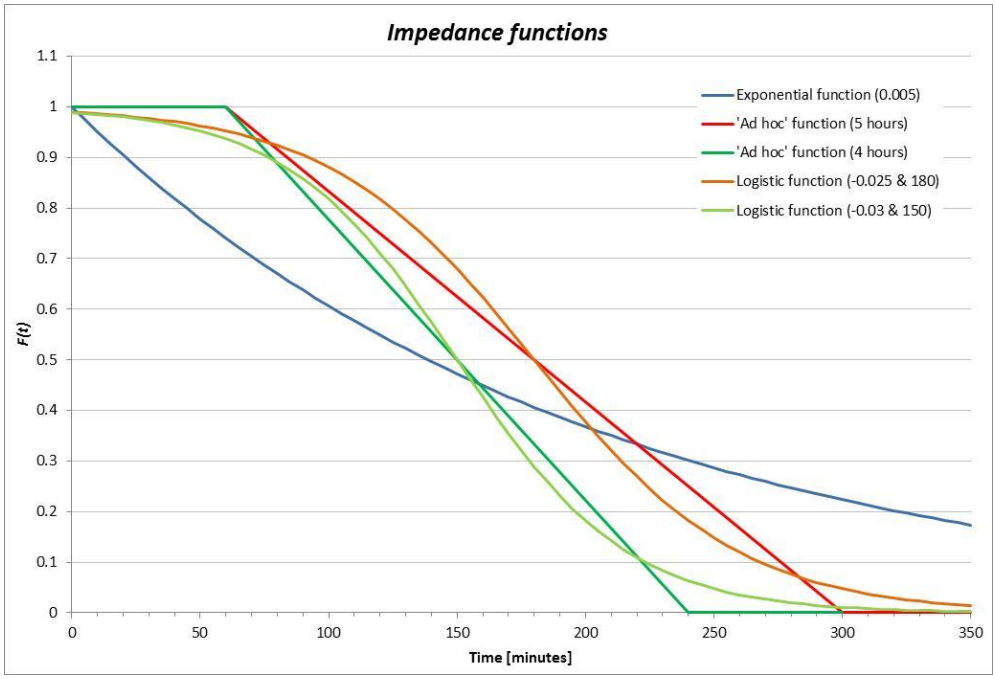


Fig. 3: Considered impedance functions

As also proposed in other studies (Spiekermann and Wegener, 1996; ESPON 2007, TIPTAP ESPON 2013) our analysis uses centroids of NUTS3 regions as origins and destinations. The ALL-OR-NOTHING assignment module calculates the minimum paths through the networks, i.e. the path with minimum travel times between the centroids of the NUTS3 regions. For each NUTS3 region the value of the potential accessibility indicator is calculated by summing up the population in all other regions weighted by the travel time to go there (by means of the impedance functions); of course each of the distance decay function entails different accessibility index and measure:

- for the exponential function, β has been set to 0.005, so considering a travel time between two regions of zero minutes the population of the destination region would be totally included (100%) in the potential accessibility of the origin region, while increasing the travel time its weight decreases, reaching a value of 0.5 after about 2 hours, and going down to about 0.2 after 5 hours;
- the logistic functions entail accessibility indicators which consider almost completely (> 95%) the population of destinations with distance in travel time lower than 60 minutes, and almost not at all the activity of zones away more than four (α=-0.03 and t_0 = 150 minutes) or five hours (α=-0.025 and t_0 = 180 minutes);
- finally this study proposes also two *'ad hoc'* impedance functions dropping linearly from 1 to zero with travel times between 1 hour and 4 (or 5) hours; since the calculations of accessibility have been implemented in Matlab with a post-processing application, it has not been difficult to reproduce these proposed shapes.

The obtained results have been exported and represented in easy-to-read ArcGis Maps; for each scenario and for each of the five above described accessibility indicators, different map types have been produced:

- Accessibility Index: since the accessibility indicators are in non-familiar units they have been standardized to the average accessibility of the EU28 member states (European average set to 100); these maps allow a ranking among of the NUT3 zones since they show which region is in a better or a worse position than the European average.

Additionally (to compare the variation in accessibility among the proposed scenarios and the baseline 2005):

- Percentage of variation of potential accessibility: this map type shows the relative change in potential accessibility between the new scenario and the 2005 baseline (or the low speed

scenario) in percent of the absolute value in 2005 (or in the low speed scenario). These maps have been produced only for the indicator with exponential impedance function.

- Index of variation in potential accessibility: the changes in accessibility for each NUT3 zone has been standardized to the average change of the EU28 member states (European average change set to 100); also these maps allow a ranking among of the NUT3 zones.

As already mentioned, the resulting maps are reported in the next chapter and/or in the Annex.

2.2. Consumer's surplus analysis

As already highlighted in the previous paragraph, the accessibility analysis has focused only on the new travel times (in the various scenarios) between each couple OD. To carry out the consumer's surplus analysis, instead, it has been necessary to forecast also the new demand level.

In particular, since the utilized T-Model demand generation module works on a country level, to evaluate the new level of demand for rail mode it has been estimated in Matlab the weighted average travel time on a country level for rail passenger (PAX RAIL AVGTIME) and for both scenarios (baseline and new scenario):

$$PAX\,RAILAVTIME_{Country} = \frac{\sum_{OD \in Country} \frac{Time_{OD}(\text{min})/60}{Length_{OD}(\text{km})} * Trips_{OD}}{\sum_{OD \in Country} Trips_{OD}}$$

Furthermore the percentage of change in PAX RAIL AVGTIME (between the hypothesized scenario and the baseline) has been imported in the T-model (Gladyste) module, obtaining the demand level for both the scenarios and so also the percentage of variation in demand at country level. This last result allows us to evaluate the change in demand for each couple of NUT3 regions (average between the countries of origin and destination).

At this stage, the consumer's surplus generated by the improvements on the rail system has been estimated, according to the following consideration:

The new scenario implies a reduction in travel cost[5] (specifically in travel time) while the demand increase from Q^0 to Q^1 as described from the new intersection between the demand curve D and the marginal cost curve S^1 (see fig. 4).

[5] Only the "Baseline (2005) versus Low Speed (45 km/h)" Scenario implies, instead, an increase in travel time and a reduction in demand.

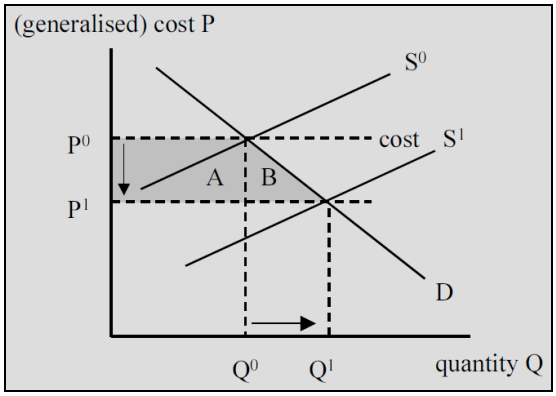


Fig. 4: Consumer's Surplus

Travelers who have already agreed to pay price P^0 (namely Q^0), are willing to pay more than the actual price (in terms of travel time) they do pay (P^1); for them, this implies an expense (or better in our analysis time) saving represented by the rectangle A. Furthermore, as consequence of the drop in cost (time) and the rise in consumption (demand), also for new users (Q^1 - Q^0) the benefits will outweigh the cost after the intervention (triangle B). The total consumer's surplus is represented by the dark grey surface in the previous figure (Area A + Area B), and can be calculated using the rule-of-half formula:

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

or (that is the same, but expressing the demand as number of trips by a specific mode and the price as generalized cost , in our case, travel time):

$$CS = \frac{1}{2}\sum\left(T_{ij}^{m^0} + T_{ij}^{m^1}\right)\left(c_{ij}^{m^0} - c_{ij}^{m^1}\right)$$

Actually, to evaluate and to represent the consumer's surplus for each NUTS3 Region, the summation in the previous formula has been extended to the couples *i* and *j* with fixed origin (*i*) and variable destination (*j*).

Moreover, also a monetary evaluation of the new scenario benefits has been implemented multiplying in the previous formula the decrease in travel time (so the time saving) for each trip purpose by the following monetary values of time VT (assumed exchange rate between pound and euro: 1.2), suggested in the reviewed literature (e.g. UK Department of transport, TAG Unit 3.5.6):

- Business (working time): 47.12 pound/h = 47.12 *1.2 euro/h
- Commuting (non-working time): 6.46 pound/h = 6.46*1.2 euro/h
- Non work (non-working time): 5.71 pound/h = 5.71*1.2 euro/h

Also for this analysis the increase in demand, the consumer's surplus and its monetary evaluation have been represented in different ArcGis map types:

- Absolute level of the parameter.
- Percentage of change, so the relative increase of the parameter compared to the starting situation (for examples the demand level in 2005, for the demand increase). The starting point is represented by the area P^0*Q^0 of the baseline scenario (see fig. 4) for the consumer's surplus increase, and by the product P^0*Q^0*VT (with VT, value of time) for the monetary indicator.
- Index of variation; the absolute variations for each NUT3 zone has been standardized to the average change of the EU28 member states (European average change set to 100).

3. Results

The results of this study are reported in the two following paragraphs. In particular from the analysis it appears quite evident that the current rail system (infrastructure and level of service) already benefits many regions mainly in Italy, Spain, Germany, UK, Austria, France, Belgium but improvements in speed or frequency could still increase significantly the accessibility and the consumer's surplus of the countries outside the European core, as Poland, Bulgaria, Romania, Slovakia, etc.. In particular by improving the frequencies on all the network profits will be will be spread out around the whole Europe, but mainly in various regions in some countries (including also areas outside the 'core') as Italy, France, UK, Bulgaria, Romania, Slovakia, etc. (see fig. 19-24) These results are also confirmed by the matrix in Annex 1 and by the maps reported in the Annex 2.

Noteworthy that the monetary evaluation of the consumer's surplus, representing an economic measure of what the travelers are willing to pay but they do not pay, could be considered a slightly indication of theoretically available (depending also from the actual possibility of frequencies increase) room in the market that could be filled through eventual competition where economically feasible (considering of course that competition would increase the services on the interested area/network)

3.1. Speed analysis

<u>Baseline scenario (do-nothing scenario, 2005):</u>

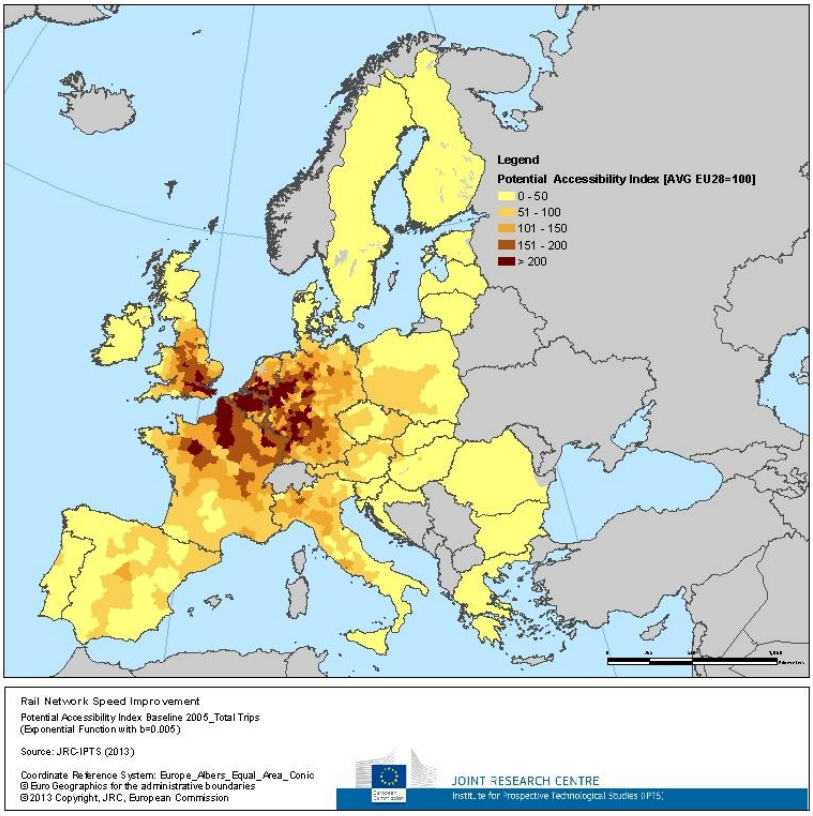


Fig. 5: Baseline scenario (2005), potential accessibility index with exponential function

Best-case scenario (200 km/h):

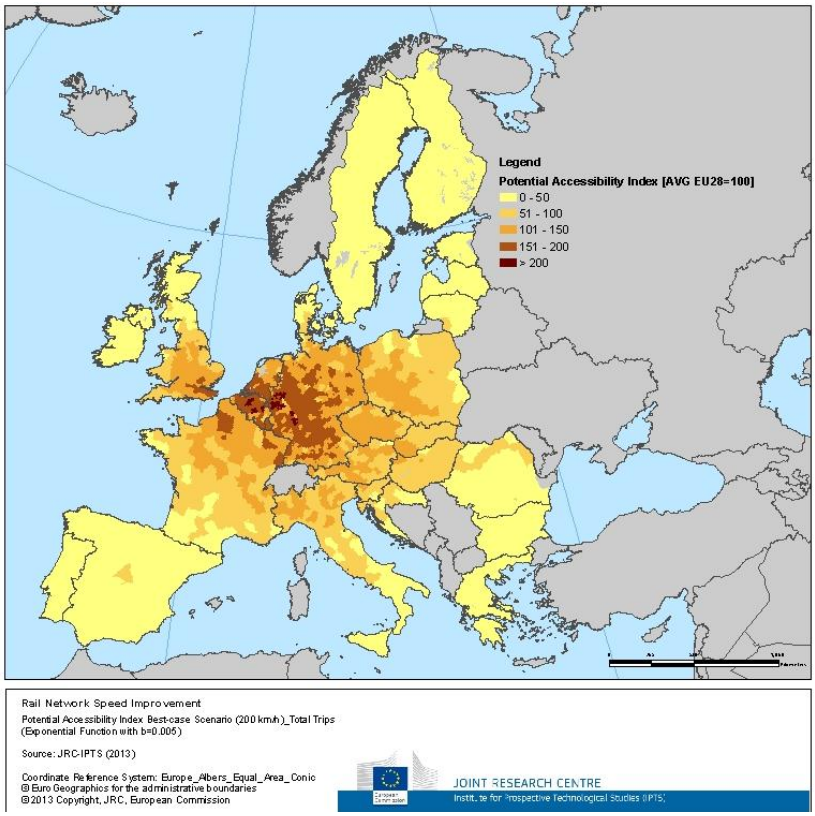


Fig. 6: Best-case scenario (200 km/h), potential accessibility index with exponential function

Low Speed Scenario (45 km/h):

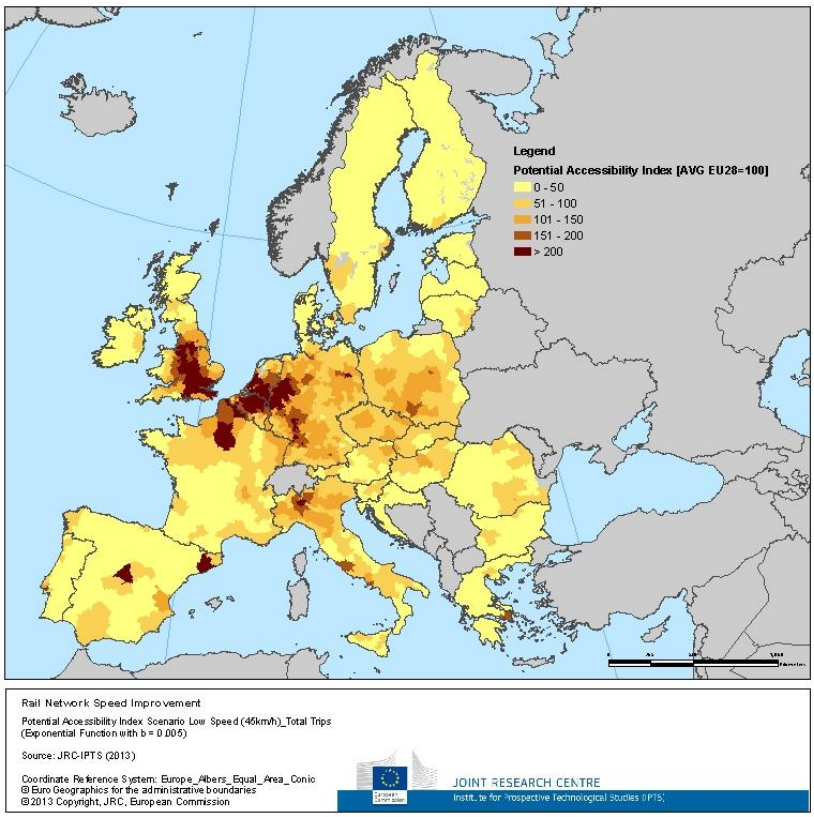


Fig. 7: Low speed scenario (45 km/h), potential accessibility index with exponential function

High Speed Scenario (90 km/h):

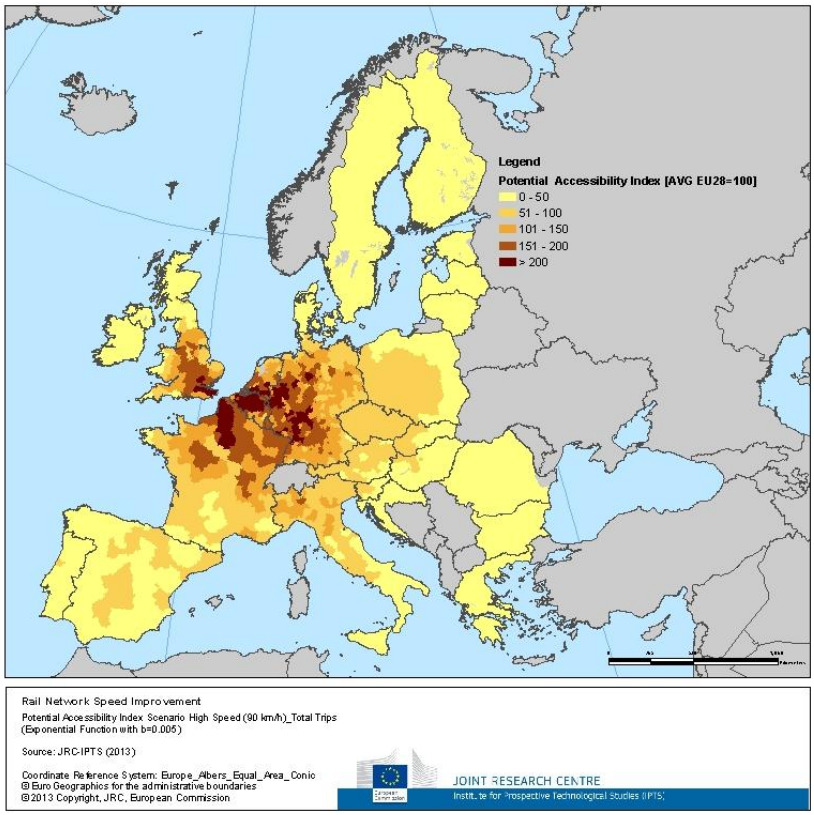


Fig. 8: High speed scenario (90 km/h), potential accessibility index with exponential function

Best-case Scenario (200 km/h) vs Baseline (2005):

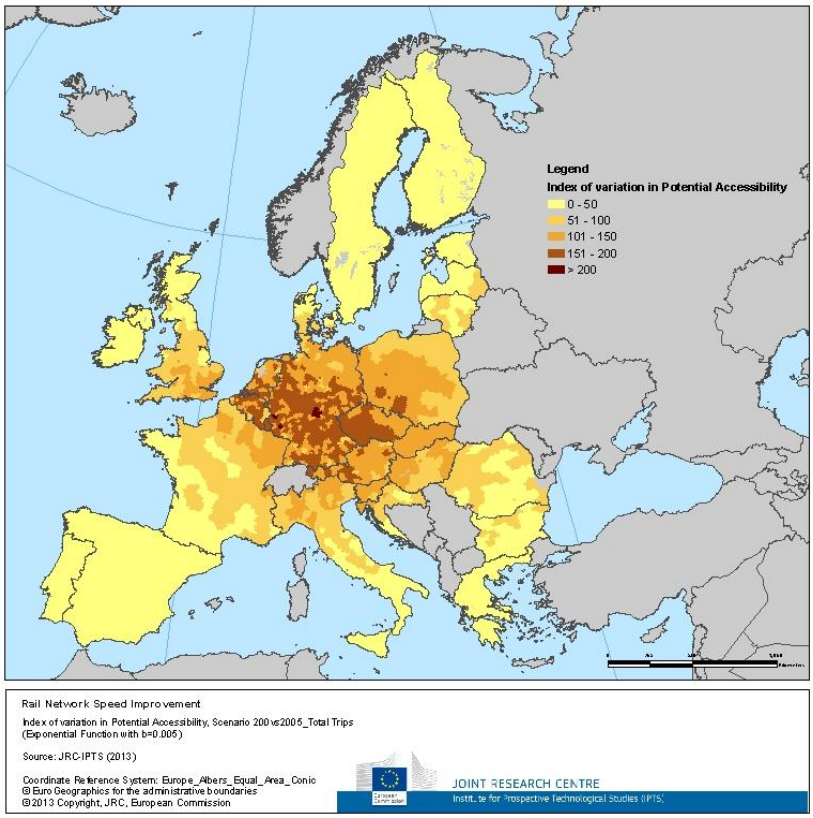


Fig. 9: Best-case Scenario (200 km/h) vs Baseline (2005), index of variation in potential accessibility with exponential function

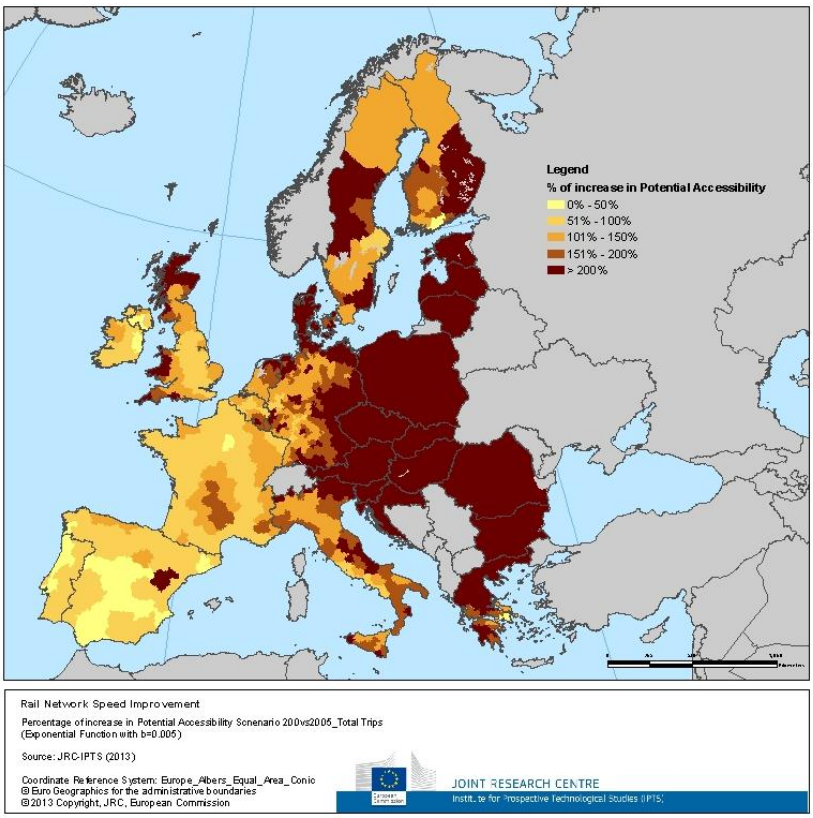


Fig. 10: Best-case Scenario (200 km/h) vs Baseline (2005), percentage of increase in potential accessibility with exponential function

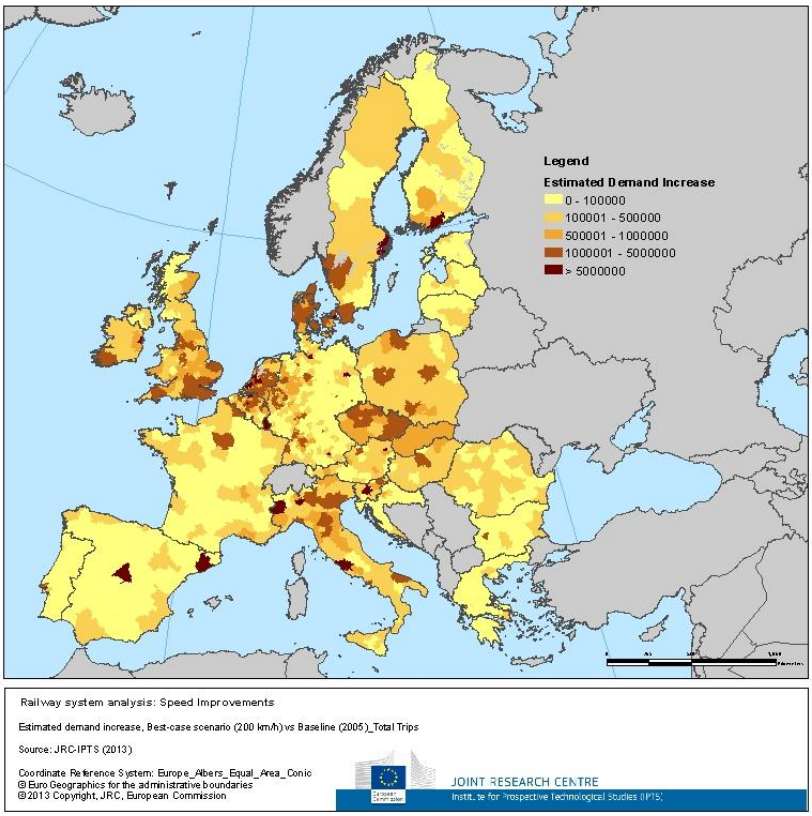


Fig. 11: Best-case Scenario (200 km/h) vs Baseline (2005), estimated demand increase [trips]

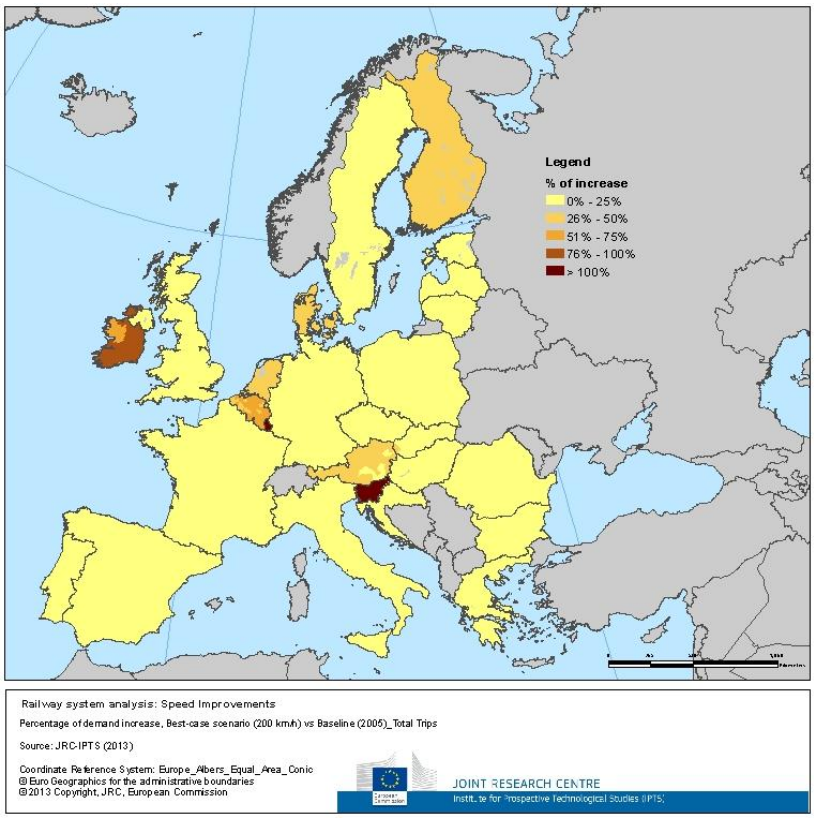


Fig. 12: Best-case Scenario (200 km/h) vs Baseline (2005), percentage of demand increase

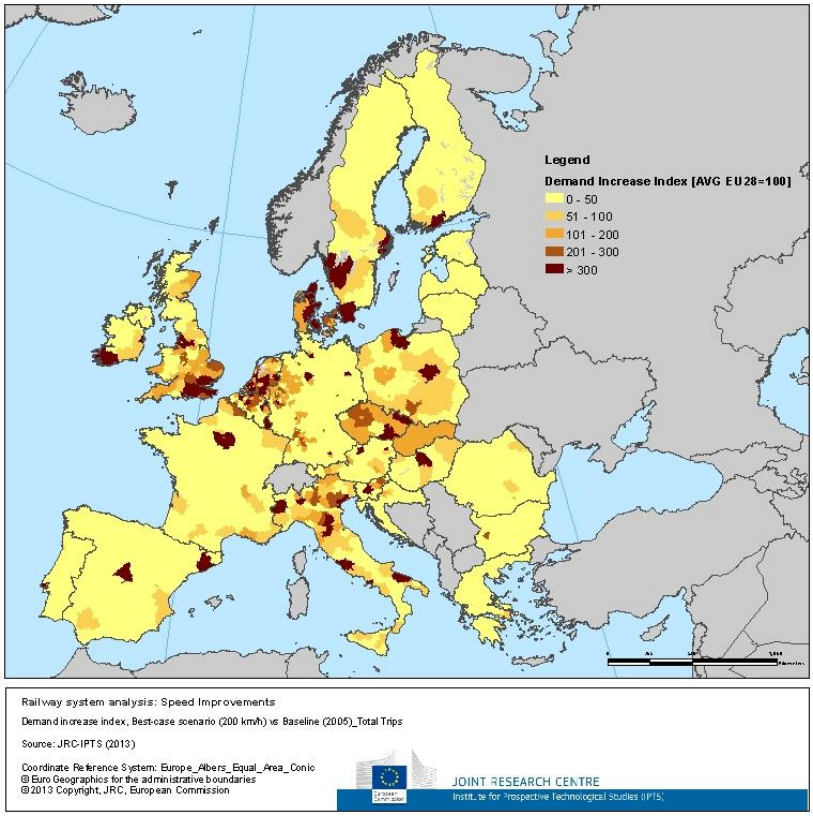


Fig. 13: Best-case Scenario (200 km/h) vs Baseline (2005), demand increase index

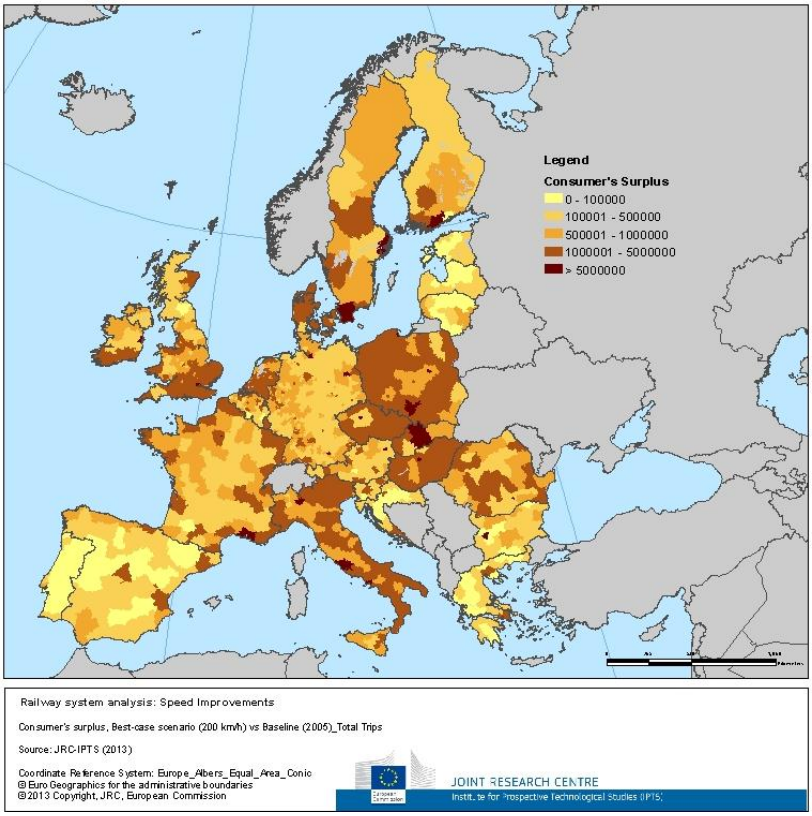


*Fig. 14: Best-case Scenario (200 km/h) vs Baseline (2005), estimated consumer's surplus [trips*hours]*

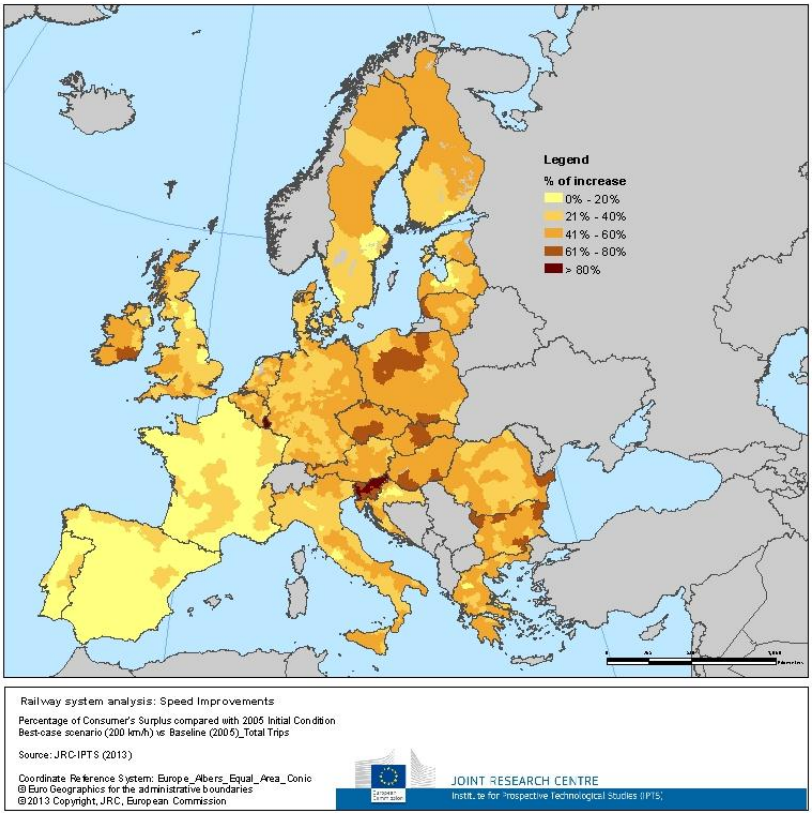


*Fig. 15: Best-case Scenario (200 km/h) vs Baseline (2005), percentage of consumer's surplus (compared with P_0*Q_0 of the Baseline 2005)*

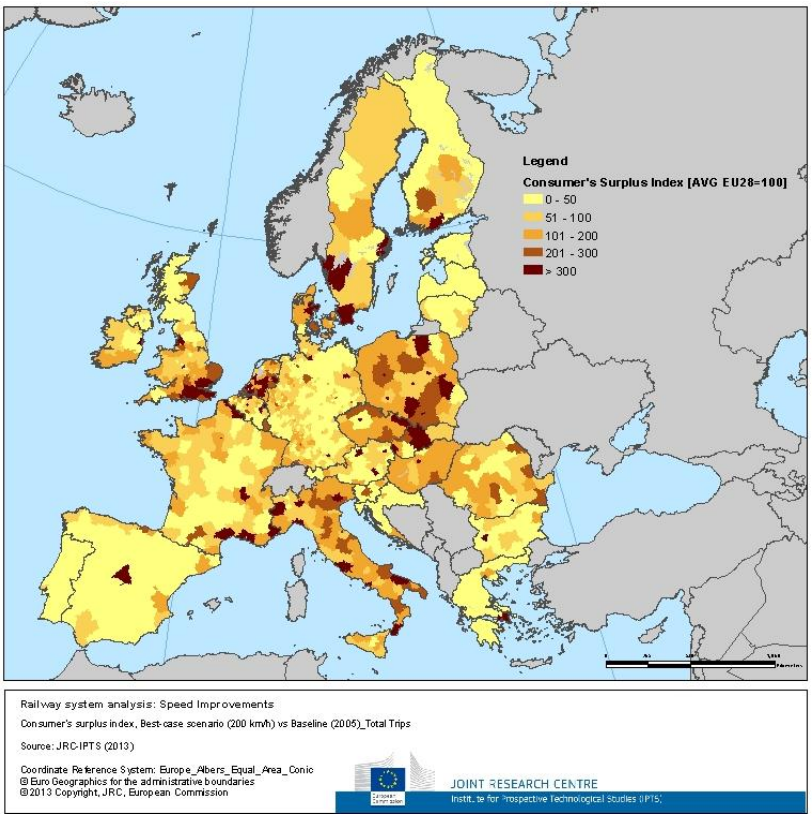


Fig. 16: Best-case Scenario (200 km/h) vs Baseline (2005), consumer's surplus index

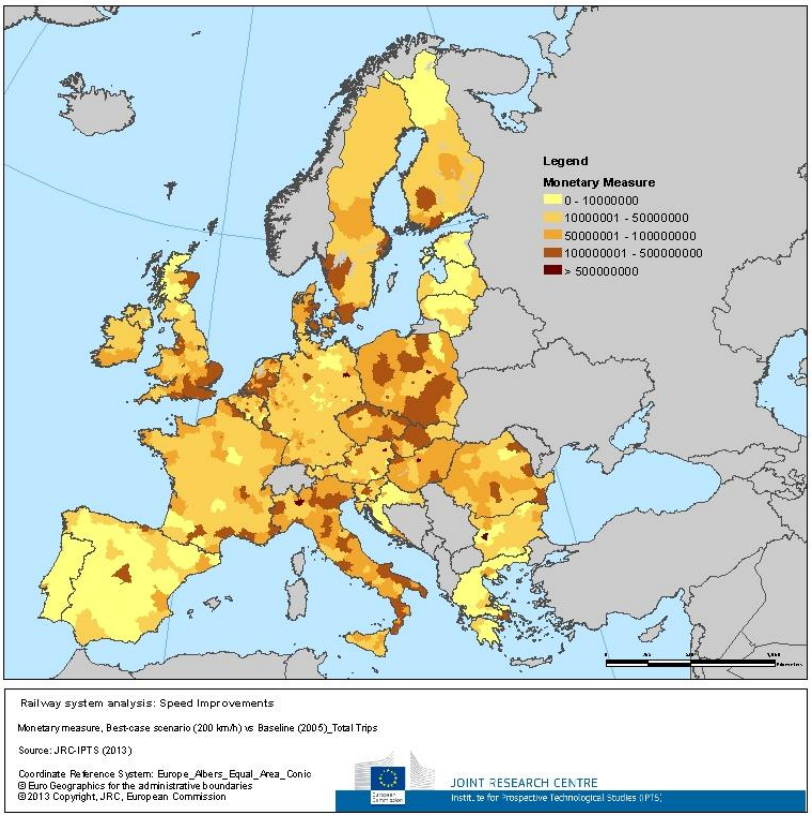


*Fig. 17: Best-case Scenario (200 km/h) vs Baseline (2005), monetary measure of consumer's surplus [trips*hours*euro]*

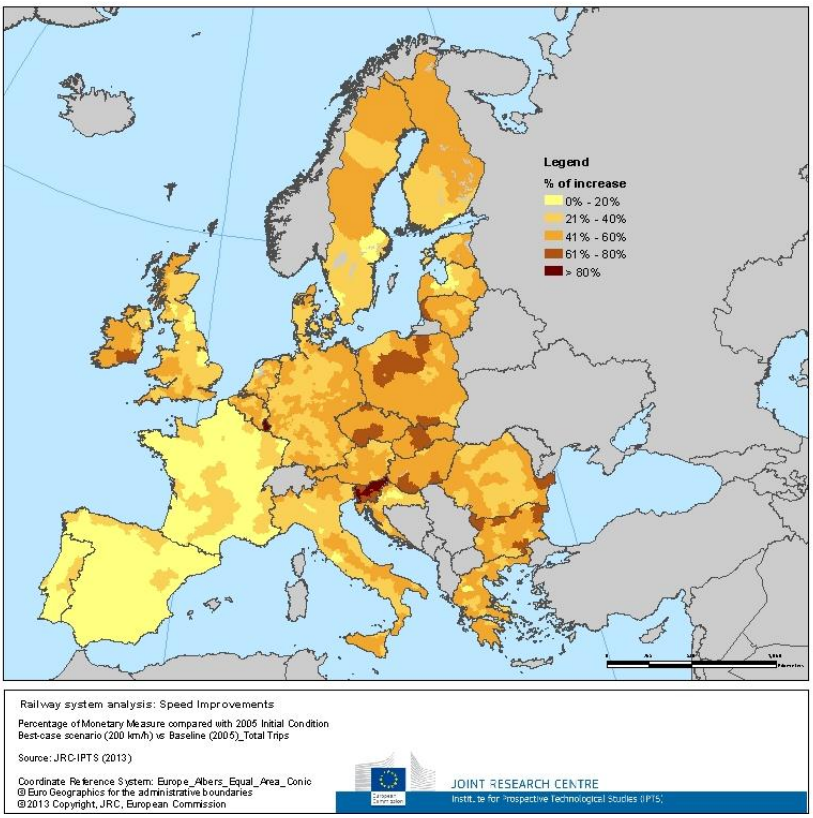


Fig. 18: Best-case Scenario (200 km/h) vs Baseline (2005), percentage of monetary measure (compared with P_0 Q_0*VT of the Baseline 2005)*

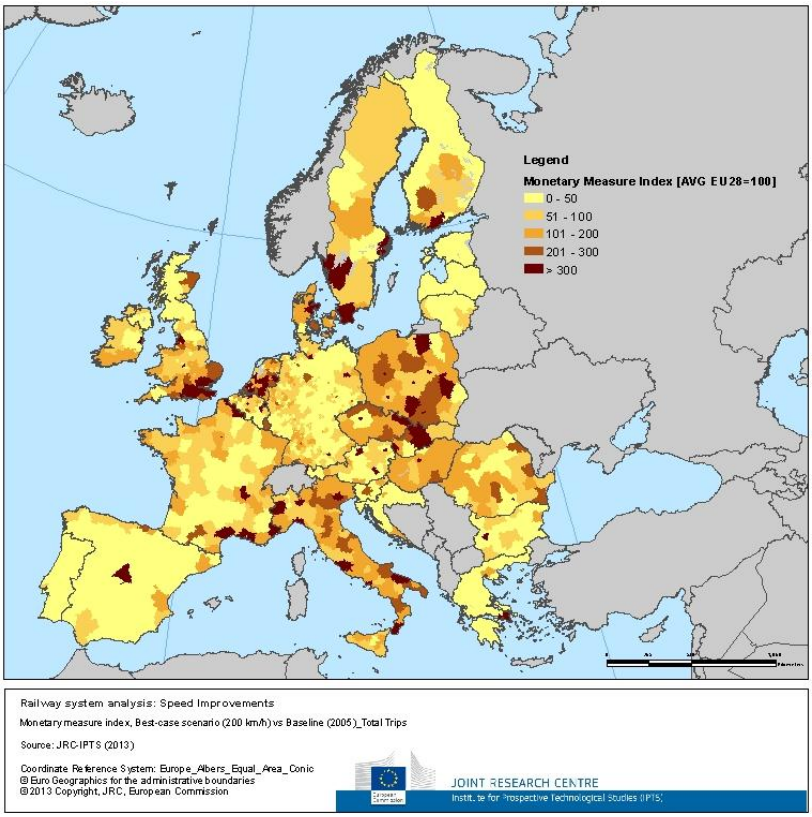


Fig. 19: Best-case Scenario (200 km/h) vs Baseline (2005), monetary measure index

High Speed Scenario (90 km/h) vs Baseline (2005) (and also Low Speed Scenario):

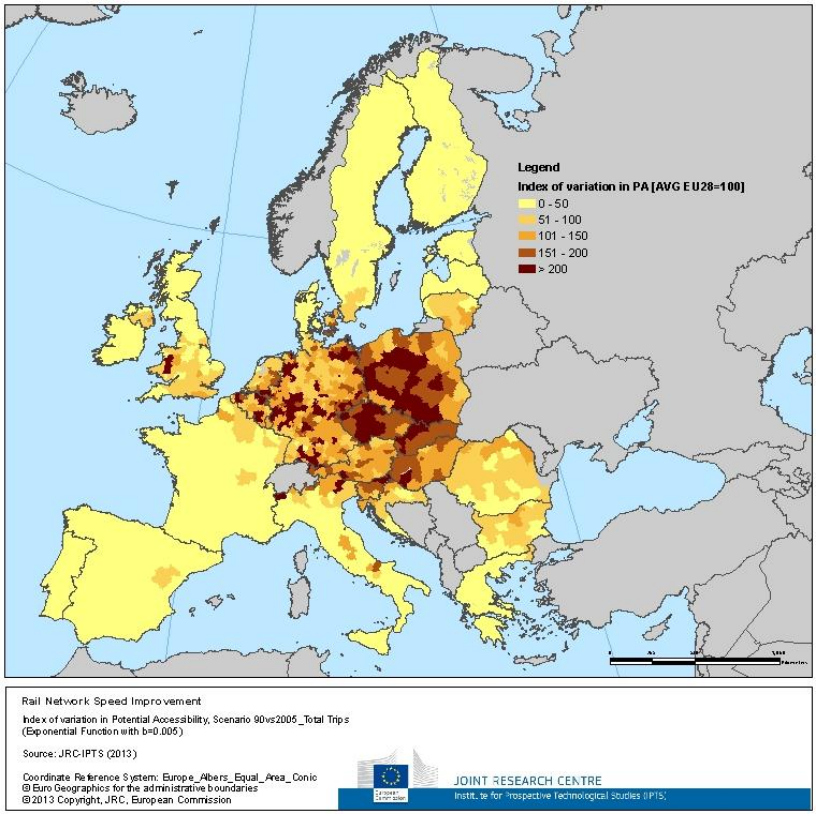


Fig. 20: High Speed Scenario (90 km/h) vs Baseline (2005), index of variation in potential accessibility with exponential function

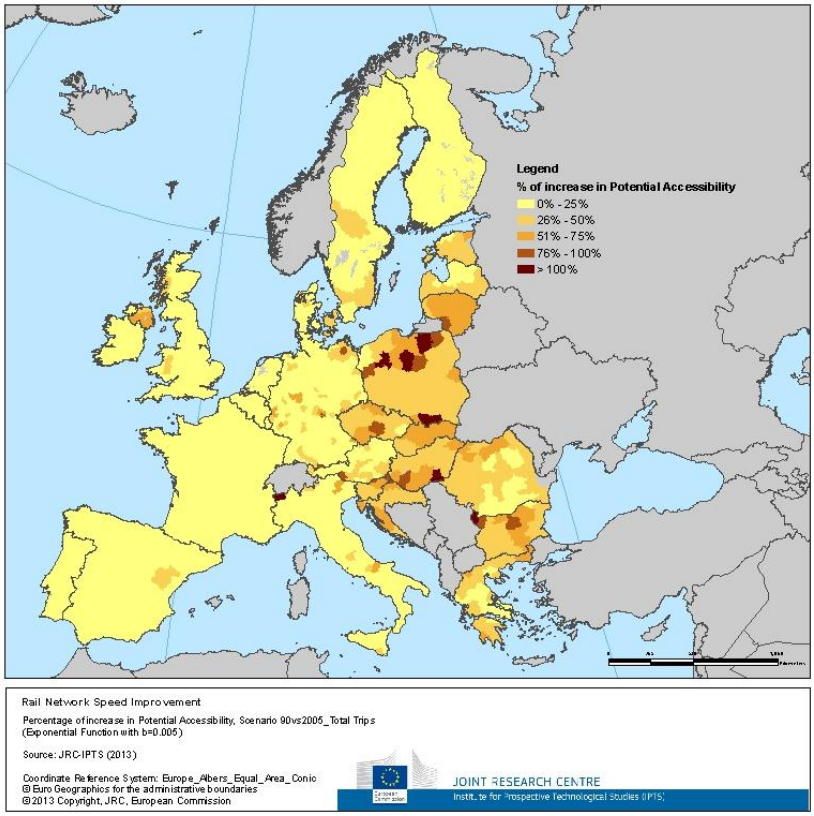


Fig. 21: High Speed Scenario (90 km/h) vs Baseline (2005), percentage of increase in potential accessibility with exponential function

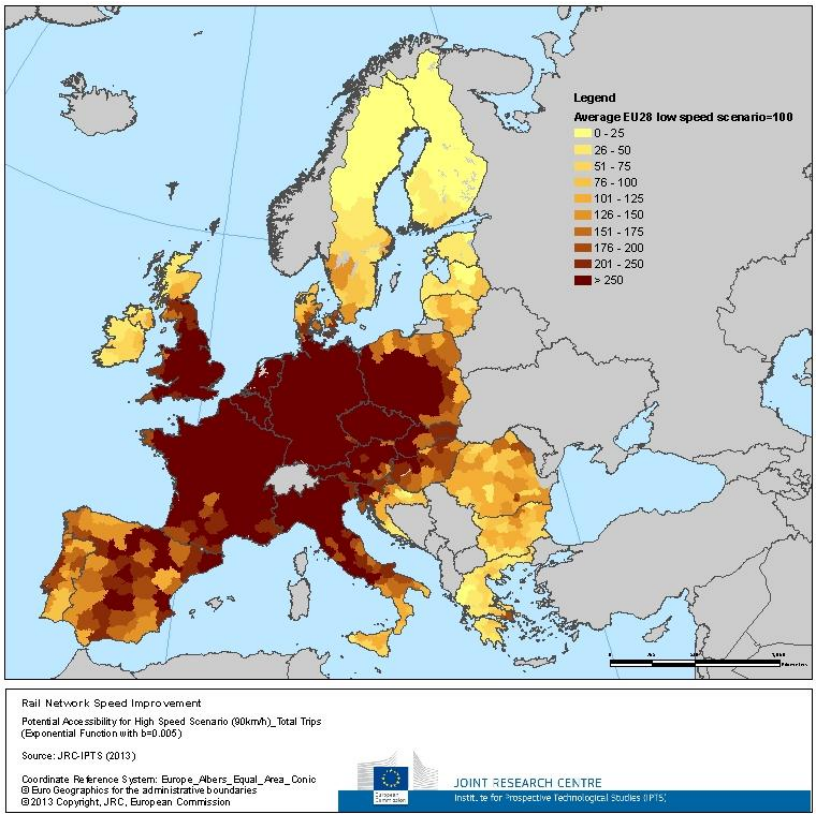


Fig. 22: High Speed Scenario (90 km/h) vs Low Speed Scenario (45 km/h), index of variation in PA with exponential function

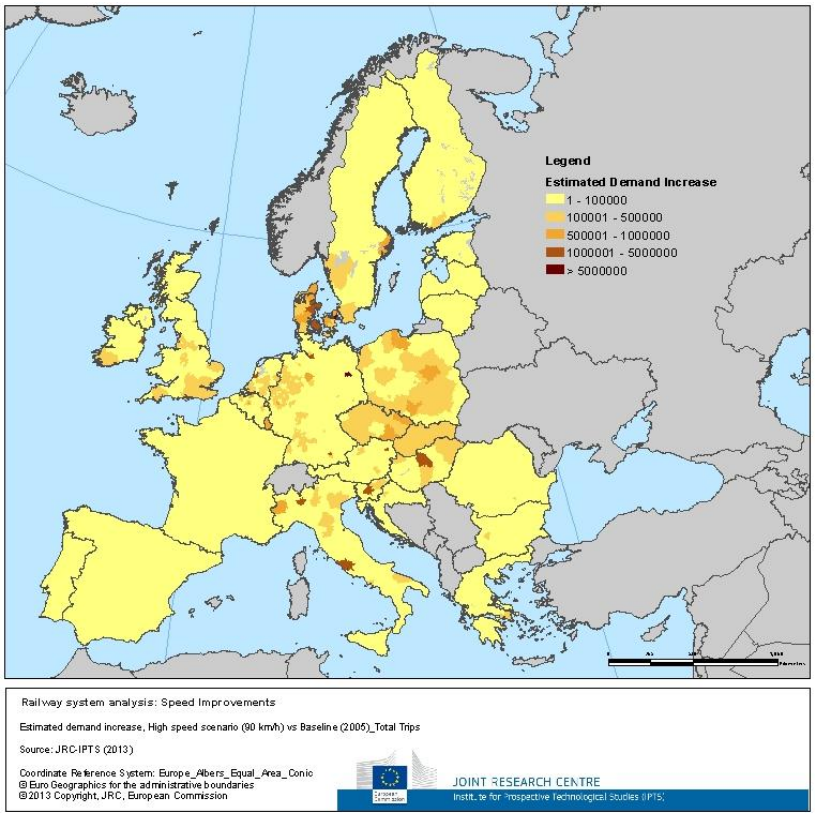


Fig. 23: High Speed Scenario (90 km/h) vs Baseline (2005), estimated demand increase [trips]

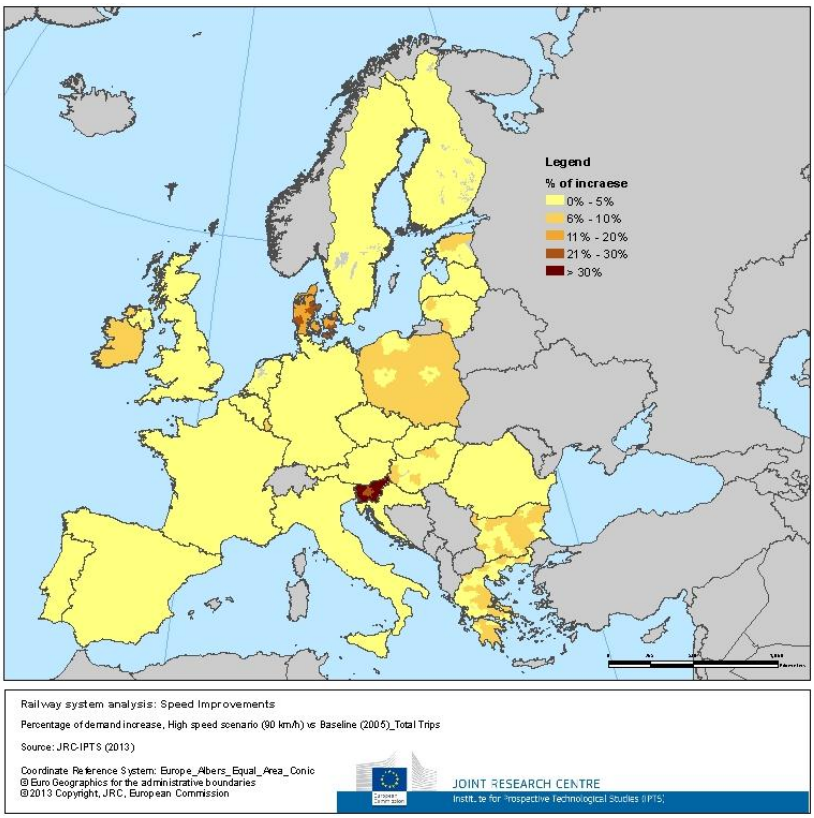


Fig. 24: High Speed Scenario (90 km/h) vs Baseline (2005), percentage of demand increase

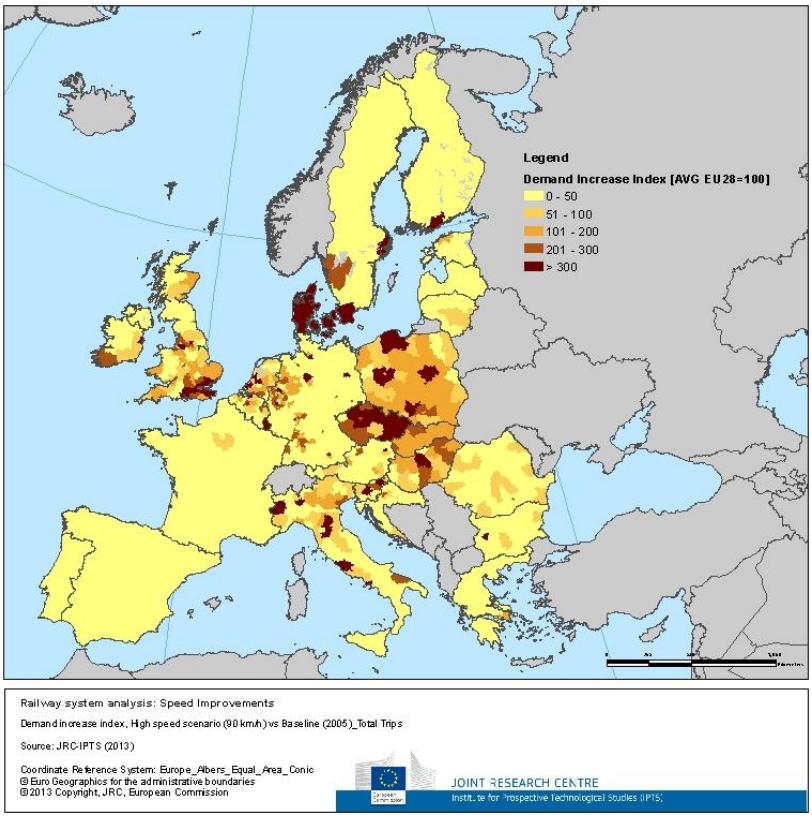


Fig. 25: High Speed Scenario (90 km/h) vs Baseline (2005), demand increase index

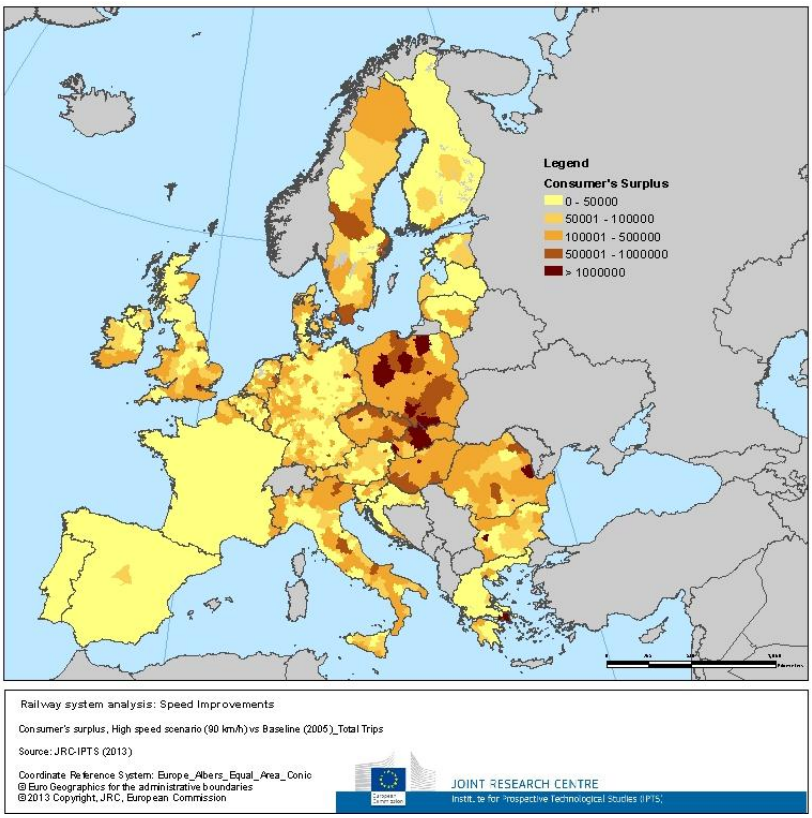


*Fig. 26: High Speed Scenario (90 km/h) vs Baseline (2005), estimated consumer's surplus [trips*hours]*

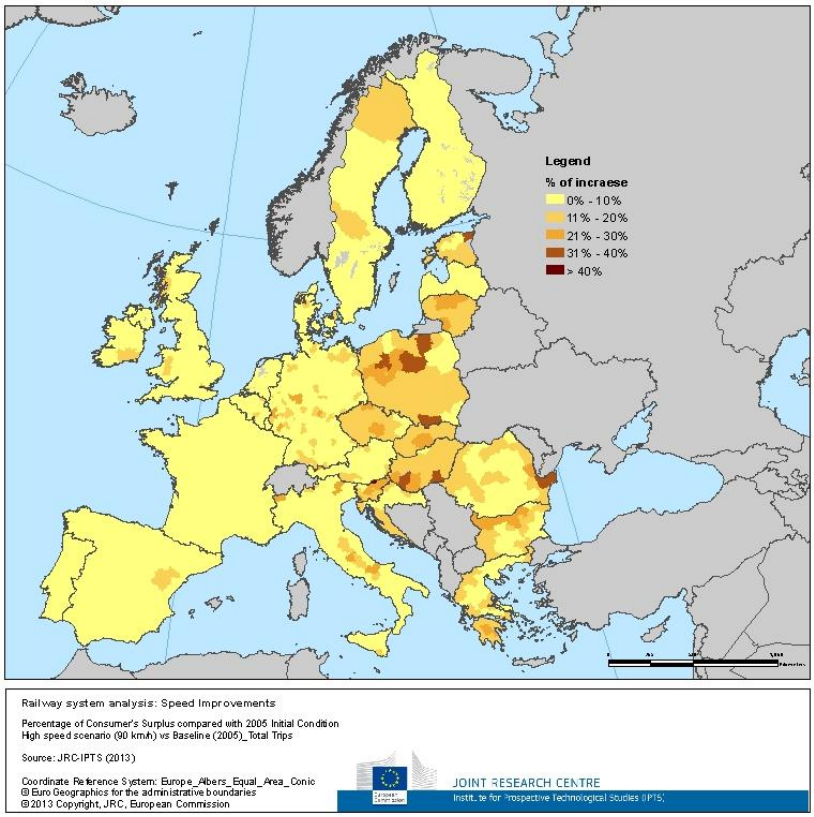


*Fig. 27: High Speed Scenario (90 km/h) vs Baseline (2005), percentage of consumer's surplus (compared with P_0*Q_0 of the Baseline 2005)*

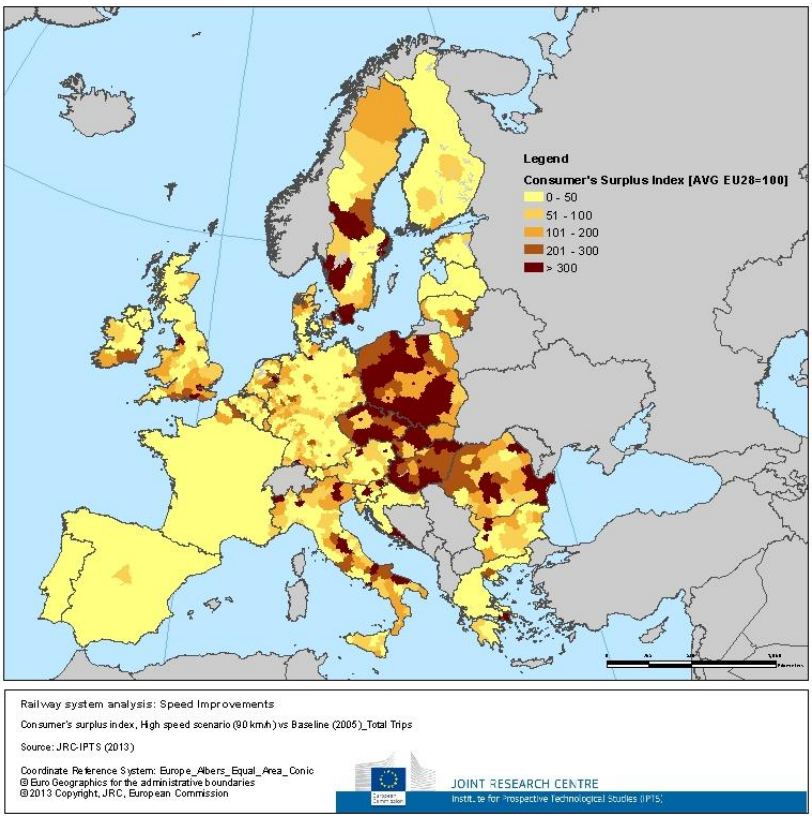


Fig. 28: High Speed Scenario (90 km/h) vs Baseline (2005), consumer's surplus index

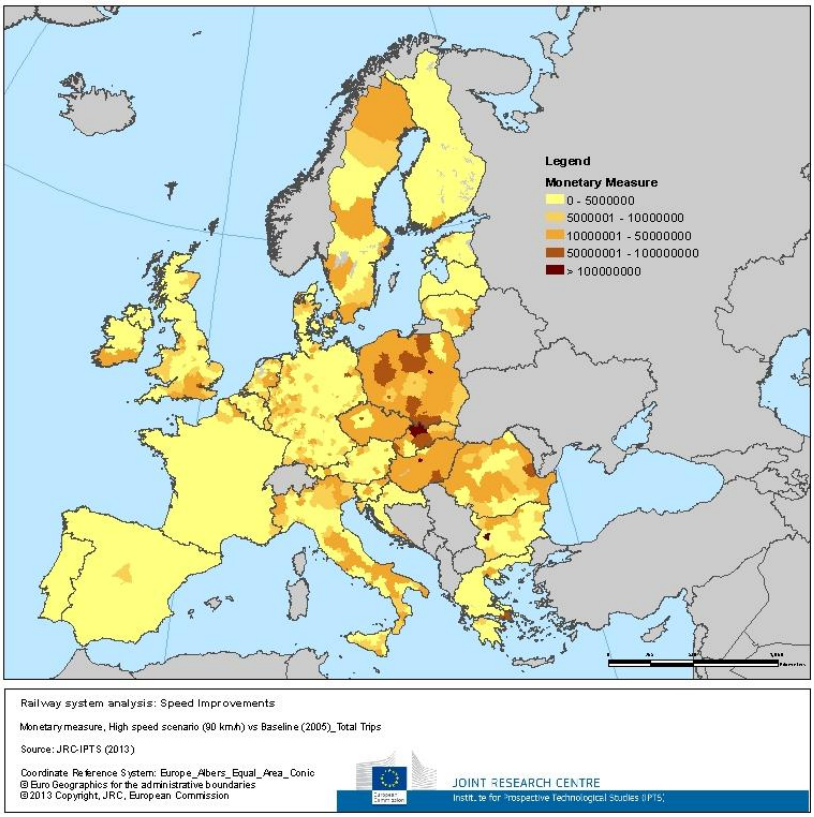


*Fig. 29: High Speed Scenario (90 km/h) vs Baseline (2005), monetary measure of consumer's surplus [trips*hours*euro]*

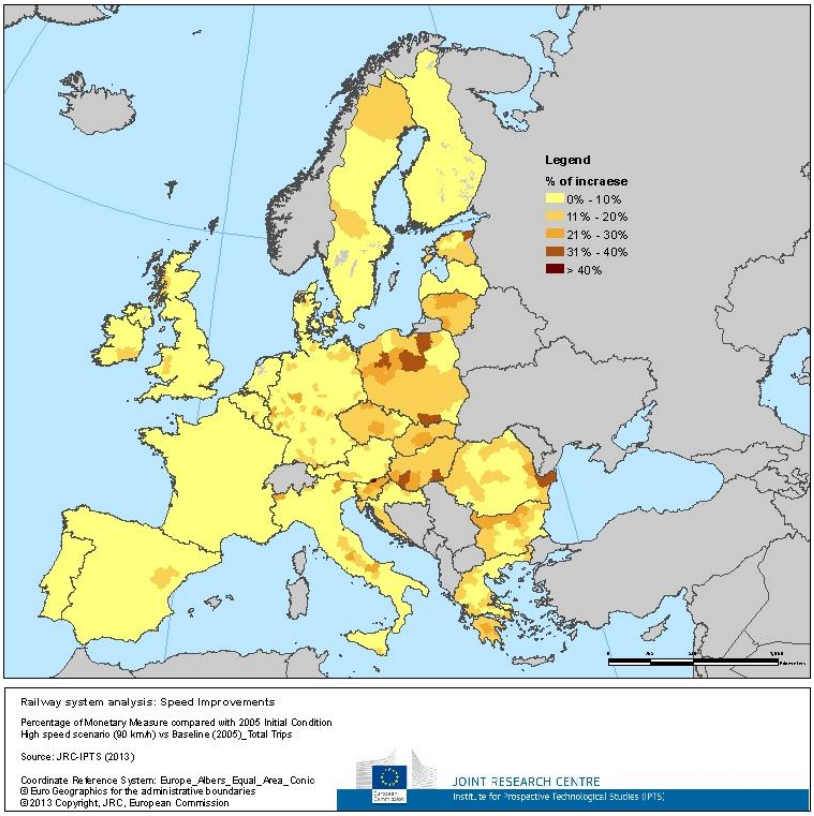


Fig. 30: High Speed Scenario (90 km/h) vs Baseline (2005), percentage of monetary measure (compared with P_0 Q_0*VT of the Baseline 2005)*

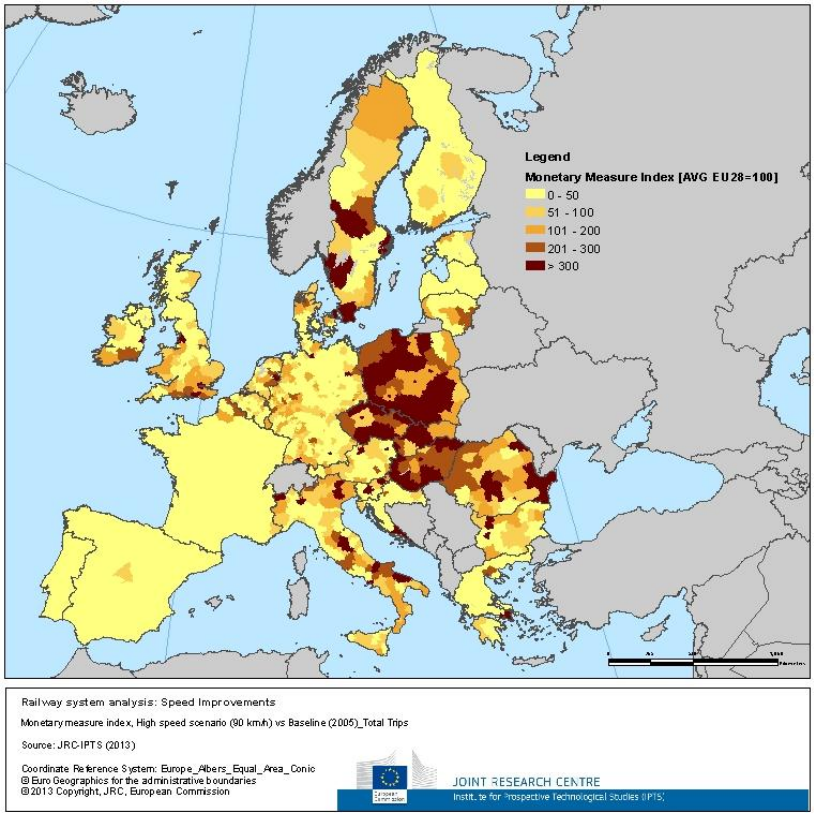


Fig. 31: High Speed Scenario (90 km/h) vs Baseline (2005), monetary measure index

Baseline (2005) vs Low Speed Scenario (45 km/h):

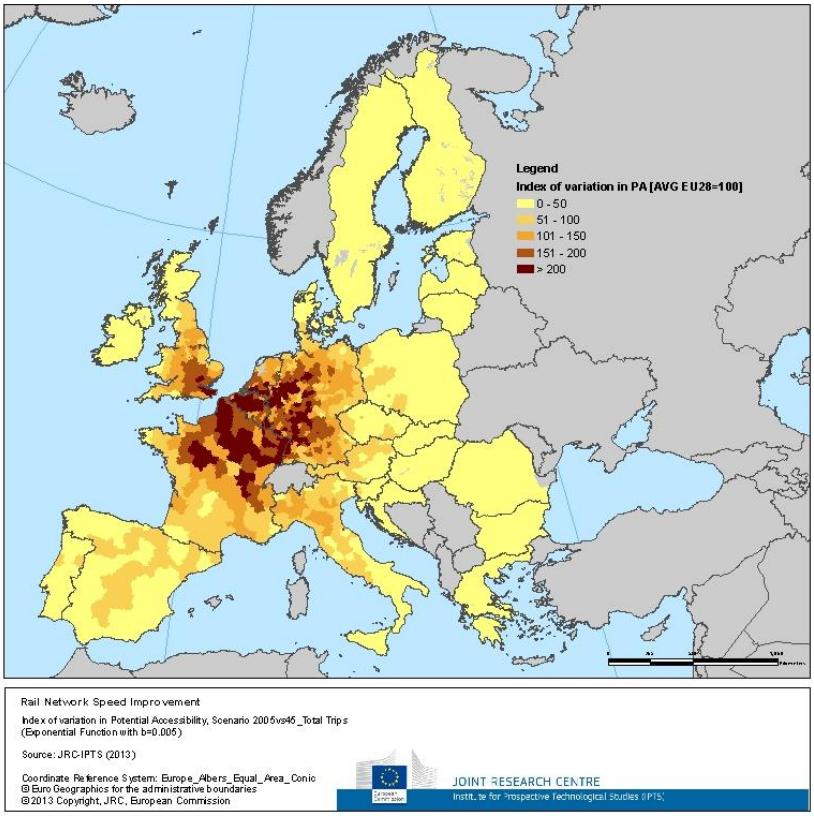


Fig. 32: Baseline (2005) vs Low Speed Scenario (45 km/h), index of variation in potential accessibility with exponential function

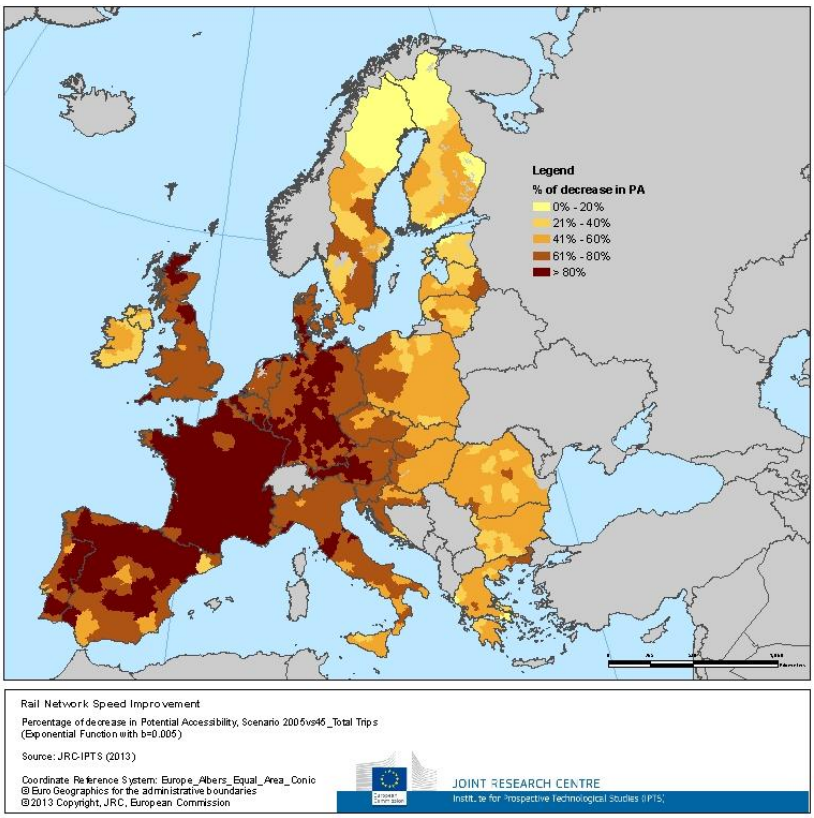


Fig. 33: Baseline (2005) vs Low Speed Scenario (45 km/h), percentage of decrease in potential accessibility with exponential function

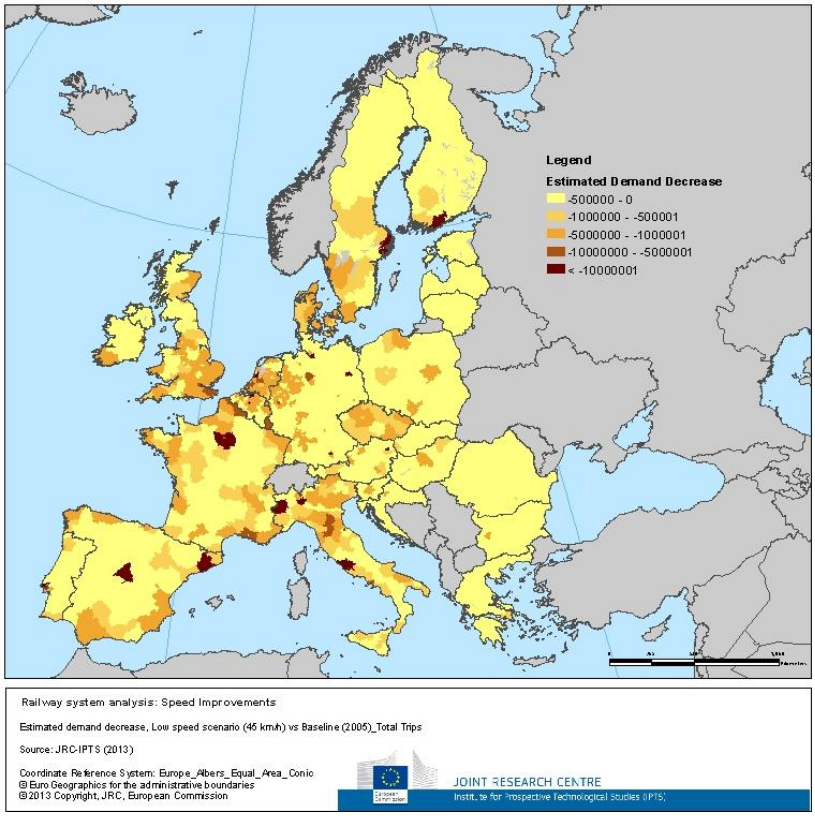


Fig. 34: Baseline (2005) vs Low Speed Scenario (45 km/h), estimated demand decrease [trips]

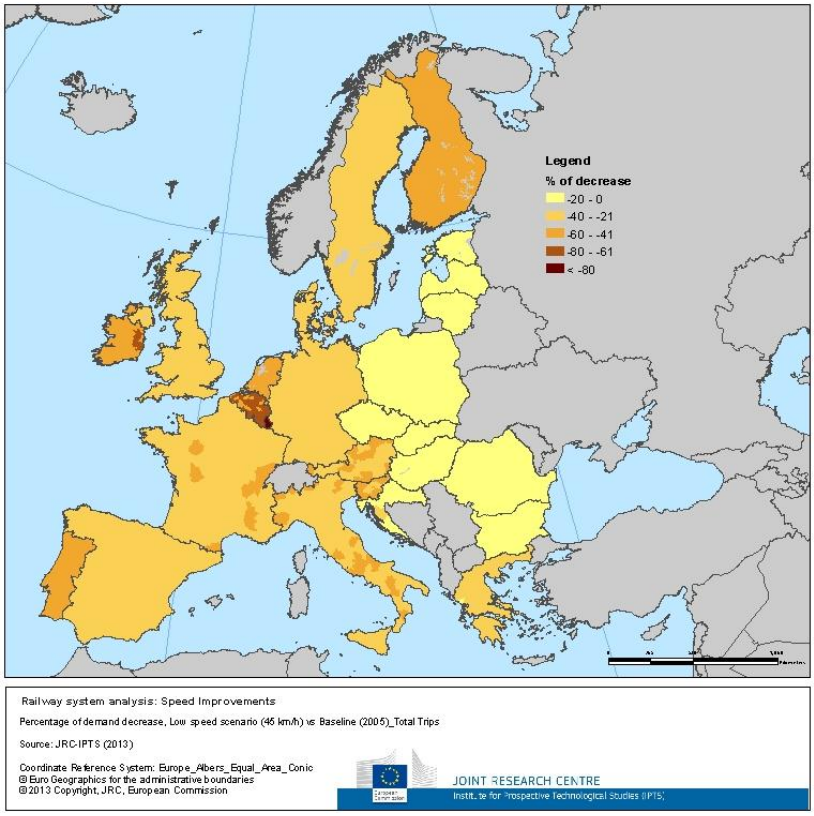


Fig. 35: Baseline (2005) vs Low Speed Scenario (45 km/h), percentage of demand decrease

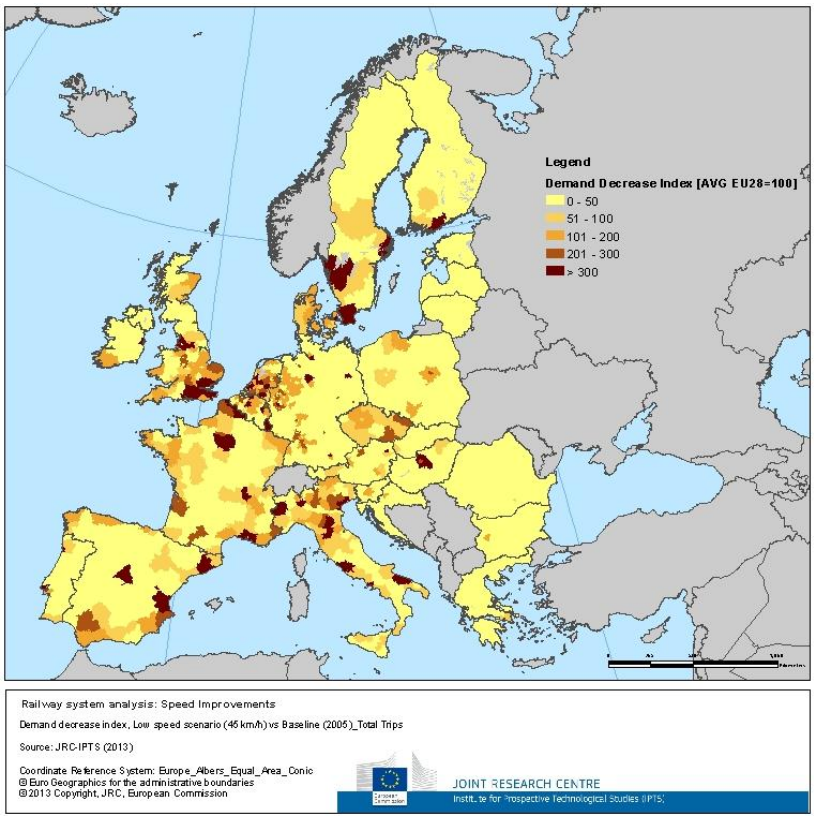


Fig. 36: Baseline (2005) vs Low Speed Scenario (45 km/h), demand decrease index

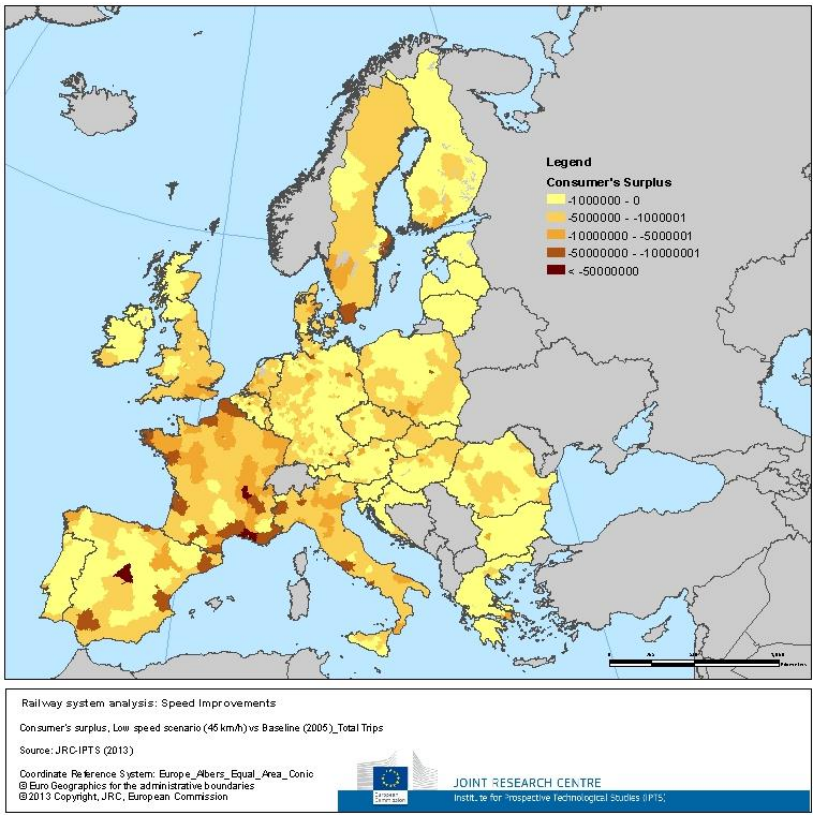


*Fig. 37: Baseline (2005) vs Low Speed Scenario (45 km/h), estimated consumer's surplus [trips*hours]*

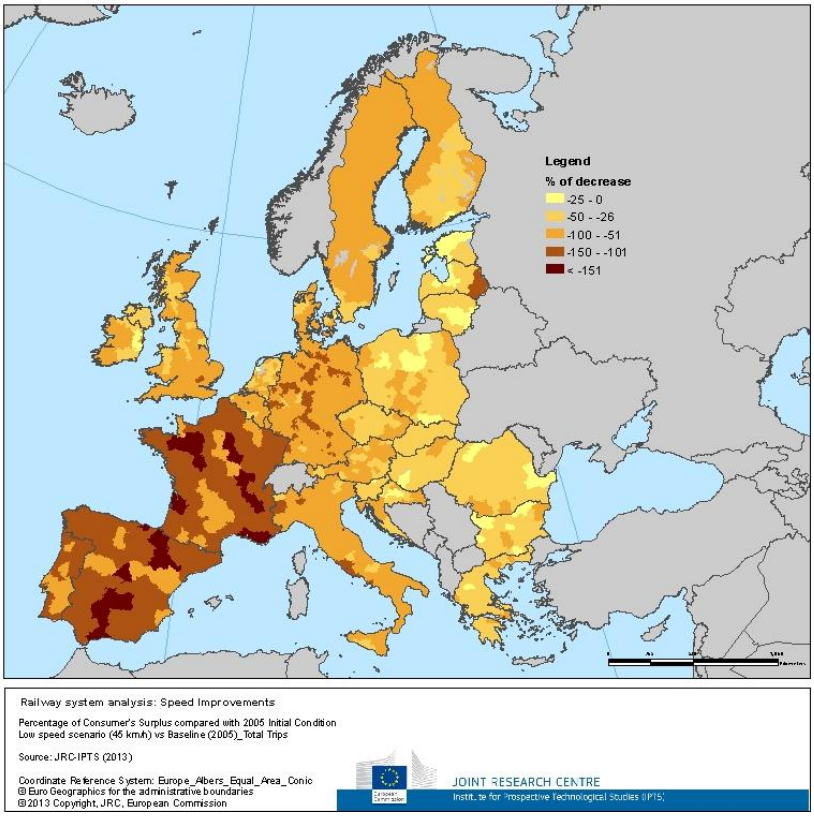


*Fig. 38: Baseline (2005) vs Low Speed Scenario (45 km/h), percentage of consumer's surplus (compared with P_0*Q_0 of the Baseline 2005)*

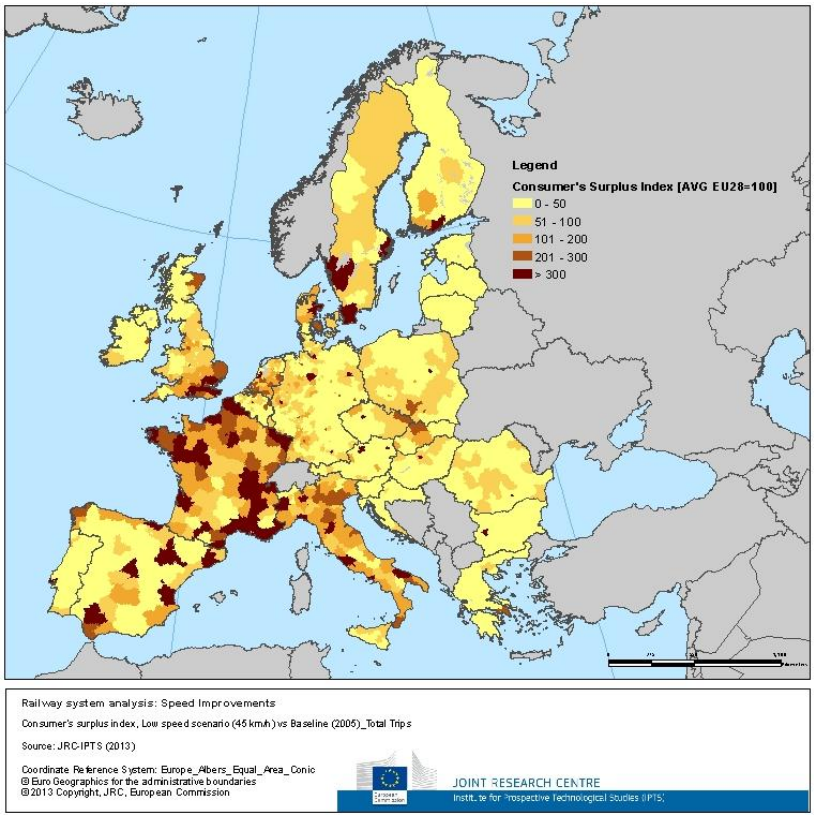


Fig. 39: Baseline (2005) vs Low Speed Scenario (45 km/h), consumer's surplus index

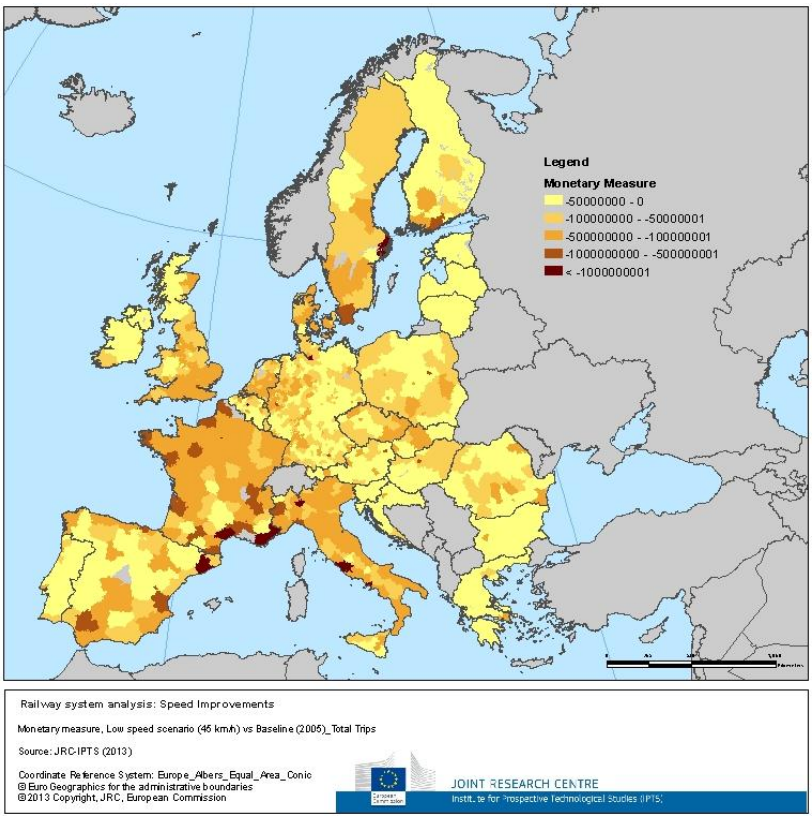


*Fig. 40: Baseline (2005) vs Low Speed Scenario (45 km/h), monetary measure of consumer's surplus [trips*hours*euro]*

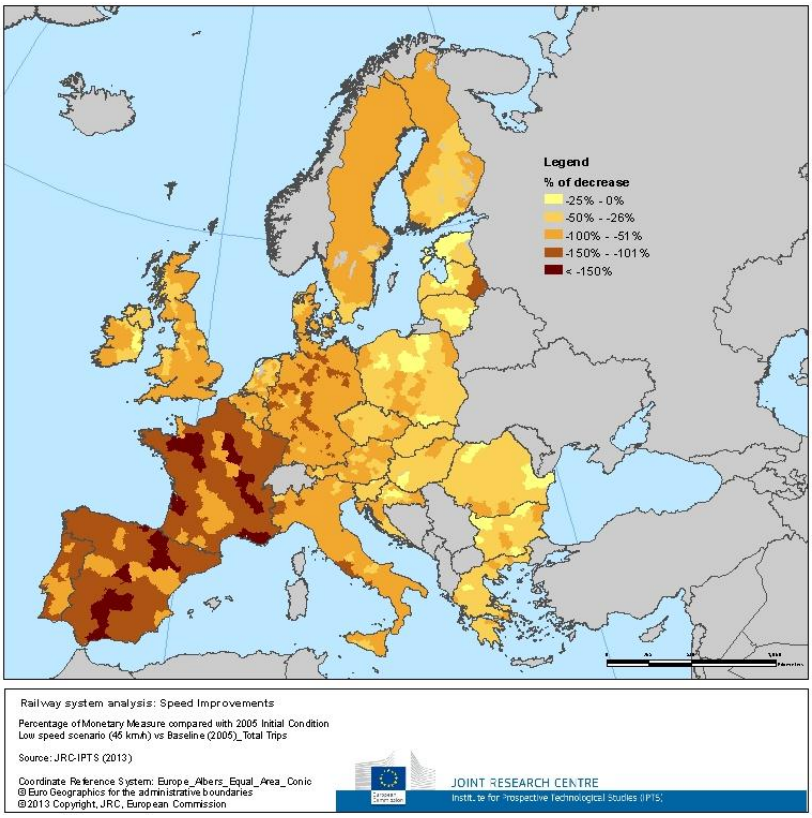


Fig.41: Baseline (2005) vs Low Speed Scenario (45 km/h), percentage of monetary measure (compared with P_0 Q_0*VT of the Baseline 2005)*

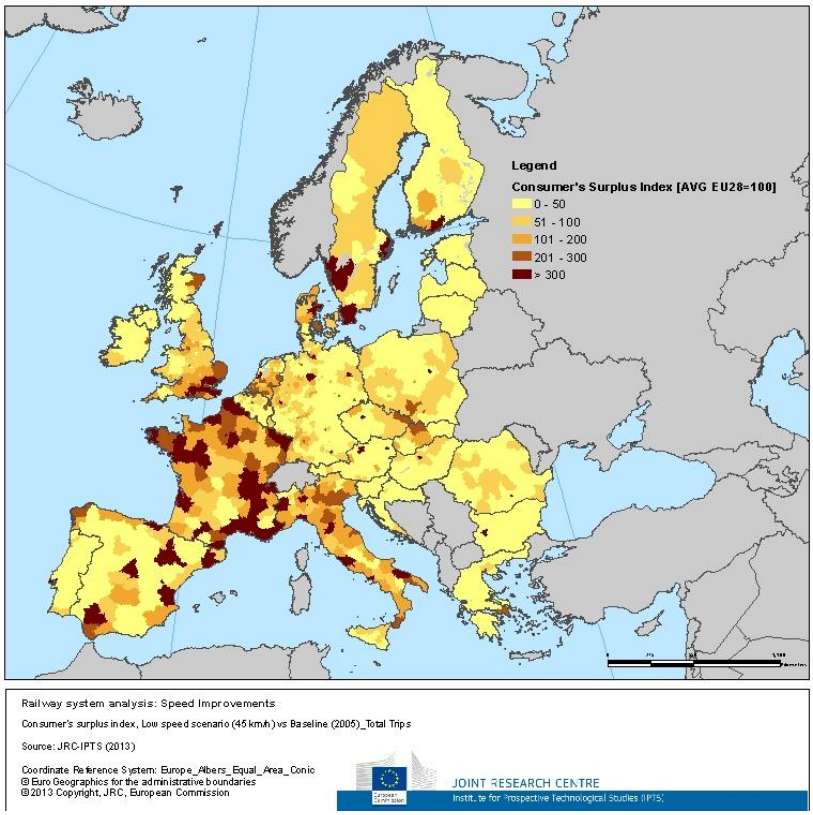


Fig. 42: Baseline (2005) vs Low Speed Scenario (45 km/h), monetary measure index

3.2. Frequency analysis

Improved Frequencies Scenario (20%) vs Baseline (2005):

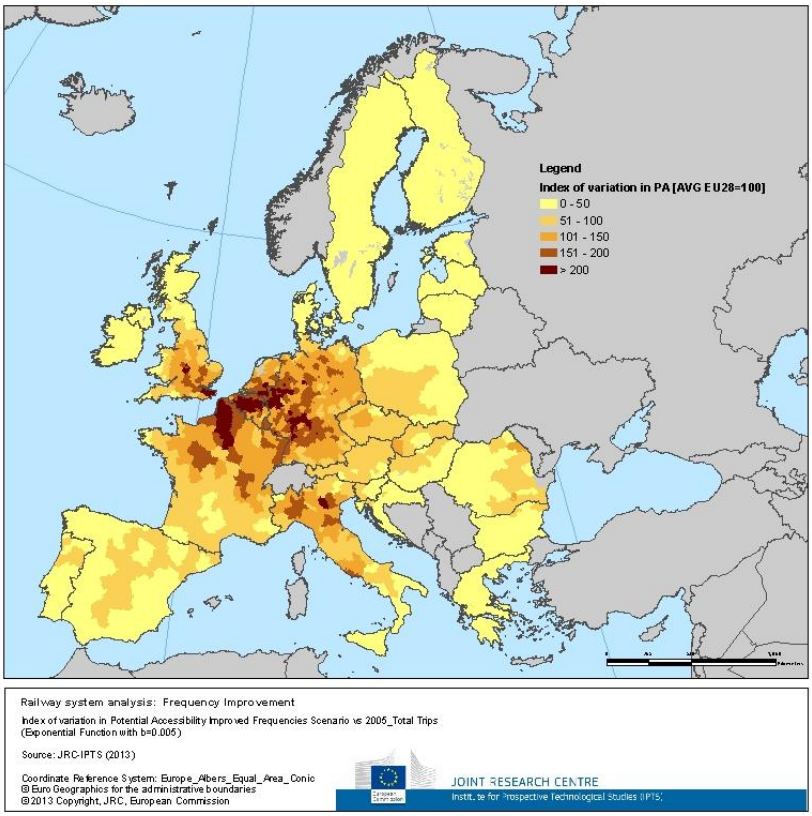


Fig. 43: Improved Frequencies Scenario (20%) vs Baseline (2005), index of variation in potential accessibility with exponential function

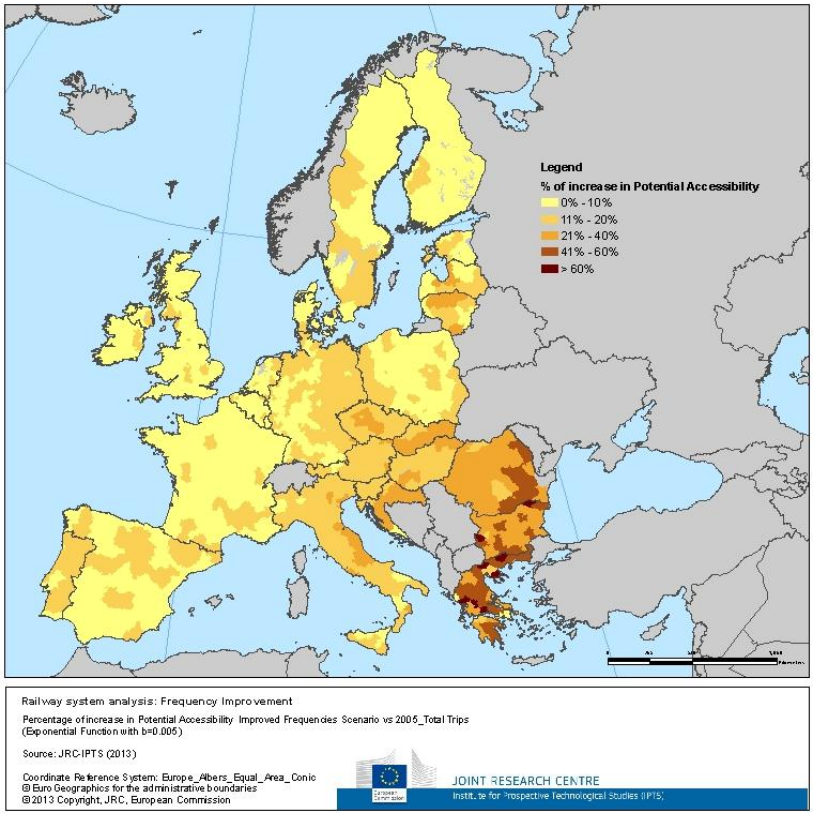


Fig. 44: Improved Frequencies Scenario (20%) vs Baseline (2005), percentage of increase in potential accessibility with exponential function

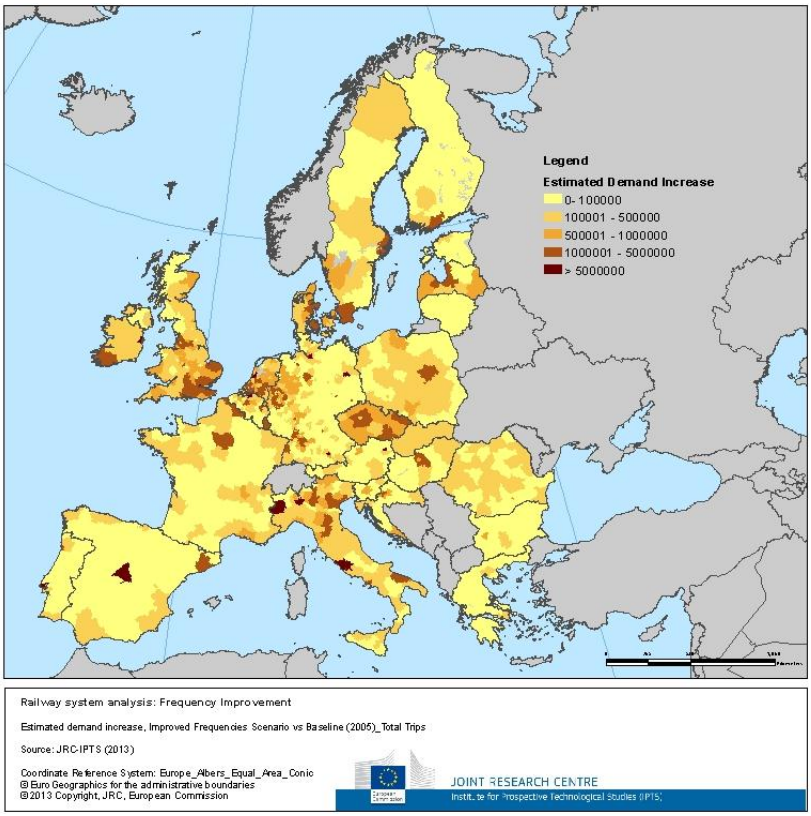


Fig. 45: Improved Frequencies Scenario (20%) vs Baseline (2005), estimated demand increase [trips]

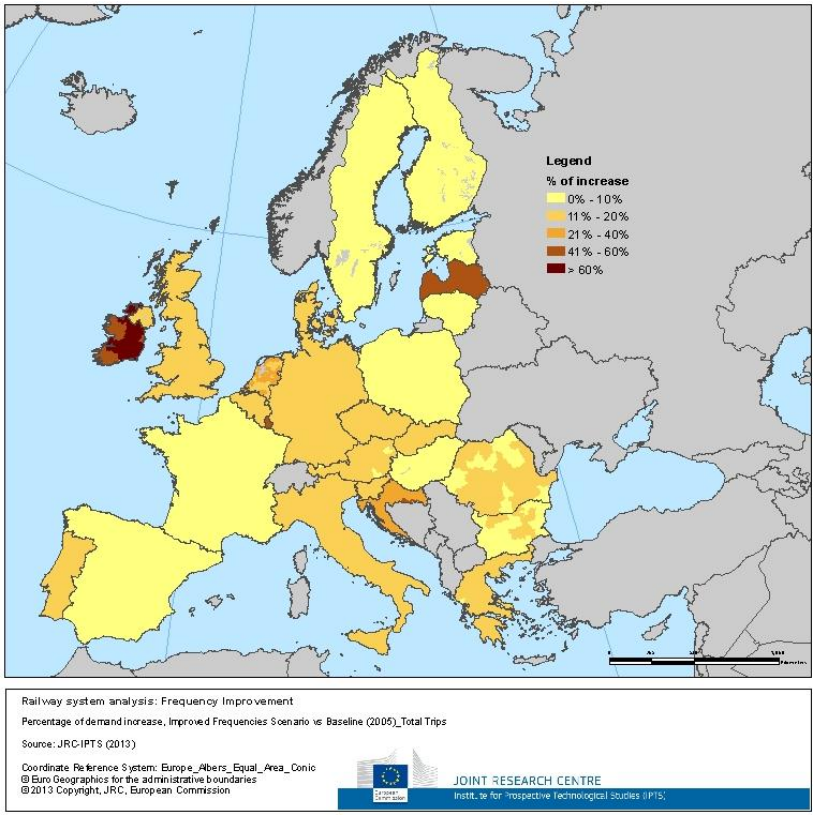


Fig. 46: Improved Frequencies Scenario (20%) vs Baseline (2005), percentage of demand increase

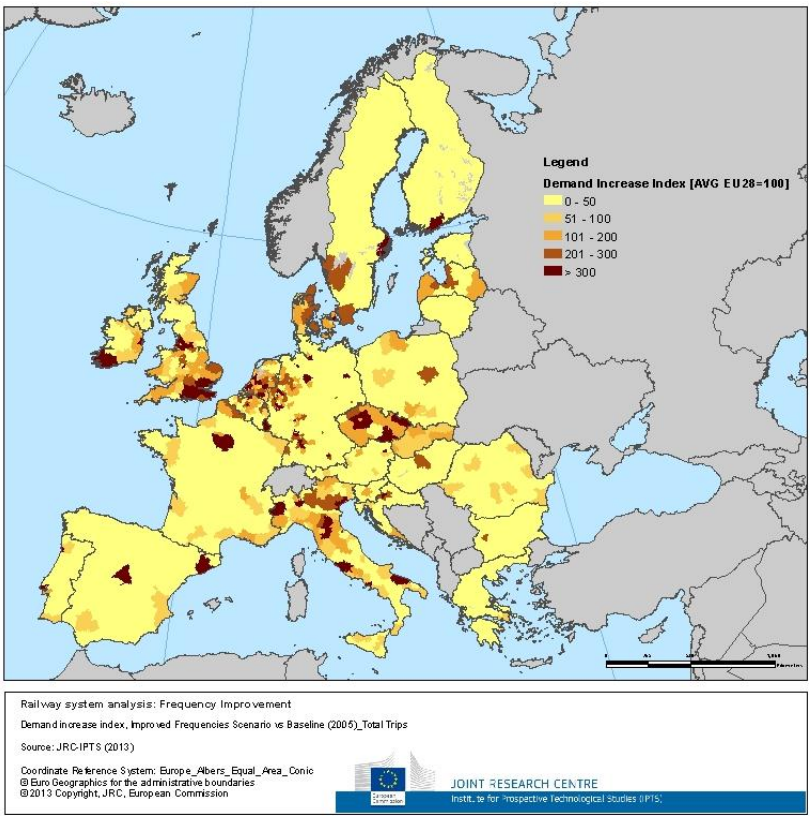


Fig. 47: Improved Frequencies Scenario (20%) vs Baseline (2005), demand increase index

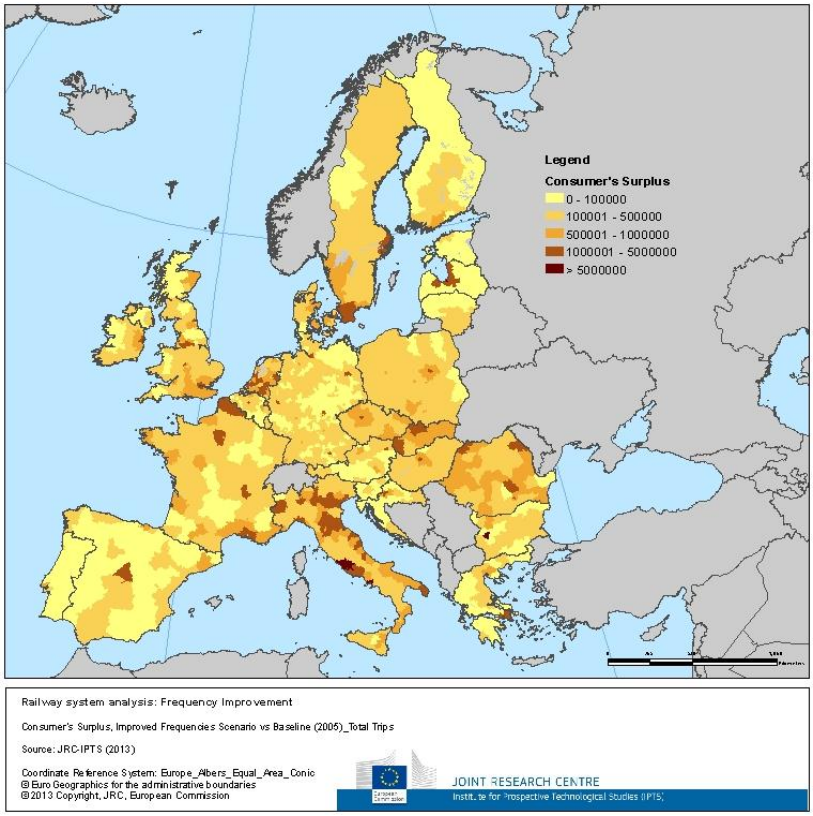


*Fig. 48: Improved Frequencies Scenario (20%) vs Baseline (2005), estimated consumer's surplus [trips*hours]*

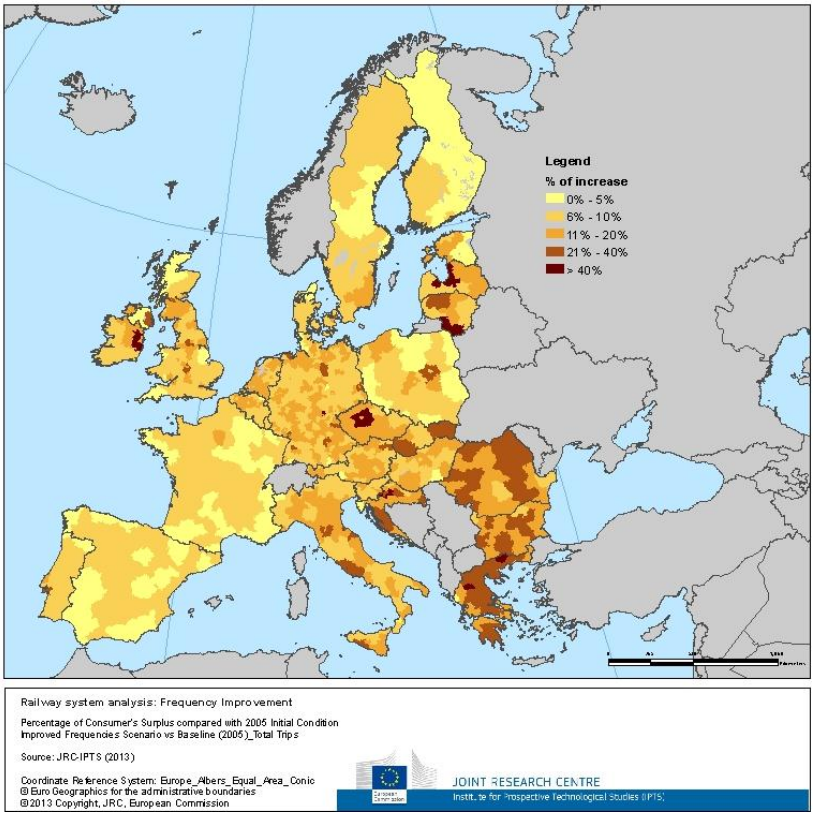


*Fig. 49: Improved Frequencies Scenario vs Baseline, percentage of consumer's surplus (compared with P_0*Q_0 of the Baseline 2005)*

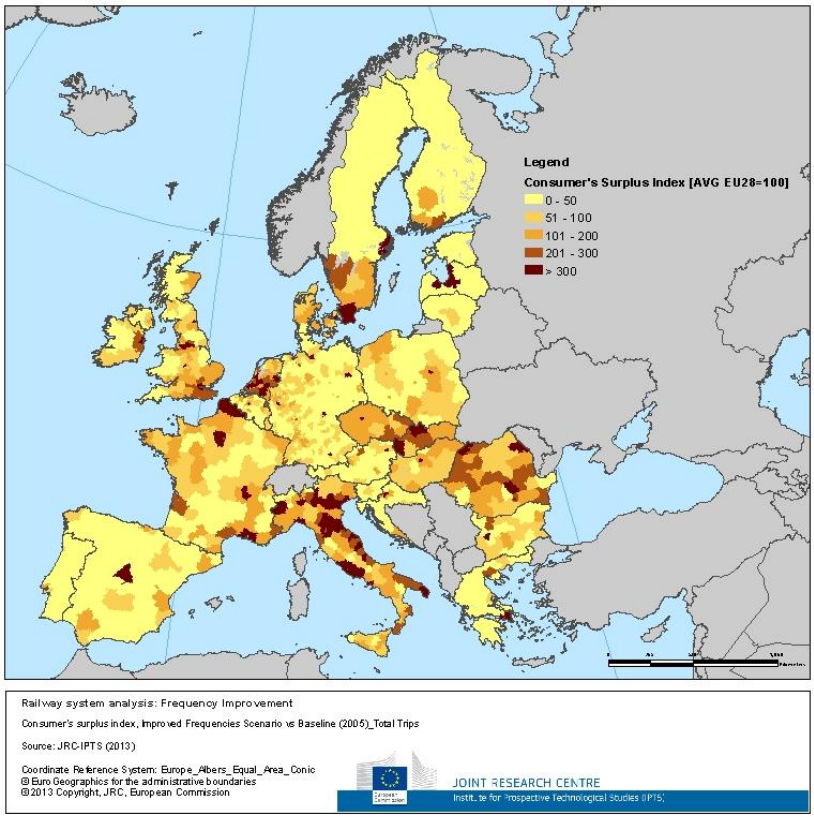


Fig. 50: Improved Frequencies Scenario (20%) vs Baseline (2005), consumer's surplus index

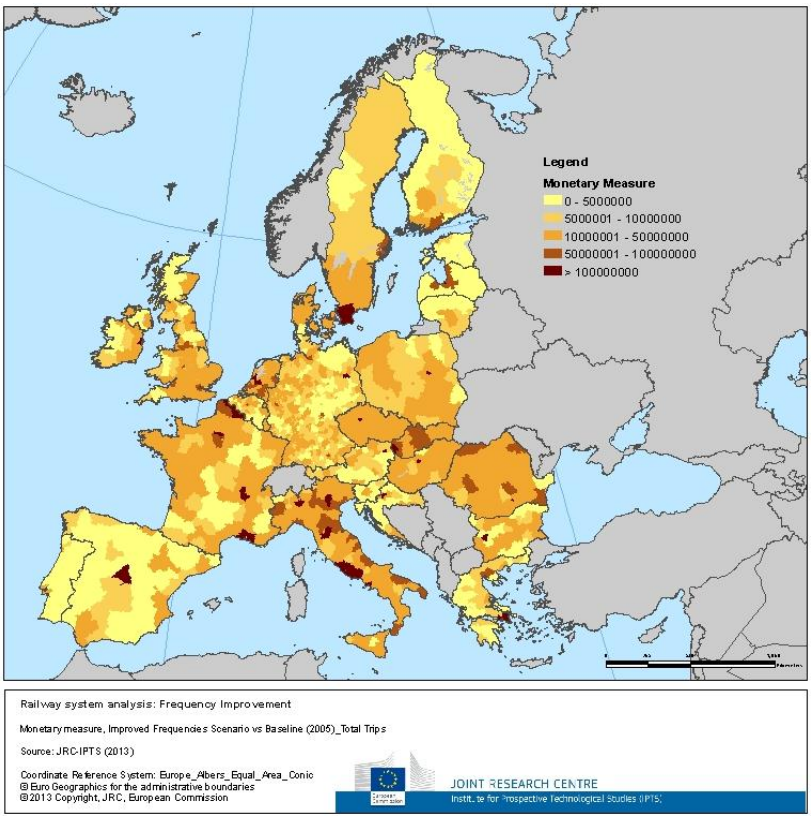


*Fig. 51: Improved Frequencies Scenario (20%) vs Baseline (2005), monetary measure of consumer's surplus [trips*hours*euro]*

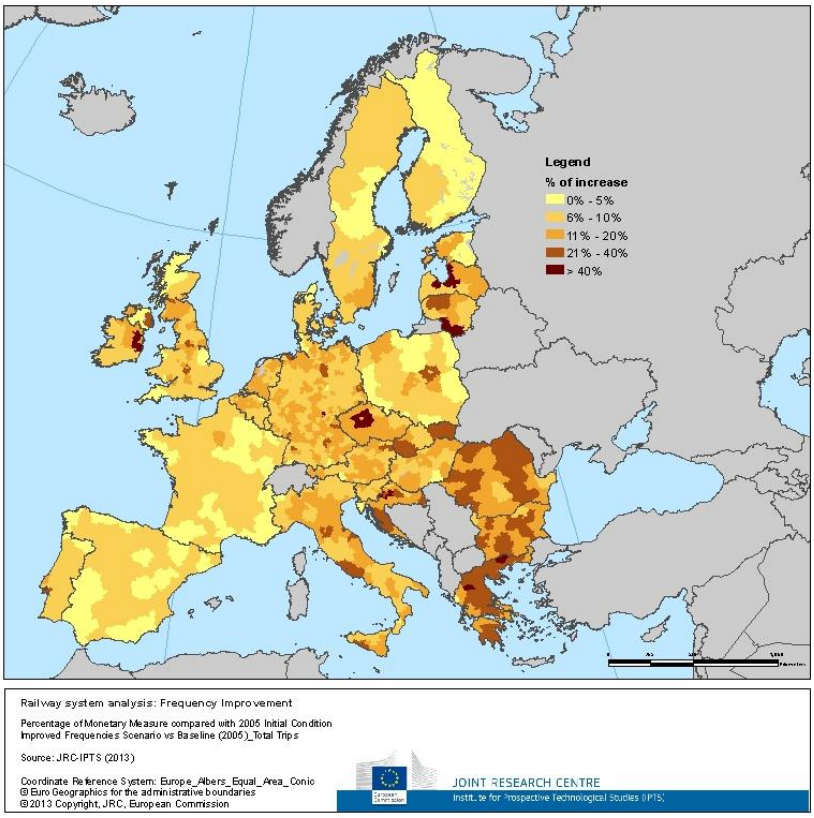


Fig. 52: Improved Frequencies Scenario vs Baseline, percentage of monetary measure (compared with P_0 Q_0*VT of the Baseline 2005)*

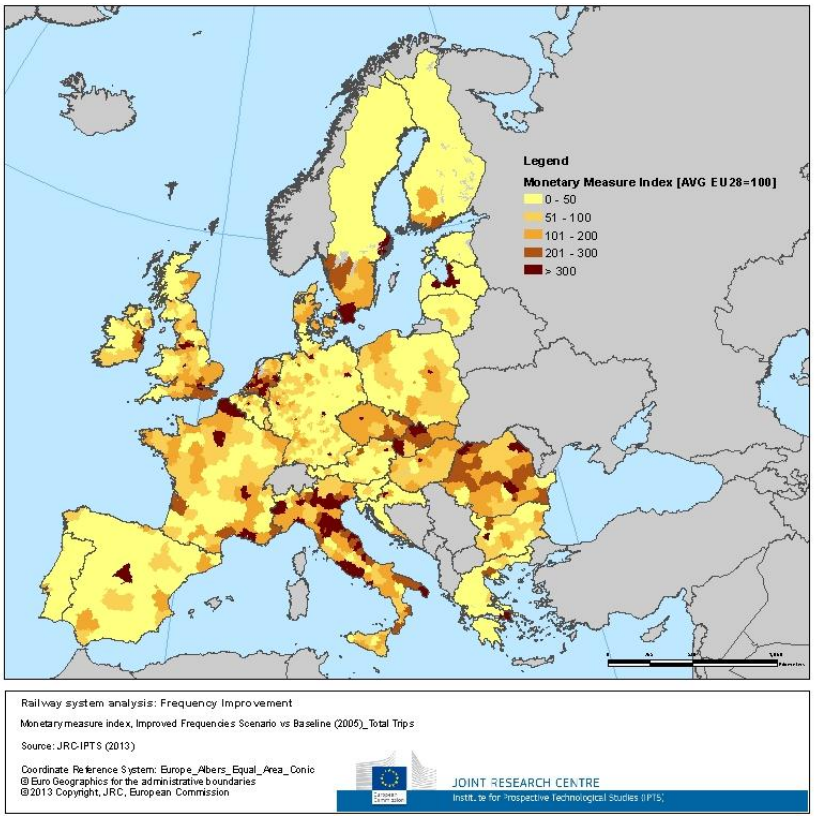


Fig. 53: Improved Frequencies Scenario (20%) vs Baseline (2005), monetary measure index

Annex 1: Average results matrix

		Baseline 2005 Vs Low Speed Scenario							High Speed Scenario vs Baseline 2005							Best-case Scenario vs Baseline 2005							Improved Frequencies Scenario vs 2005							Average Speed on the networkweighted on the length of links [km/h]			
		% Time	% Demand	% Potential accessibility	Consumer's surplus	% Consumer's surplus	Monetary evaluation	% Monetary evaluation	% Time	% Demand	% Potential accessibility	Consumer's surplus	% Consumer's surplus	Monetary evaluation	% Monetary evaluation	% Time	% Demand	% Potential accessibility	Consumer's surplus	% Consumer's surplus	Monetary evaluation	% Monetary evaluation	% Time	% Demand	% Potential accessibility	Consumer's surplus	% Consumer's surplus	Monetary evaluation	% Monetary evaluation	Scenario 45	Scenario 2005	Scenario 90	Scenario 200
1	Austria	68%	-27%	77%	-47508143	-64%	-2689721046	-64%	-4%	2%	24%	4308517	6%	243930992	6%	-35%	19%	368%	35865852	48%	2030581083	48%	-14%	8%	13%	7628418	9%	431890494	9%	44.6	86.0	94.4	200.0
2	Belgium	82%	-44%	80%	-62999135	-81%	-3566759026	-81%	-2%	2%	7%	2108833	3%	119393705	3%	-33%	33%	108%	31046859	40%	1757748983	40%	-13%	12%	10%	8281184	10%	468847489	10%	44.8	92.1	101.1	201.1
3	Bulgaria	34%	-10%	45%	-12741713	-36%	-721384803	-36%	-13%	5%	51%	5113262	14%	289492446	14%	-39%	15%	486%	17907919	51%	1013874726	51%	-24%	9%	34%	9950917	21%	563381130	21%	44.9	67.3	90.1	200.0
4	Czech Republic	49%	-17%	65%	-26794889	-49%	-1517019433	-49%	-12%	5%	40%	7378886	14%	417763033	14%	-44%	21%	436%	29275532	53%	1657463520	53%	-30%	15%	18%	8691960	13%	492104000	13%	45.0	70.8	91.2	200.0
5	Germany	69%	-20%	80%	-575770904	-91%	-32597845480	-91%	-4%	2%	11%	32333538	5%	1830595585	5%	-28%	11%	164%	251272045	39%	14226018076	39%	-25%	10%	11%	78049790	11%	4418866939	11%	44.7	94.0	105.6	200.2
6	Denmark	37%	-24%	68%	-36806908	-57%	-2083859917	-57%	-18%	15%	23%	3207540	5%	181598091	5%	-30%	27%	269%	20938352	32%	1185445749	32%	-16%	13%	9%	7476984	10%	423316919	10%	44.6	83.0	98.7	200.0
7	Estonia	20%	-7%	28%	-467390	-23%	-26461741	-23%	-11%	6%	35%	291083	14%	16479937	14%	-27%	18%	589%	758846	38%	42962849	38%	-10%	9%	9%	189112	8%	10706750	8%	43.8	62.0	90.0	200.0
8	Spain	133%	-30%	76%	-192496285	-147%	-10898369676	-147%	-0.07%	0.00%	1%	248453	0%	14066420	0%	-13%	4%	61%	18749471	14%	1061520066	14%	-8%	2%	9%	7978098	6%	451688008	6%	45.0	147.1	147.9	201.9
9	Finland	55%	-31%	38%	-26063459	-47%	-1475608817	-47%	-1%	1%	7%	827707	1%	46861446	1%	-23%	21%	196%	16096373	29%	911312230	29%	-5%	5%	7%	3018601	5%	170901111	5%	45.0	92.0	96.9	200.0
10	France	104%	-22%	86%	-733172553	-132%	-41509297276	-132%	-0.24%	0.06%	2%	1187232	0%	67216303	0%	-14%	4%	85%	87050831	15%	4928469852	15%	-13%	4%	10%	44095427	7%	2496506684	7%	44.4	140.9	142.2	204.9
11	Greece	45%	-20%	43%	-10530205	-47%	-596178093	-47%	-9%	4%	27%	2500617	11%	141574930	11%	-34%	16%	324%	10380525	46%	587703780	46%	-26%	13%	37%	5836950	20%	330464755	20%	45.0	77.8	94.8	200.0
12	Croatia	25%	-12%	65%	-6945576	-43%	-393230737	-43%	-4%	2%	47%	1851475	12%	104823127	12%	-17%	9%	618%	6673593	42%	377832129	42%	-35%	33%	19%	4268415	21%	241660558	21%	44.7	83.3	98.7	200.0
13	Hungary	45%	-14%	56%	-26314796	-43%	-1489838474	-43%	-15%	5%	44%	10237101	17%	579583725	17%	-48%	14%	499%	34004466	56%	1925196874	56%	-13%	5%	17%	7843440	11%	444064227	11%	44.6	67.4	90.2	200.0
14	Ireland	57%	-46%	38%	-9607577	-51%	-543942600	-51%	-5%	6%	17%	1099952	6%	62274892	6%	-33%	54%	66%	10260581	54%	580913060	54%	-23%	35%	10%	3882327	17%	219801836	17%	45.0	80.3	93.8	200.0
15	Italy	79%	-28%	73%	-378392763	-80%	-21423084657	-80%	-2%	1%	7%	13828794	3%	782931004	3%	-25%	16%	163%	157546190	33%	8919635081	33%	-19%	12%	15%	79977448	14%	4528003204	14%	44.9	101.6	107.7	200.1
16	Lithuania	20%	-6%	42%	-1316716	-29%	-74547170	-29%	-14%	4%	63%	779076	17%	44108193	17%	-32%	11%	661%	2082061	45%	117877951	45%	-18%	6%	17%	812671	15%	46010204	15%	44.4	77.4	90.7	200.0
17	Luxembourg	91%	-100%	87%	-1723770	-71%	-97592940	-71%	-5%	3%	8%	135672	6%	7681211	6%	-38%	175%	151%	2071567	85%	117283809	85%	-9%	26%	10%	194282	7%	10999465	7%	45.0	78.2	91.4	200.0
18	Latvia	19%	-12%	42%	-3361863	-49%	-190335219	-49%	-1%	1%	27%	241726	4%	13685573	4%	-11%	7%	492%	2112110	31%	119579203	31%	-65%	69%	17%	8118442	57%	459633736	57%	45.0	80.1	97.1	200.0
19	Netherlands	56%	-33%	73%	-95606681	-51%	-5412867847	-51%	-2%	2%	8%	4643318	2%	262886100	2%	-28%	24%	149%	75909613	41%	4297698645	41%	-15%	12%	10%	25856883	12%	1463913281	12%	44.8	87.3	94.1	200.0
20	Poland	38%	-13%	55%	-77406283	-43%	-4382434117	-43%	-14%	6%	43%	30411088	17%	1721754130	17%	-42%	18%	409%	97935292	55%	5544704508	55%	-16%	7%	10%	13905446	7%	787270740	7%	44.7	69.4	92.3	200.4
21	Portugal	108%	-44%	76%	-23764964	-123%	-1345477222	-123%	-0.004%	0.000%	0%	8948	0%	506604	0%	-7%	4%	53%	2716149	14%	153777478	14%	-17%	12%	12%	1760308	8%	99661590	8%	45.0	138.3	139.1	200.0
22	Romania	37%	-11%	48%	-41565564	-40%	-2353275993	-40%	-8%	3%	31%	11006357	11%	623135919	11%	-32%	12%	400%	44643594	43%	2527541702	43%	-28%	11%	35%	26808690	20%	1517800766	20%	45.0	75.2	90.9	200.0
23	Sweden	63%	-25%	52%	-66235664	-64%	-3749998349	-64%	-2%	1%	16%	3729177	4%	211131107	4%	-22%	11%	154%	28416278	27%	1608815991	27%	-9%	5%	10%	8214329	7%	465062445	7%	43.8	91.6	104.4	200.0
24	Slovenia	42%	-39%	71%	-2363850	-35%	-133831757	-35%	-19%	32%	44%	1561134	23%	88385184	23%	-51%	120%	521%	6218562	91%	352070122	91%	-10%	15%	13%	645673	9%	36555420	9%	44.0	68.7	90.7	200.0
25	Slovak Republic	43%	-14%	58%	-14964158	-46%	-847210772	-46%	-15%	5%	46%	5781261	18%	327311872	18%	-47%	24%	485%	20417950	62%	1155982630	62%	-28%	13%	22%	7309150	18%	413814856	18%	44.5	68.7	90.4	200.0
26	United Kingdom	57%	-24%	71%	-289519406	-68%	-16391430693	-68%	-3%	2%	5%	17312839	4%	980183714	4%	-26%	15%	104%	153819717	36%	8708657090	36%	-19%	0	8%	51085076	11%	2892232679	11%	44.7	96.6	103.5	200.0

Table 2: Average Results Matrix (Country Level)

Annex 2: Detailed results (maps)

Baseline scenario (do-nothing scenario, 2005):

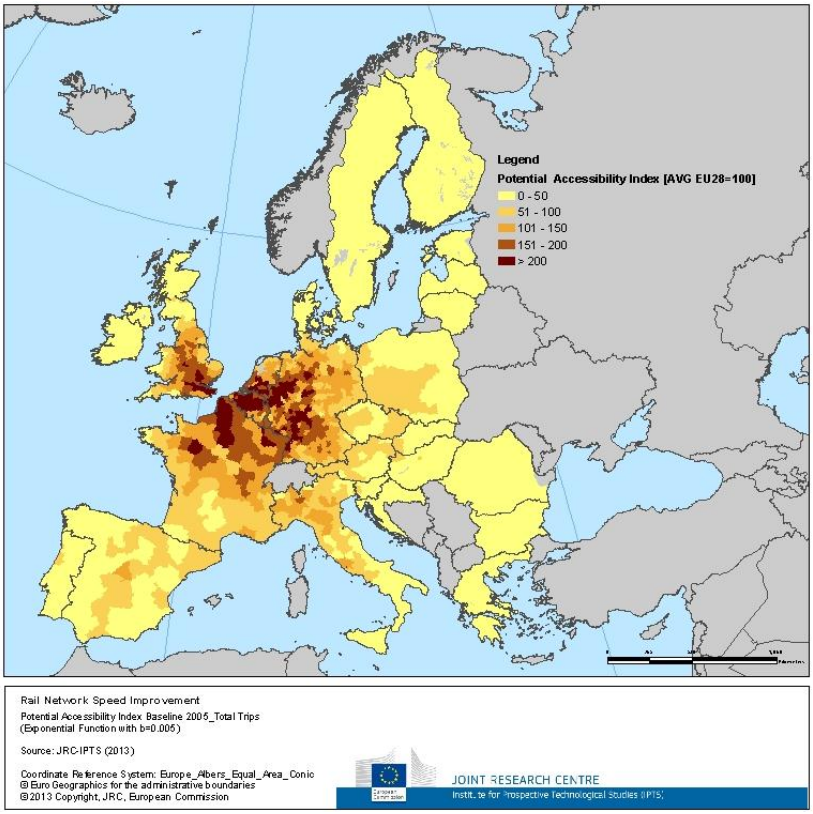


Fig. 54: Baseline scenario (2005), potential accessibility index with exponential function

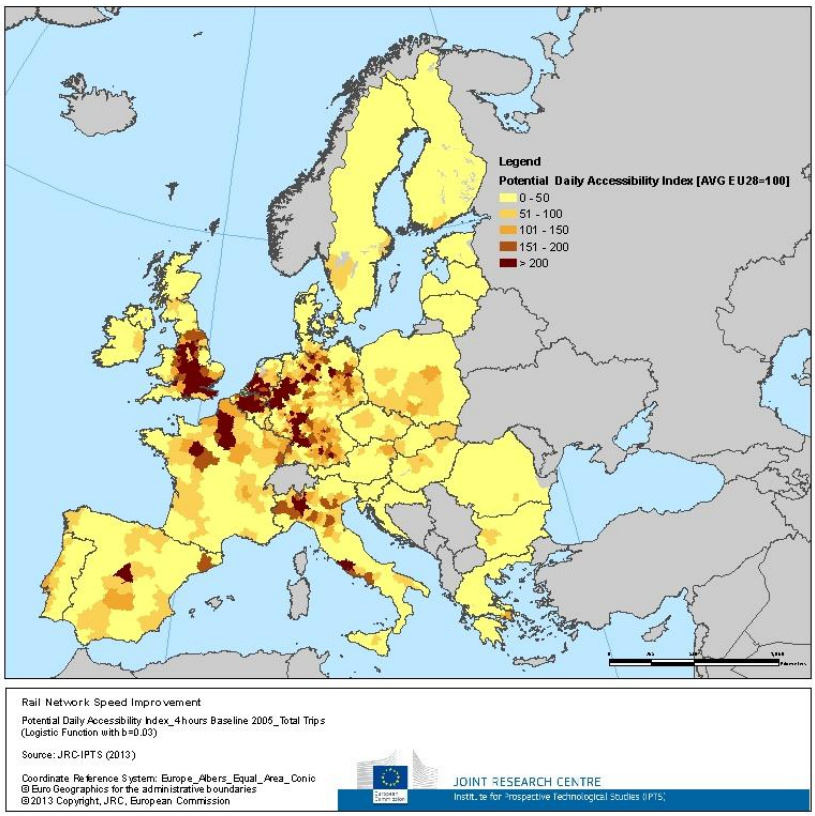


Fig. 55: Baseline scenario (2005), potential accessibility index with logistic function (α=-0.03 & t_0=150 minutes)

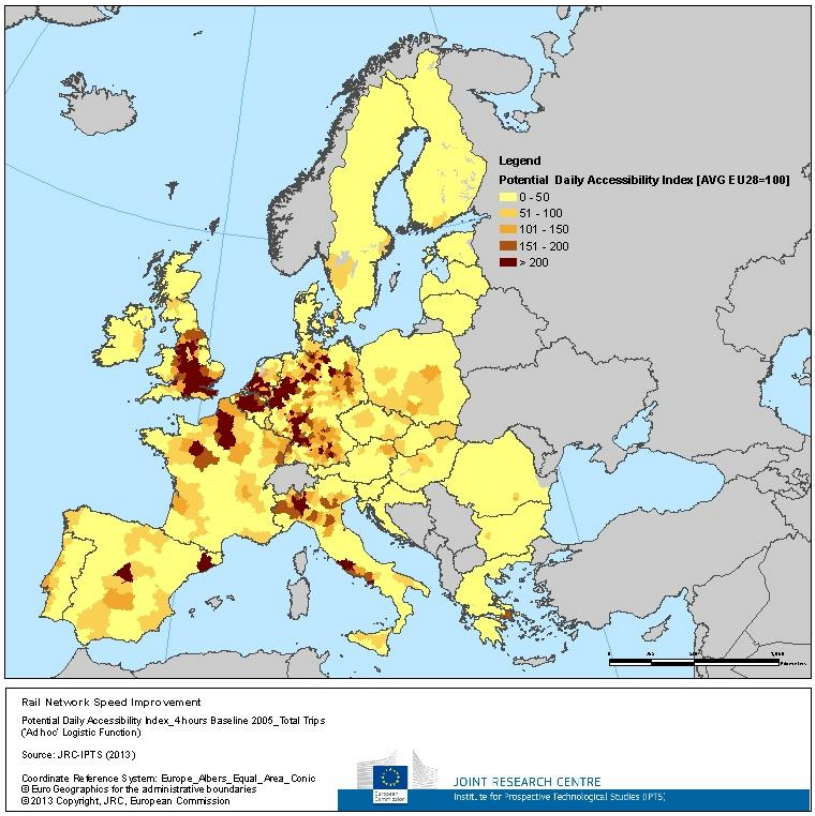


Fig. 56: Baseline scenario (2005), absolute level of potential accessibility with 'ad hoc' function (dropping in 4 hours)

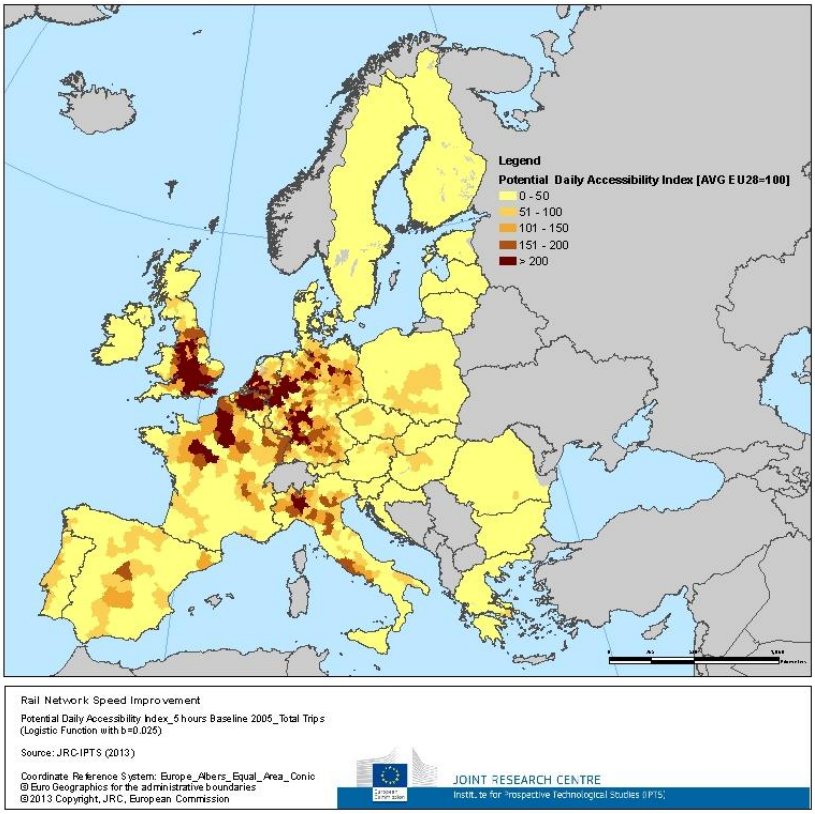


Fig. 57: Baseline scenario (2005), potential accessibility index with logistic function (α=-0.025 & t_0=180 minutes)

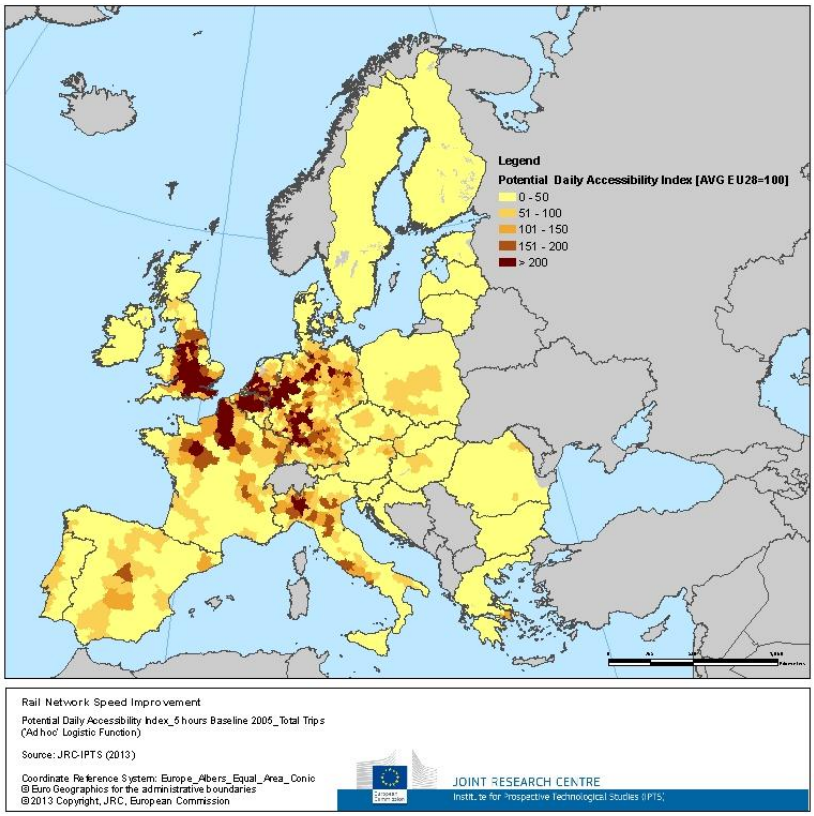


Fig. 58: Baseline scenario (2005), absolute level of potential accessibility with 'ad hoc' function (dropping in 5 hours)

Best-case scenario (200 km/h):

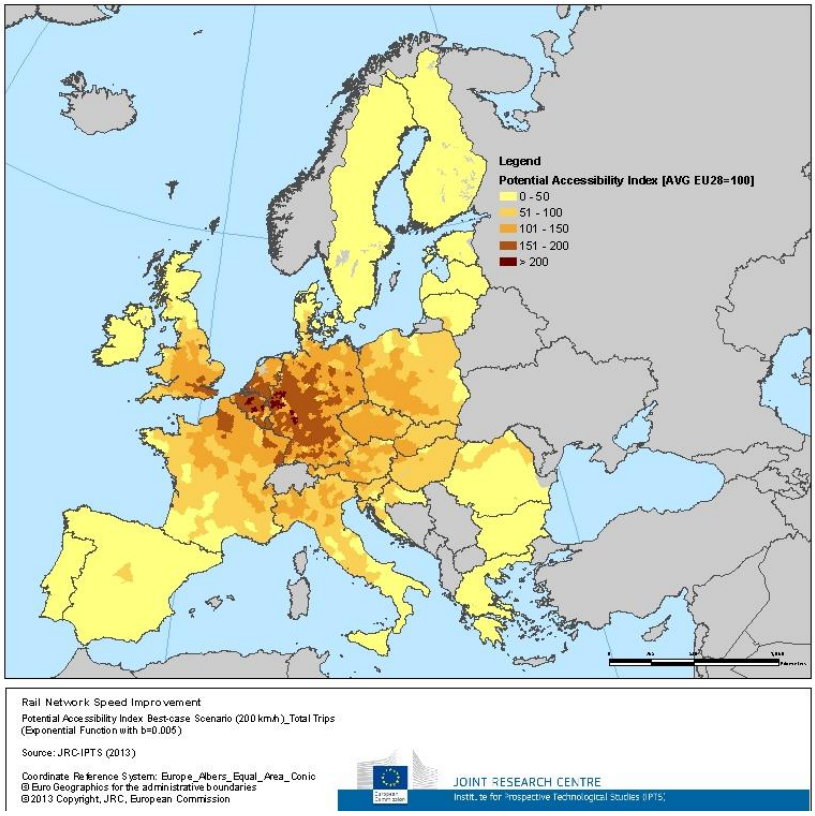


Fig. 59: Best-case scenario (200 km/h), potential accessibility index with exponential function

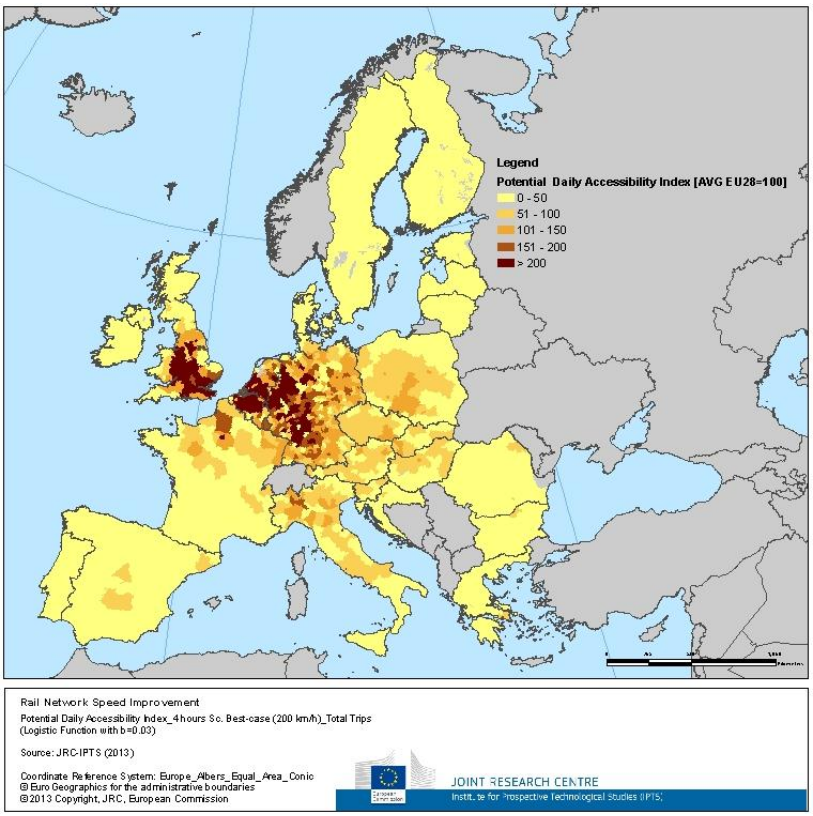


Fig. 60: Best-case scenario (200 km/h), potential accessibility index with logistic function (α=-0.03 & t_0=150 minutes)

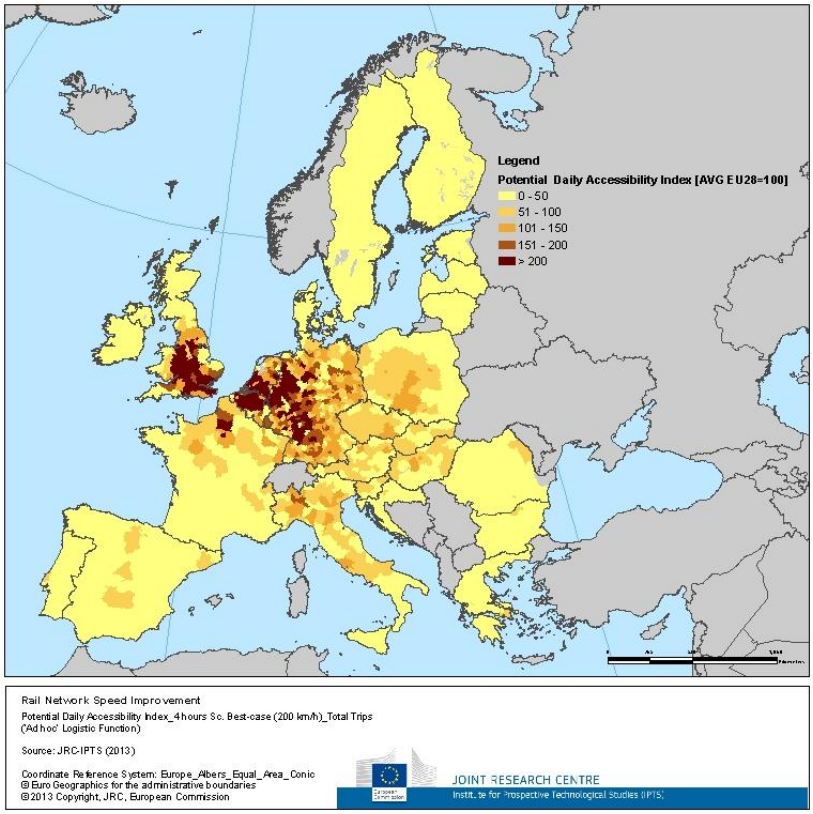


Fig. 61: Best-case scenario (200 km/h), absolute level of potential accessibility with 'ad hoc' function (dropping in 4 hours)

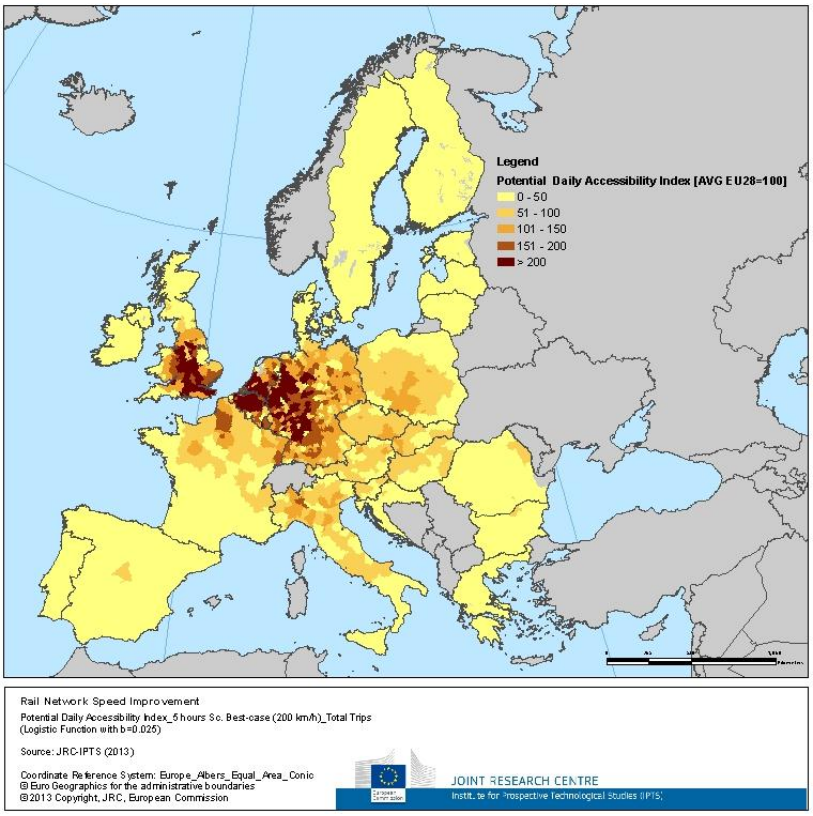


Fig. 62: Best-case scenario (200 km/h), potential accessibility index with logistic function (α=-0.025 & t_0=180 minutes)

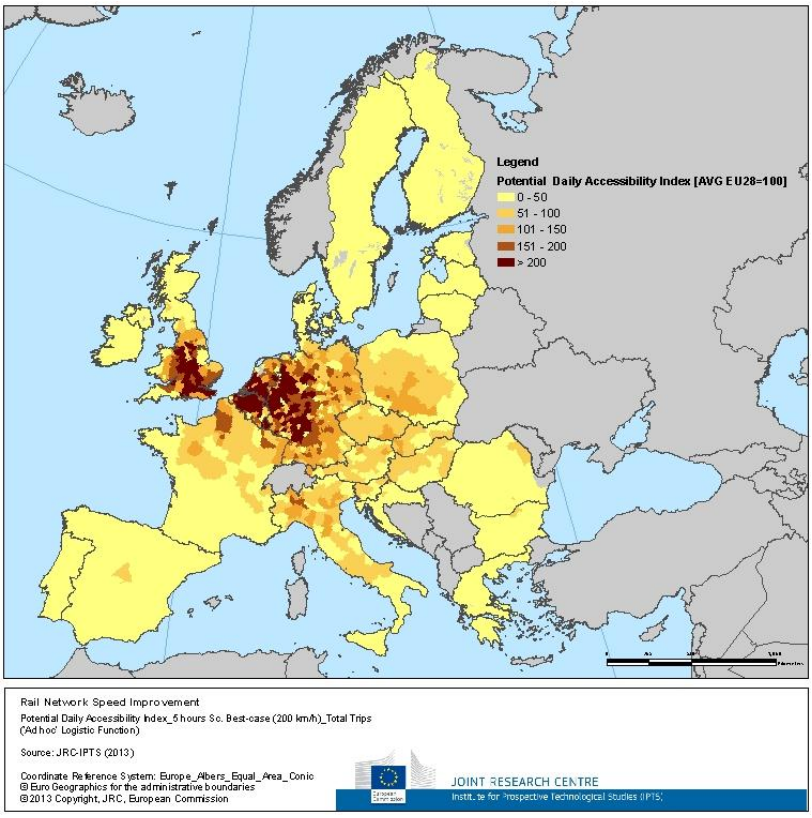


Fig. 63: Best-case scenario (200 km/h), absolute level of potential accessibility with 'ad hoc' function (dropping in 5 hours)

Low Speed Scenario (45 km/h):

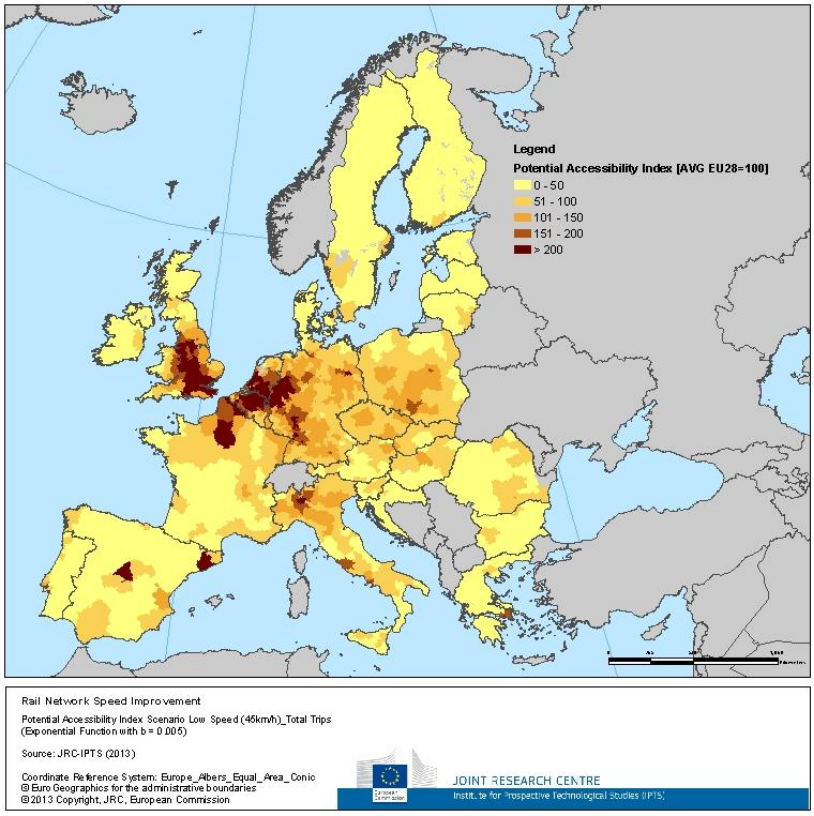


Fig. 64: Low speed scenario (45 km/h), potential accessibility index with exponential function

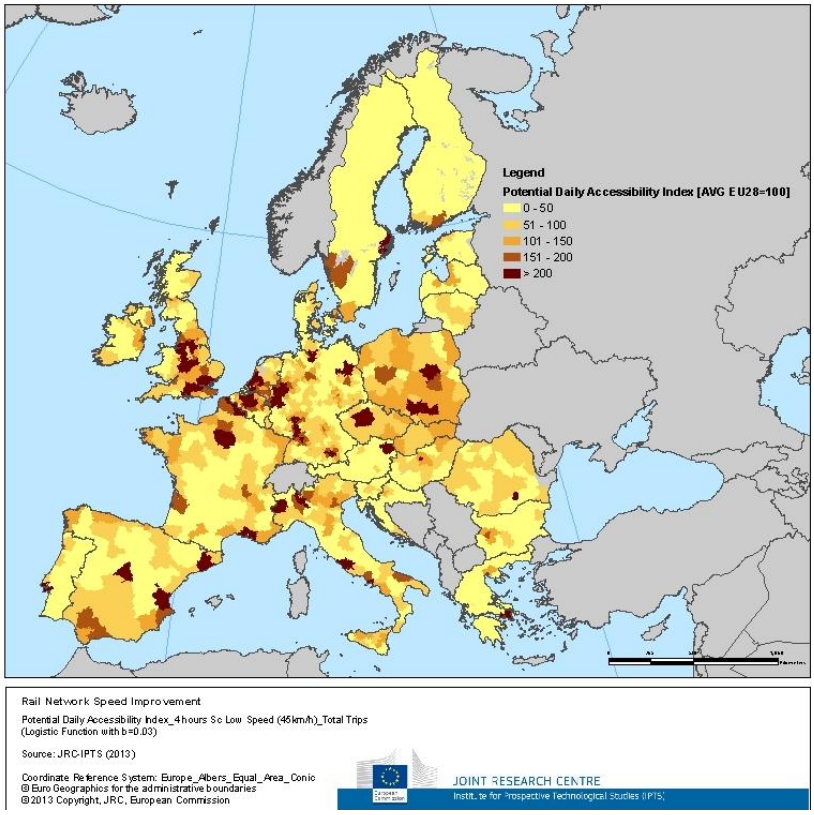


Fig. 65: Low speed scenario (45 km/h), potential accessibility index with logistic function (α=-0.03 & t_0=150 minutes)

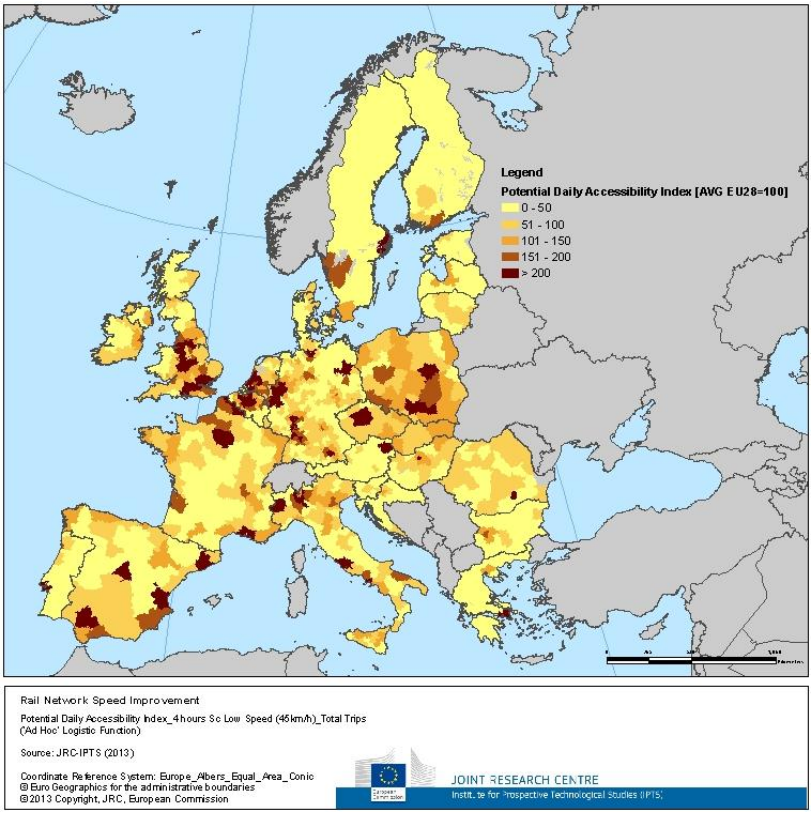


Fig. 66: Low speed scenario (45 km/h), potential accessibility index with 'ad hoc' function (dropping in 4 hours)

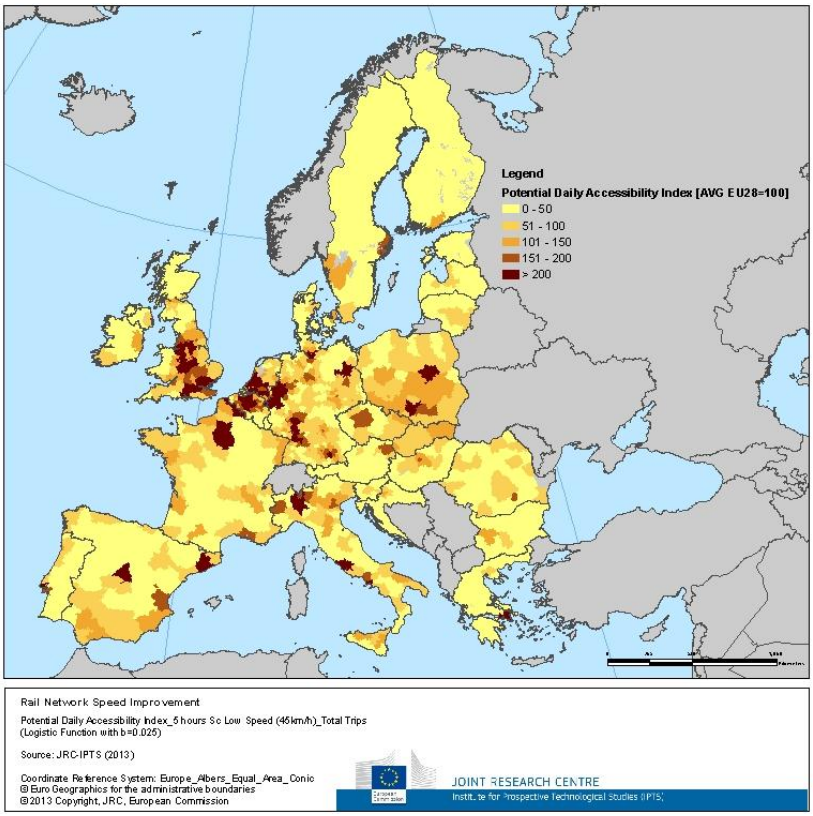


Fig. 67: Low speed scenario (45 km/h), potential accessibility index with logistic function (α=-0.025 & t_0=180 minutes)

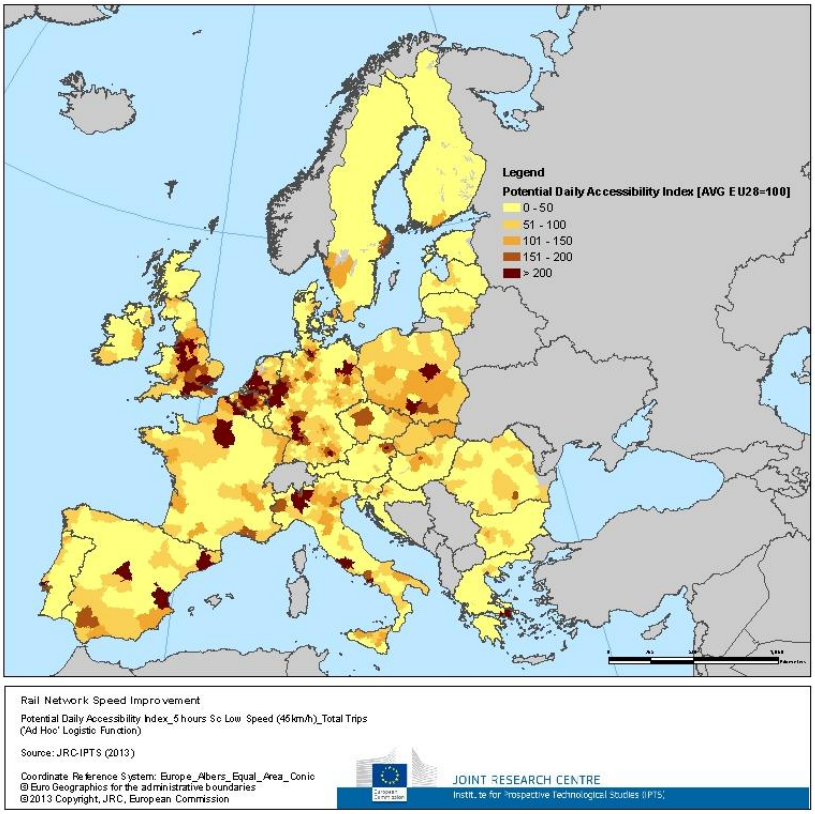


Fig. 68: Low speed scenario (45 km/h), potential accessibility index with 'ad hoc' function (dropping in 5 hours)

<u>High Speed Scenario (90 km/h):</u>

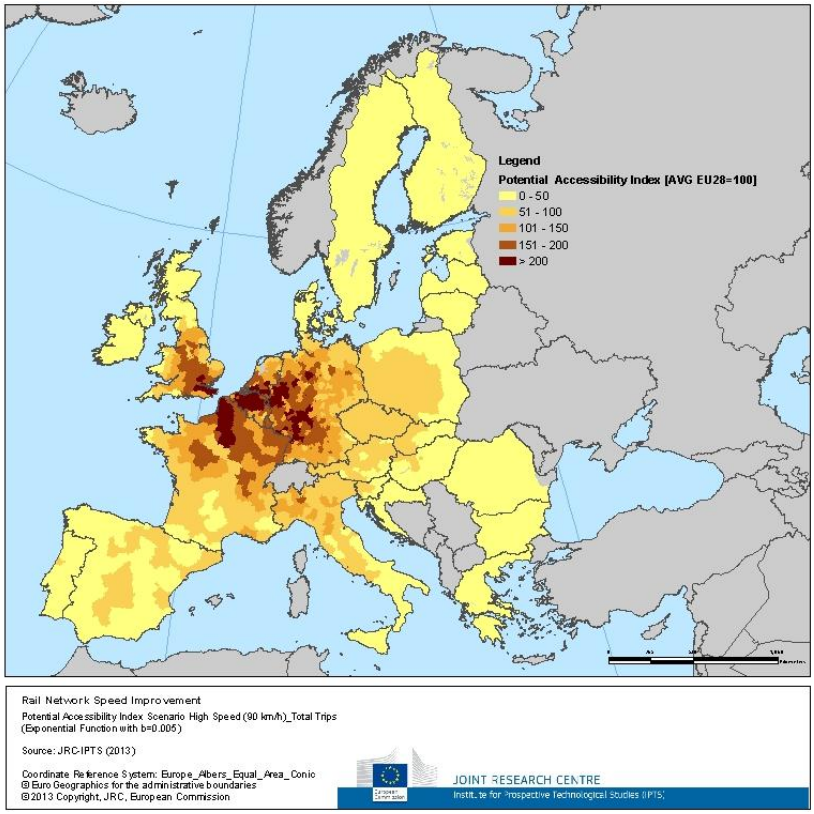


Fig. 69: High speed scenario (90 km/h), potential accessibility index with exponential function

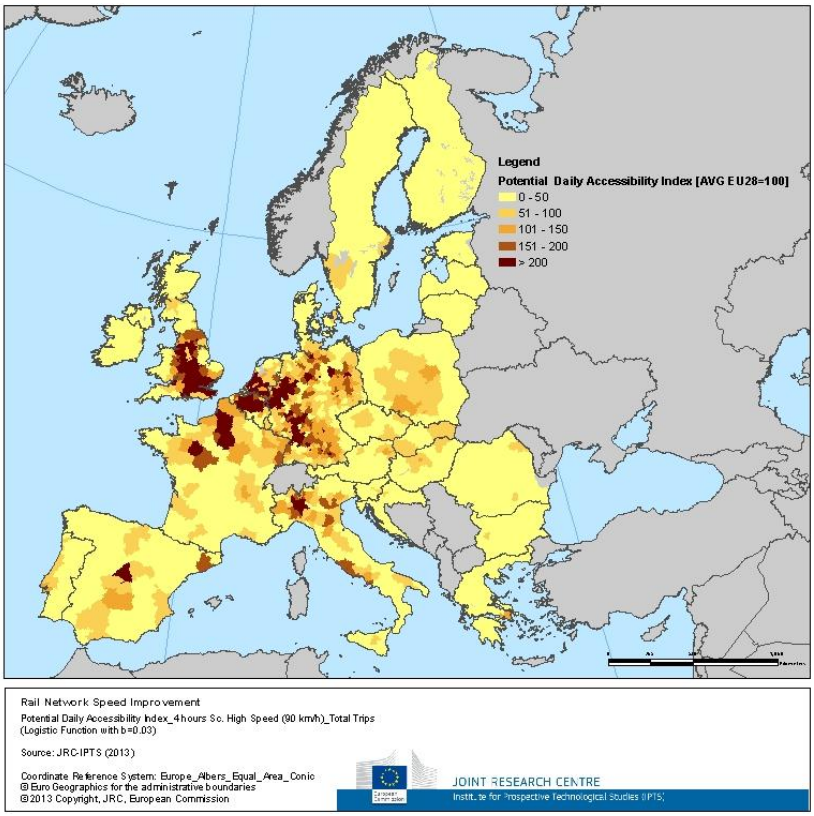


Fig. 70: High speed scenario (90 km/h), potential accessibility index with logistic function (α=-0.03 & t_0=150 minutes)

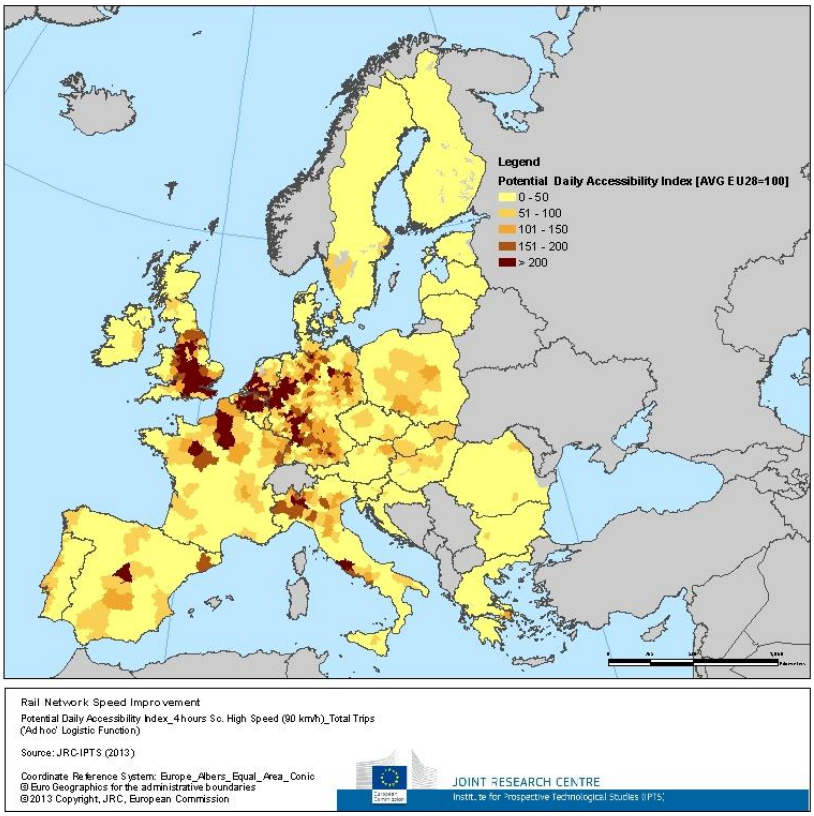


Fig. 71: High speed scenario (90 km/h), potential accessibility index with 'ad hoc' function (dropping in 4 hours)

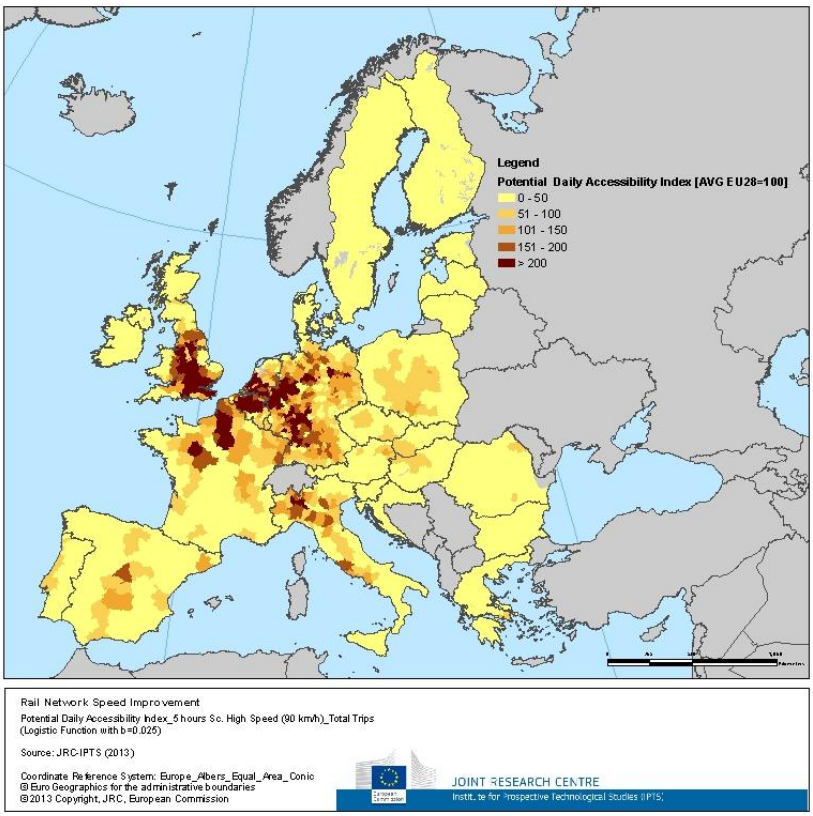


Fig. 72: High speed scenario (90 km/h), potential accessibility index with logistic function (α=-0.025 & t_0=180 minutes)

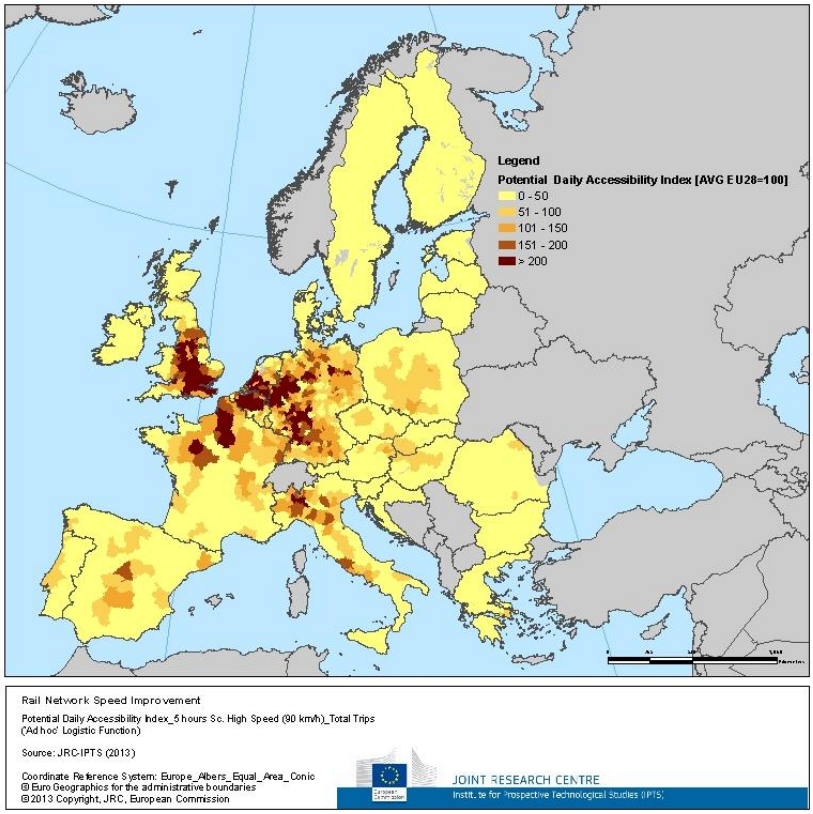


Fig. 73: High speed scenario (90 km/h), potential accessibility index with 'ad hoc' function (dropping in 5 hours)

Best-case Scenario (200 km/h) vs Baseline (2005):

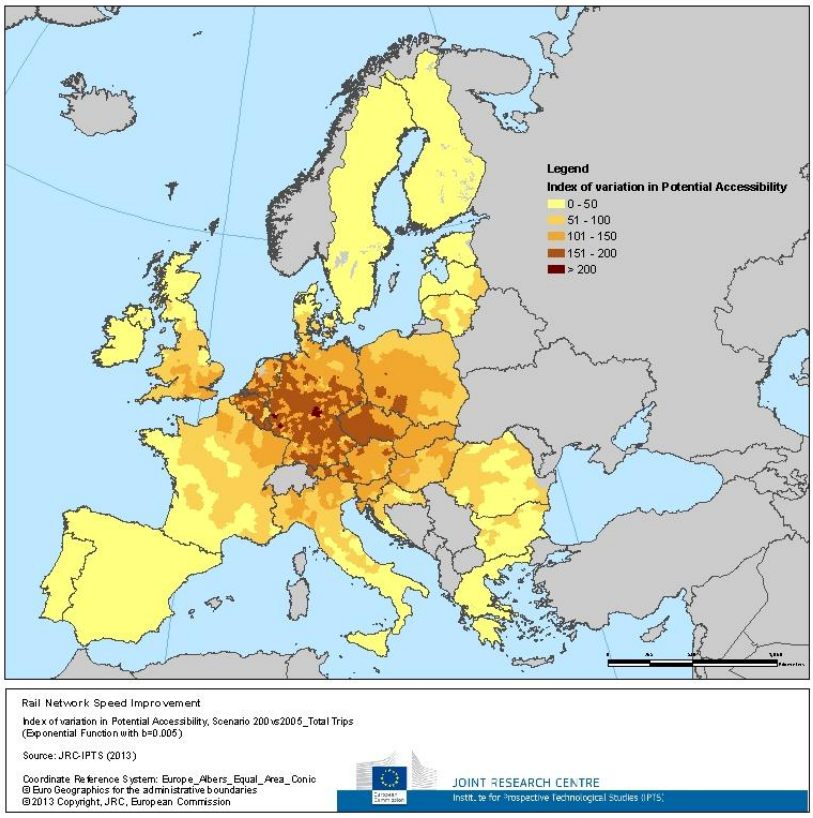


Fig. 74: Best-case Scenario (200 km/h) vs Baseline (2005), index of variation in potential accessibility with exponential function

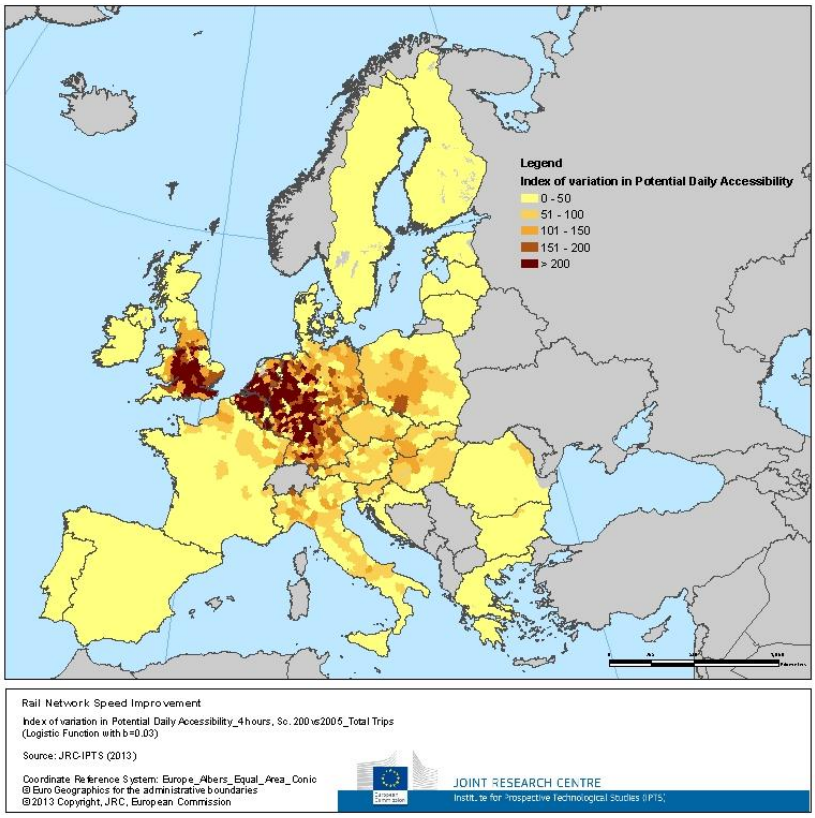


Fig. 75: Best-case Scenario (200 km/h) vs Baseline (2005), index of variation in PDA with logistic function (α=-0.03 & t_0=150 minutes)

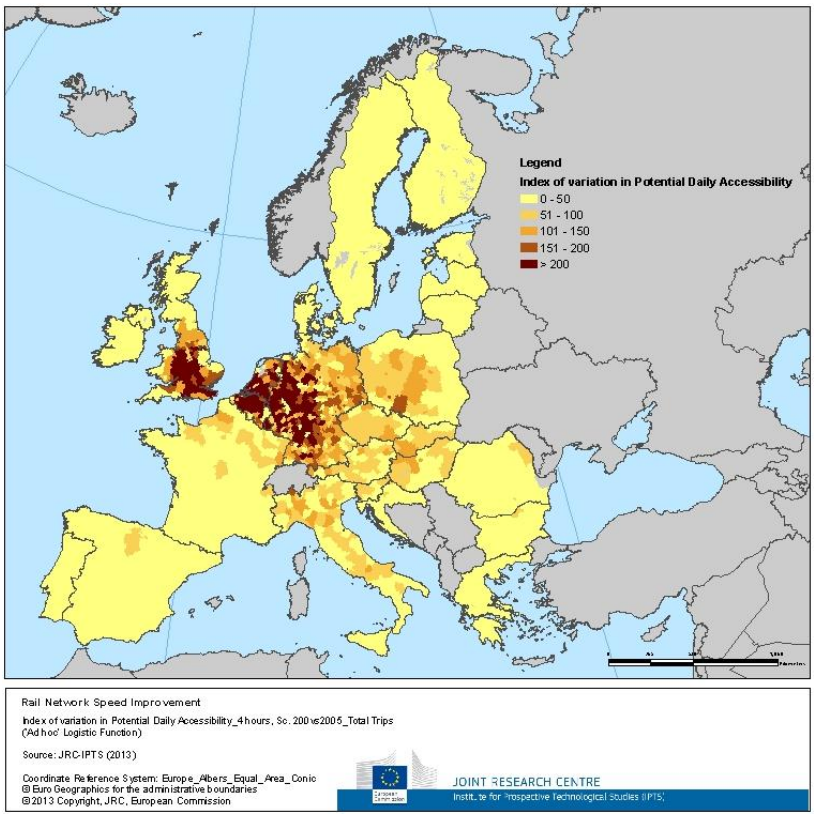


Fig. 76: Best-case Scenario (200 km/h) vs Baseline (2005), index of variation in PDA with 'ad hoc' function (dropping in 4 hours)

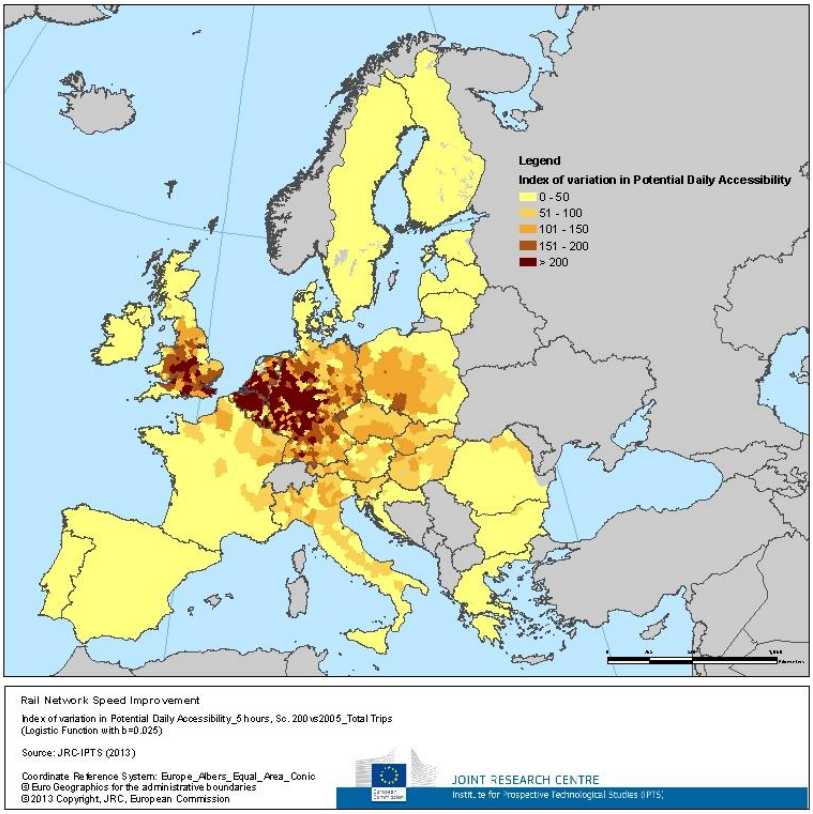


Fig. 77: Best-case Scenario (200 km/h) vs Baseline (2005), index of variation in PDA with logistic function (α=-0.025 & t_0=180 minutes)

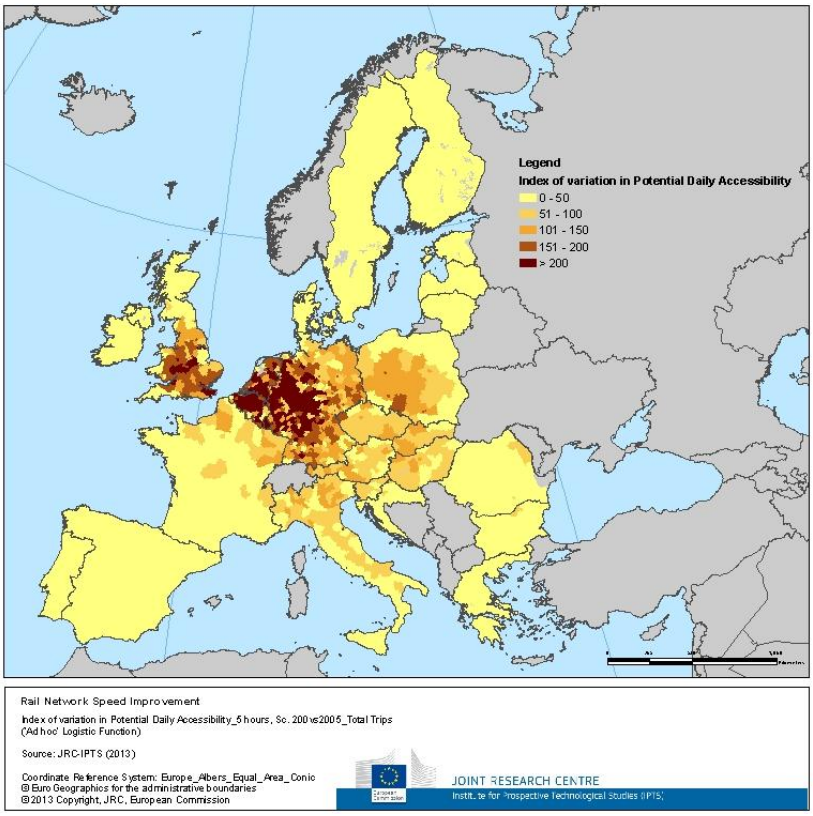


Fig. 78: Best-case Scenario (200 km/h) vs Baseline (2005), index of variation in PDA with 'ad hoc' function (dropping in 5 hours)

<u>High Speed Scenario (90 km/h) vs Baseline (2005):</u>

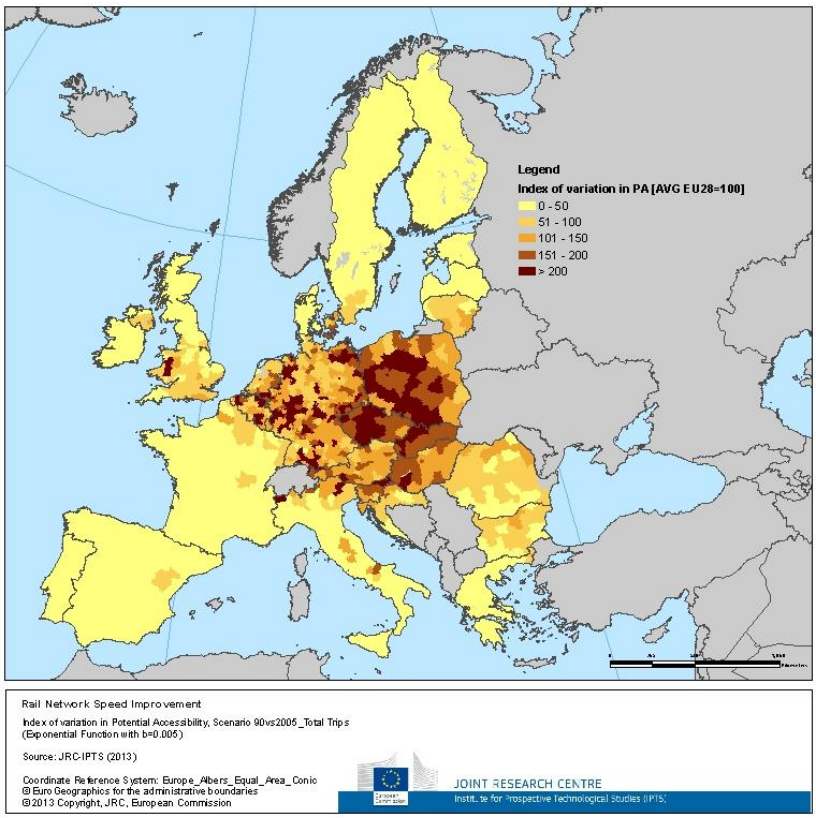


Fig. 79: High Speed Scenario (90 km/h) vs Baseline (2005), index of variation in potential accessibility with exponential function

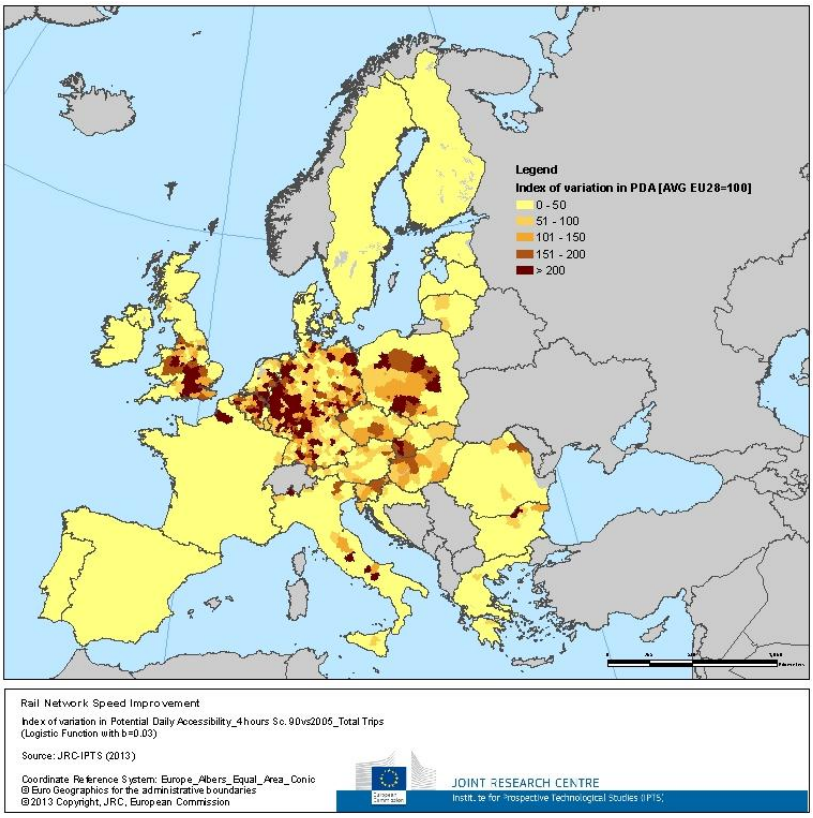


Fig. 80: High Speed Scenario (90 km/h) vs Baseline (2005), index of variation in PDA with logistic function (α=-0.03 & t_0=150 minutes)

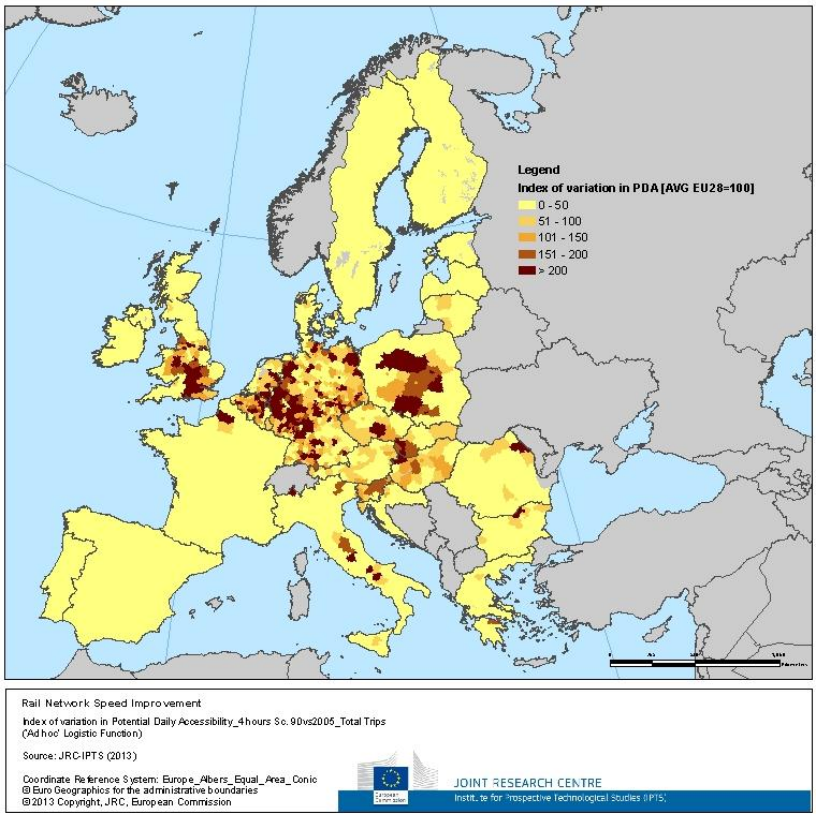


Fig. 81: High Speed Scenario (90 km/h) vs Baseline (2005), index of variation in PDA with 'ad hoc' function (dropping in 4 hours)

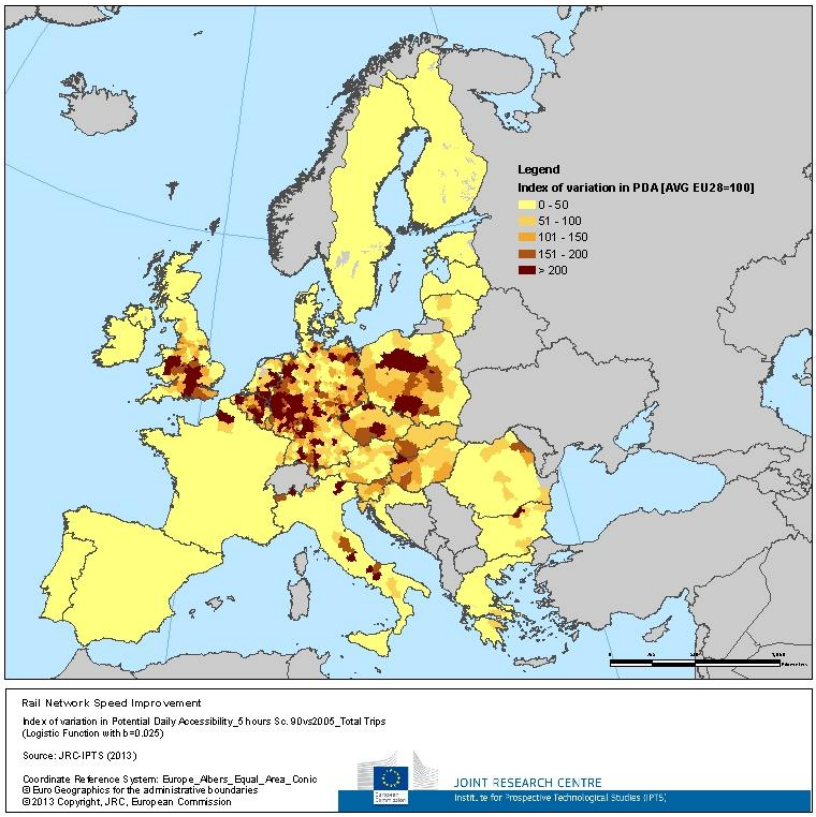


Fig. 82: High Speed Scenario (90 km/h) vs Baseline (2005), index of variation in PDA with logistic function (α=-0.025 & t_0=180 minutes)

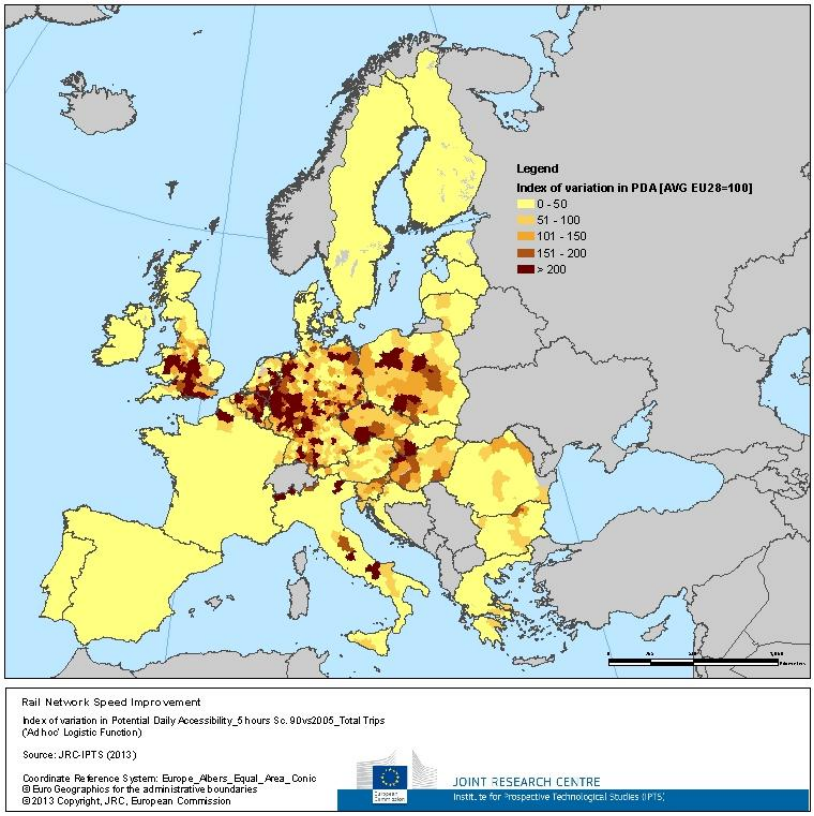


Fig. 83: High Speed Scenario (90 km/h) vs Baseline (2005), index of variation in PDA with 'ad hoc' function (dropping in 5 hours)

Baseline (2005) vs Low Speed Scenario (45 km/h):

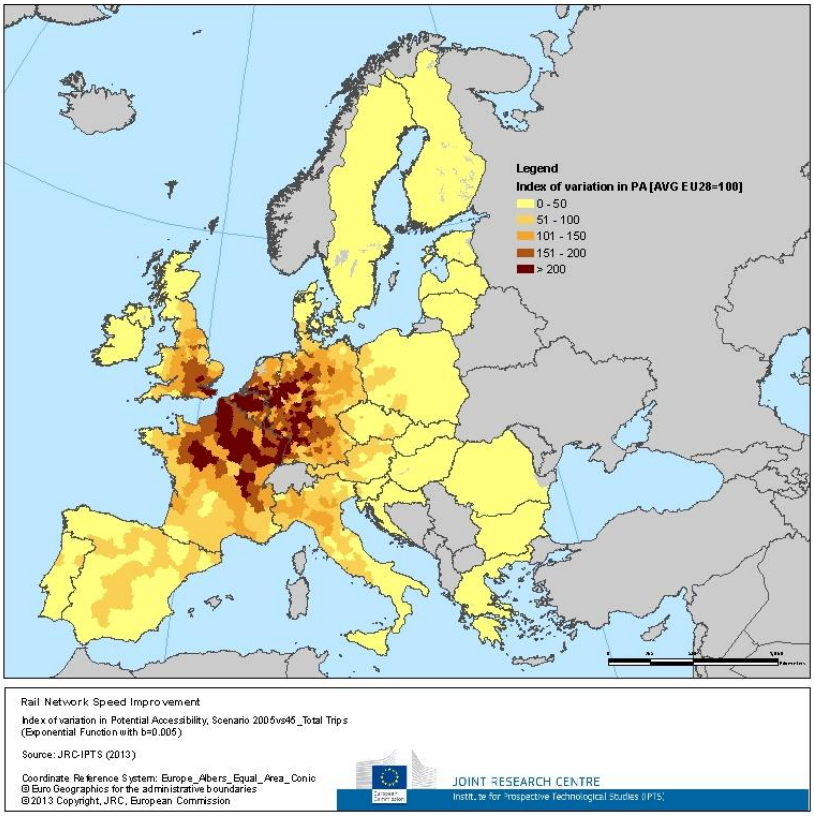


Fig. 84: Baseline (2005) vs Low Speed Scenario (45 km/h), index of variation in potential accessibility with exponential function

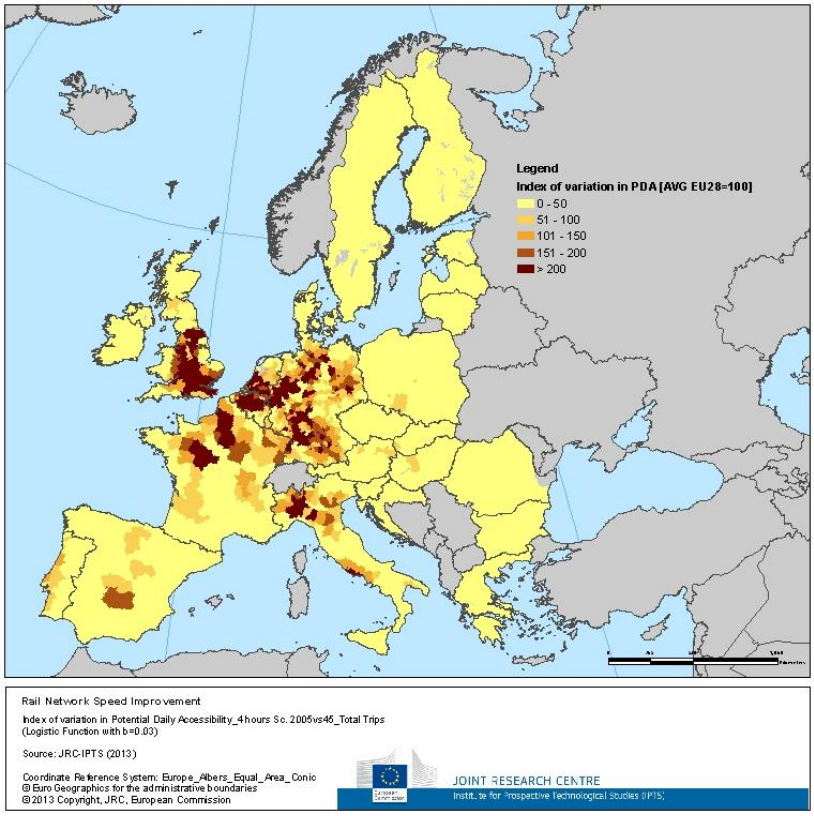


Fig. 85: Baseline (2005) vs Low Speed Scenario (45 km/h), index of variation in PDA with logistic function (α=-0.03 & t_0=150 minutes)

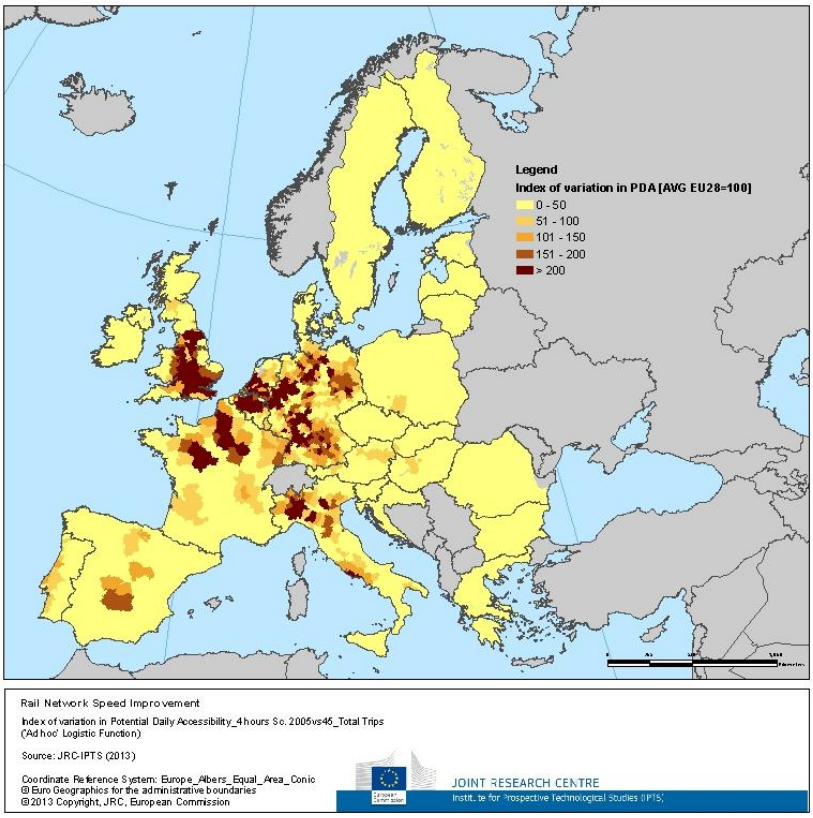


Fig. 86: Baseline (2005) vs Low Speed Scenario (45 km/h), index of variation in PDA with 'ad hoc' function (dropping in 4 hours)

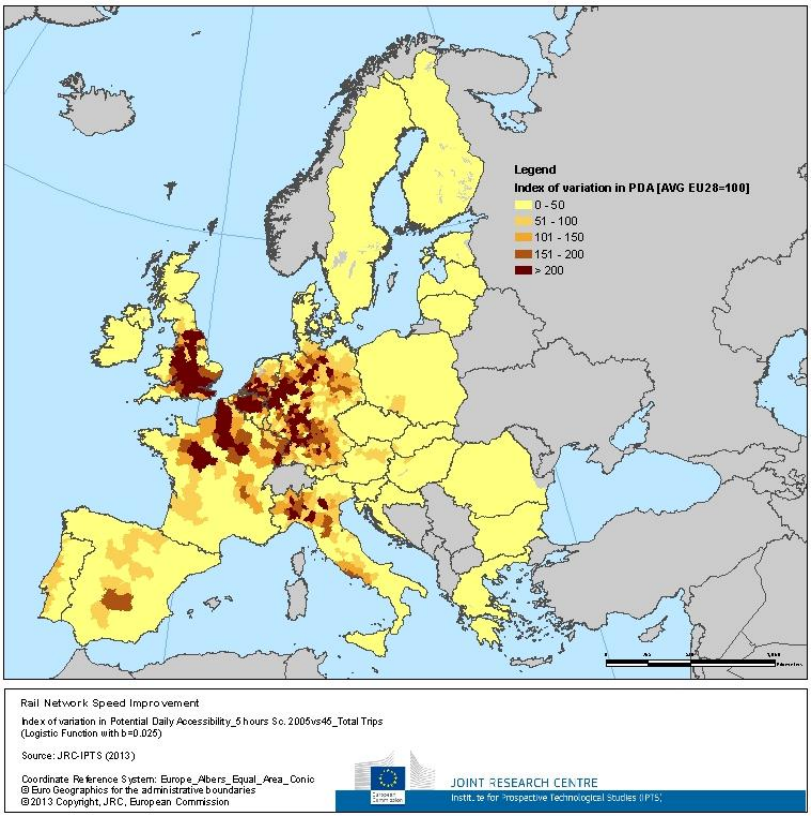


Fig. 87: Baseline (2005) vs Low Speed Scenario (45 km/h), index of variation in PDA with logistic function (α=-0.025 & t_0=180 minutes)

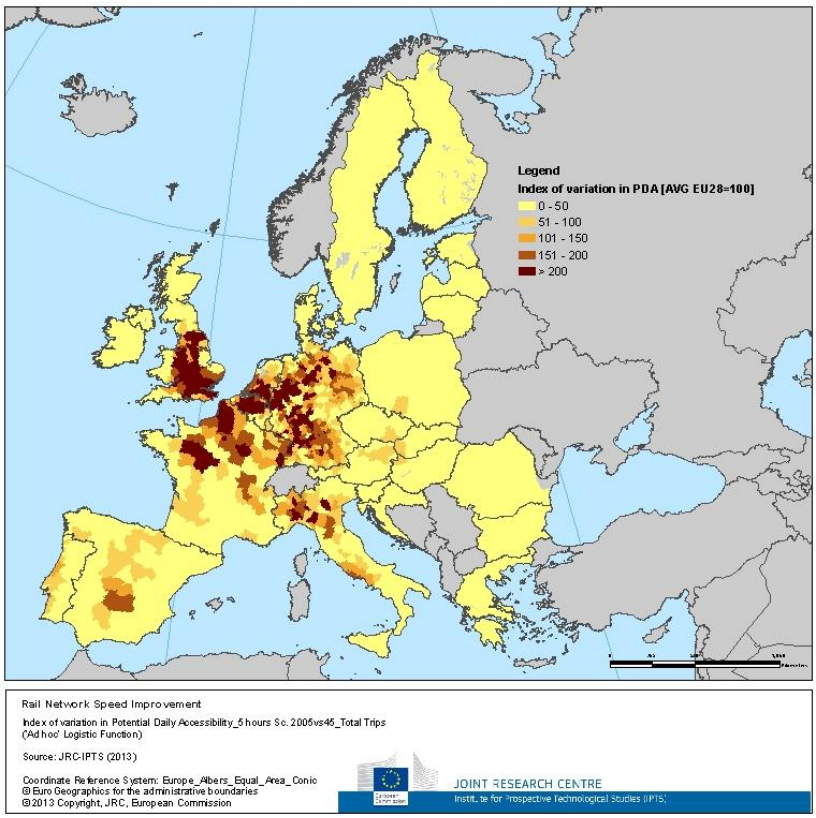


Fig. 88: Baseline (2005) vs Low Speed Scenario (45 km/h), index of variation in PDA with 'ad hoc' function (dropping in 5 hours)

Improved Frequencies Scenario (20%) vs Baseline (2005):

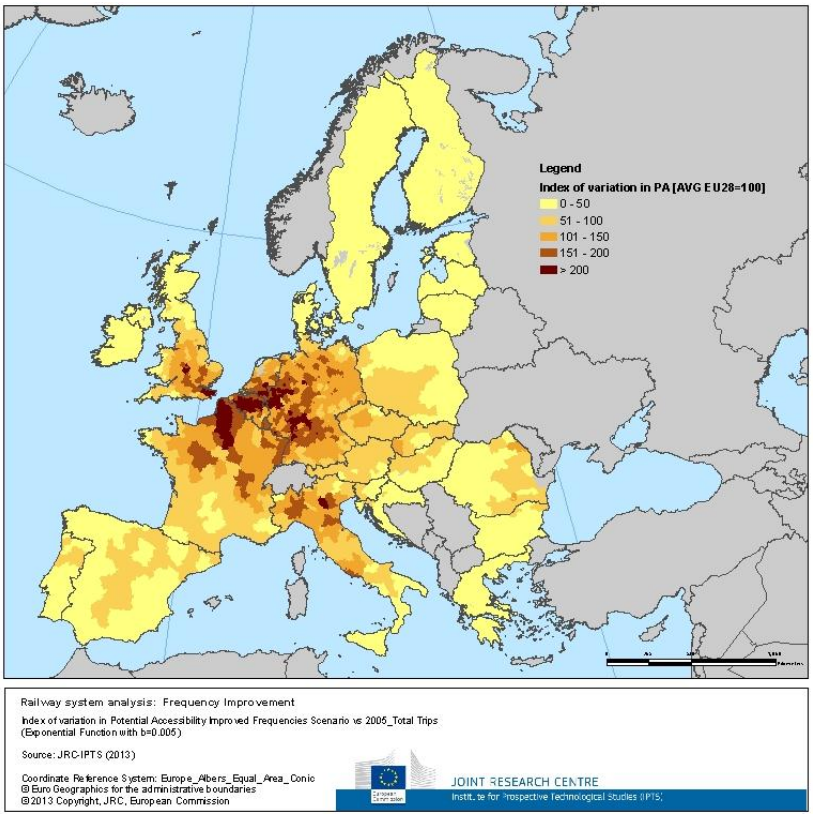


Fig. 89: Improved Frequencies Scenario (20%) vs Baseline (2005), index of variation in potential accessibility with exponential function

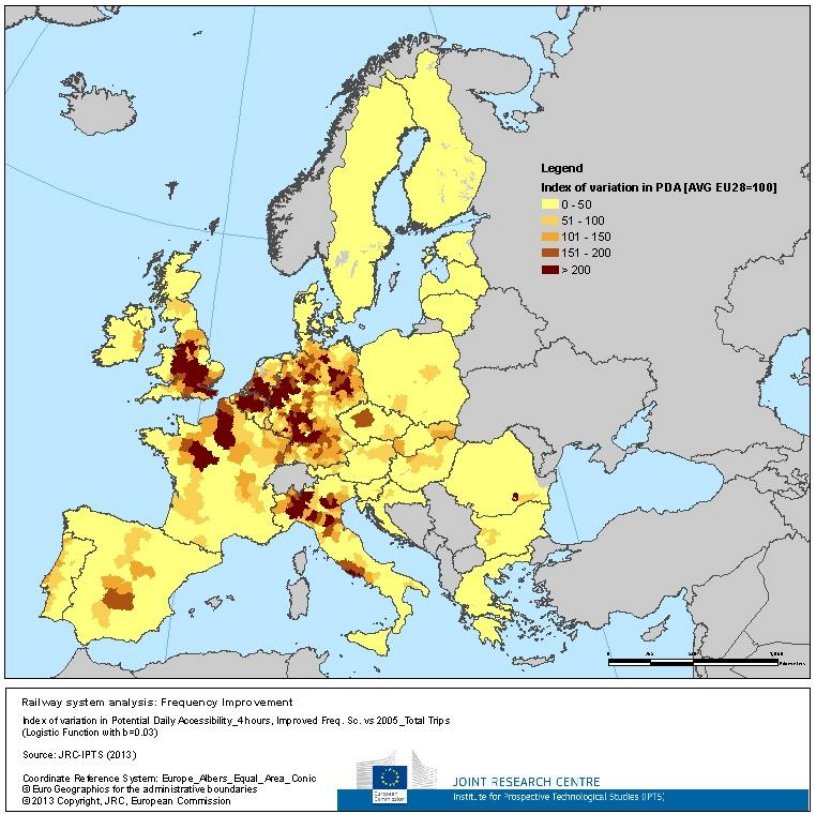


Fig. 90: Improved Frequencies Scenario (20%) vs Baseline (2005), index of variation in PDA with logistic function (α=-0.03 & t_0=150 minutes)

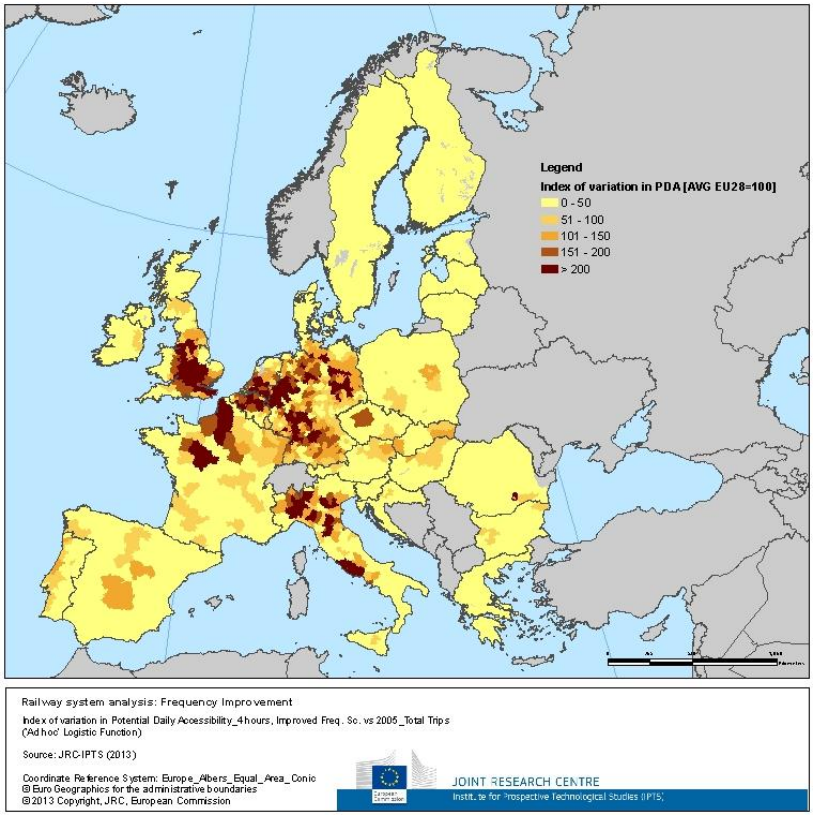


Fig. 91: Improved Frequencies Scenario (20%) vs Baseline (2005), index of variation in PDA with 'ad hoc' function (dropping in 4 hours)

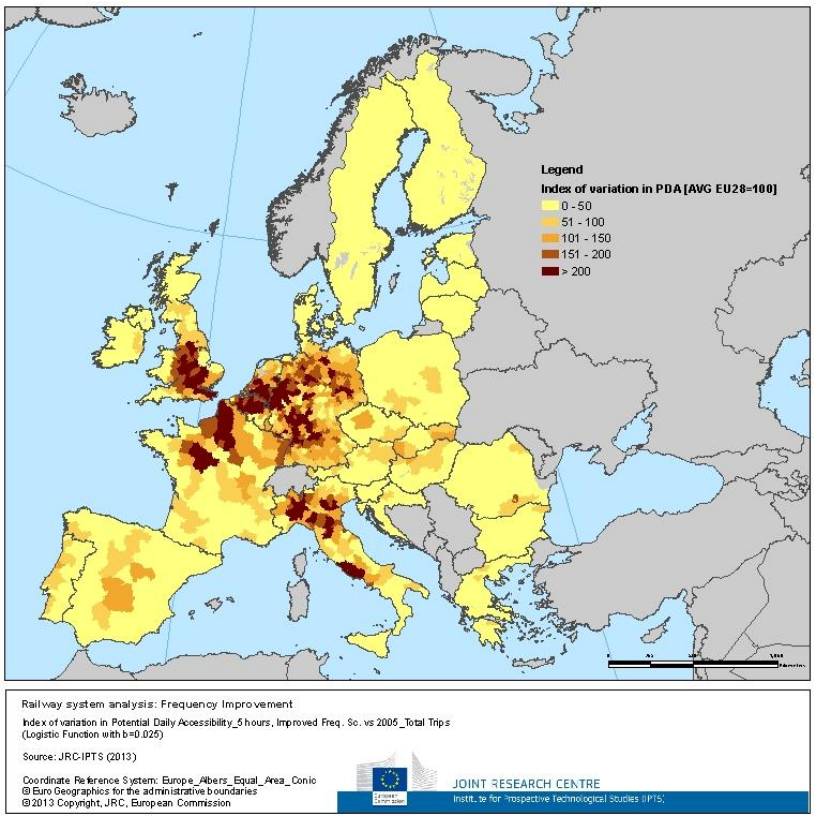


Fig. 92: Improved Frequencies Scenario (20%) vs Baseline (2005), index of variation in PDA with logistic function (α=-0.025 & t_0=180)

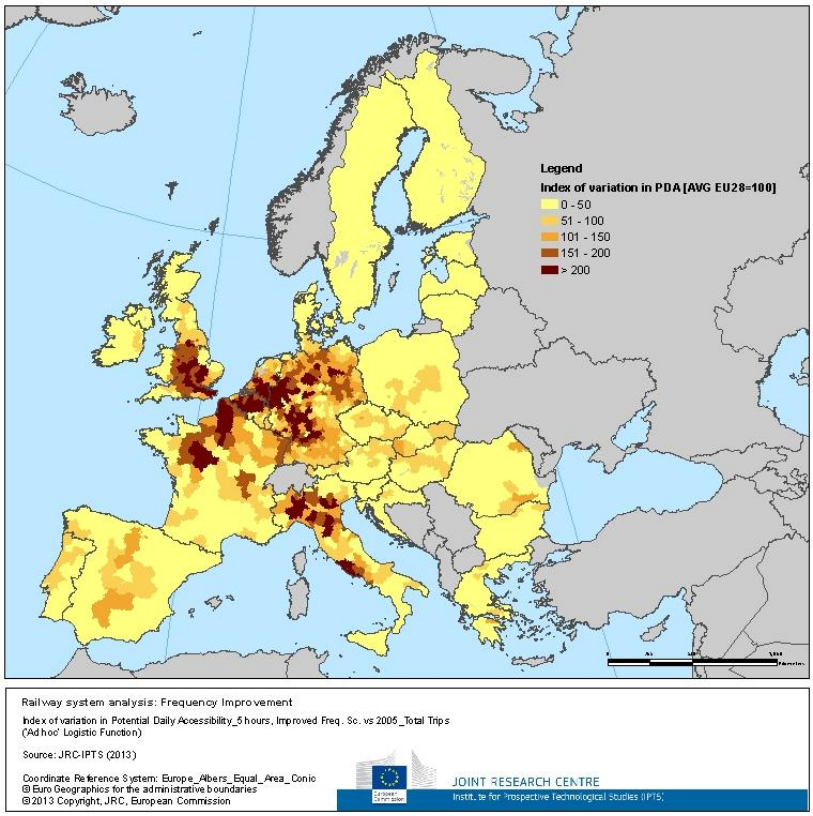


Fig. 93: Improved Frequencies Scenario (20%) vs Baseline (2005), index of variation in PDA with 'ad hoc' function (dropping in 5 hours)

Annex 3: Model-T: demand module

The Model-T demand module is a stand-alone transport demand modeling tool that includes an endogenous demand generation algorithm. The module provides forecasts of the size of future transport demand under a set of exogenous assumptions concerning key variables at the aggregated level (like population and GDP). Changes of transport demand caused by specific local conditions, transitory changes caused by variables outside the model domain (e.g. the fall of air demand after 11/9), breaks due to new socioeconomic paradigms (e.g. new protectionism) or to external constraints (e.g. oil shortage) cannot be simulated by the demand generation algorithm. By the way, most of these aspects are not managed even in the most sophisticated transport models.

Thanks to the endogenization of the demand generation phase, Model-T simulates the cumulative effect of policy measures over the simulation period. In addition, it is easy to simulate measures applied only for sub-periods (e.g. a temporary discount of fuel taxation to counterbalance high resource price of oil).

The first step consists of demand generation. The demand generation algorithm is general to represent both Europe and non-European regions, taking into account different level of economic development (and therefore with a different level of expected growth). Given the aggregated level of the analysis and given the above considerations, the algorithm simulates the overall long-term trend, not reproducing observed short-term fluctuations of demand in specific countries or years.

The module generates transport demand first at aggregate level (passenger-km, tonnes-km) segmented into the groups related to “macro” circumstances: geographical dimensions (national vs. international; long distance vs. short distance; urban vs. non-urban) as well as trip purposes and period of time (peak vs. off-peak). These dimensions depend on the macroscopic context rather than on individual choices. Of course, the macroscopic context can change over time (and the module allows to simulate changes) also because of individual decisions, but such decisions belong mainly to domains outside the scope of the prototype (e.g. moving house, change regions where to produce, change job, etc.) and therefore only the additional impact of the model variables (e.g. travel cost) on these elements is considered in the model in aggregate terms. The generation phase is modelled by means of a mathematical equation depending on policy-sensitive variables, coming form exogenous data (e.g. population, trade, GDP) or other part of the model (motorization rate).

In a second step, demand is further segmented according to “micro” decisions. They include the segmentation of demand according to transport mode and road type. These two elements can be reasonably interpreted in terms of choices between alternatives, where the key variables in Model-T play a significant role in the choice process. In the second step, break down is modelled by means of a discrete choice algorithm (nested logit model) mainly depending on the generalised cost of transport for each alternative (mode or network type). For generalised cost we mean a function of at least transport cost and travel time expressed in monetary terms (i.e. using the value of travel time savings to convert time into money). In some case, other variables are part of the generalised cost to take into account additional

endogenous factors or for calibration purposes. For instance, measures for the simulation of the Mohring effect or of the infrastructure network availability are included in some cases.

In any case, both the generation phase and the further steps to split up demand into segments are directly or indirectly sensitive to parameters whose value can change according to specific policy measures implemented. In particular, change of generalised cost occurring in the mode split/road type choice affects both demand generation and aggregate segmentation into distance, etc.

Demand module structure

Figure 1 below shows the basic structure of the demand module.

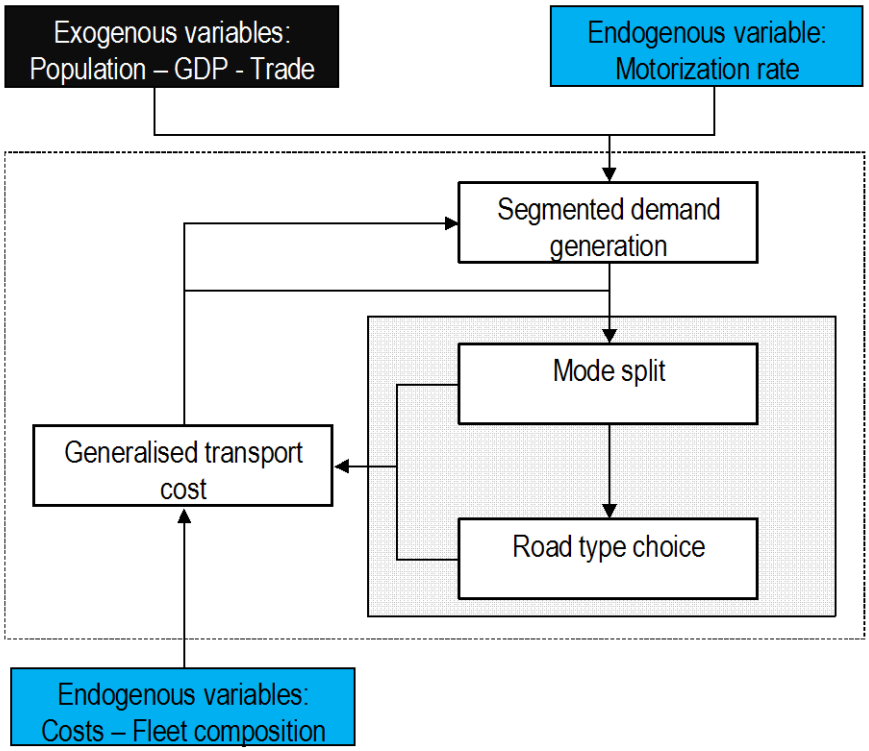


Figure 1 demand module outline

Variables and equations

The following figures summarize the main variables and relations for estimating transport demand for passengers.

On one hand transport demand within the same macro-region is estimated: first in aggregated terms by distance travelled, then split by mode and segmented by time period and network where requested. Generalized cost is one of the main drivers for distributing demand in both generation and mode split phases.

On the other hand the estimation of transport demand between different macro-regions is managed: in this case only air mode is available for passenger and air and maritime modes for freight. Demand is estimated separately from the rest of the module and directly by mode.

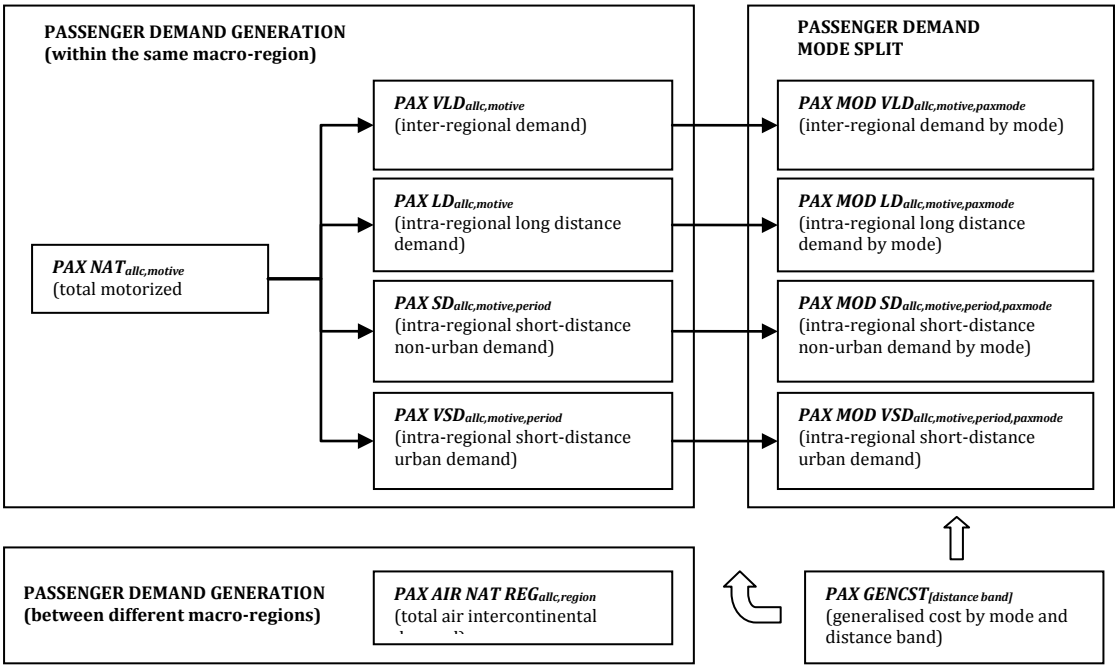


Figure 2 passenger demand main variables

Passenger transport demand generation

This part of the module estimates total motorized passenger transport demand (passengers-km) with the required level of segmentation (except mode split), i.e.:

- Region where the trip is originated (according to the zoning system),
- Purpose: business, commuting or personal,
- Region of destination: intra-regional or inter-regional trip,
- Distance travelled: short distance or long distance (for intra-regional trips only),
- Urban level: urban or non-urban (for intra-regional trips only),
- Time period of the day: peak or off-peak (for intra-regional trips only).

In modelling terms, four variables are the main product of this process sent to the next step:

- ***PAX VLD$_{allc,motive}$***: motorized pkm generated by region and purpose with inter-regional destination,

- ***PAX LD$_{allc,motive}$***: motorized pkm generated by region and purpose with intra-regional long distance destination,

- ***PAX SD$_{allc,motive,period}$***: motorized pkm generated by region, purpose and time period with intra-regional short distance destination at non-urban level,

- ***PAX VSD$_{allc,motive,period}$***: motorized pkm generated by region, purpose and time period with intra-regional short distance destination at urban level,

The sum of these variables represents the total amount of motorized demand generated within the same world region ("continental" demand).

The process can be interpreted as a sequence of splits: first aggregated demand is generated, then it is separated into trip purposes, afterwards it is further split into intra-regional and inter-regional, etc. At each step, a specific set of variables and parameters are used for compute the shares.

For the estimation over time, passenger demand at one given year ***t*** is estimated based on input variables of the year ***t-1***.

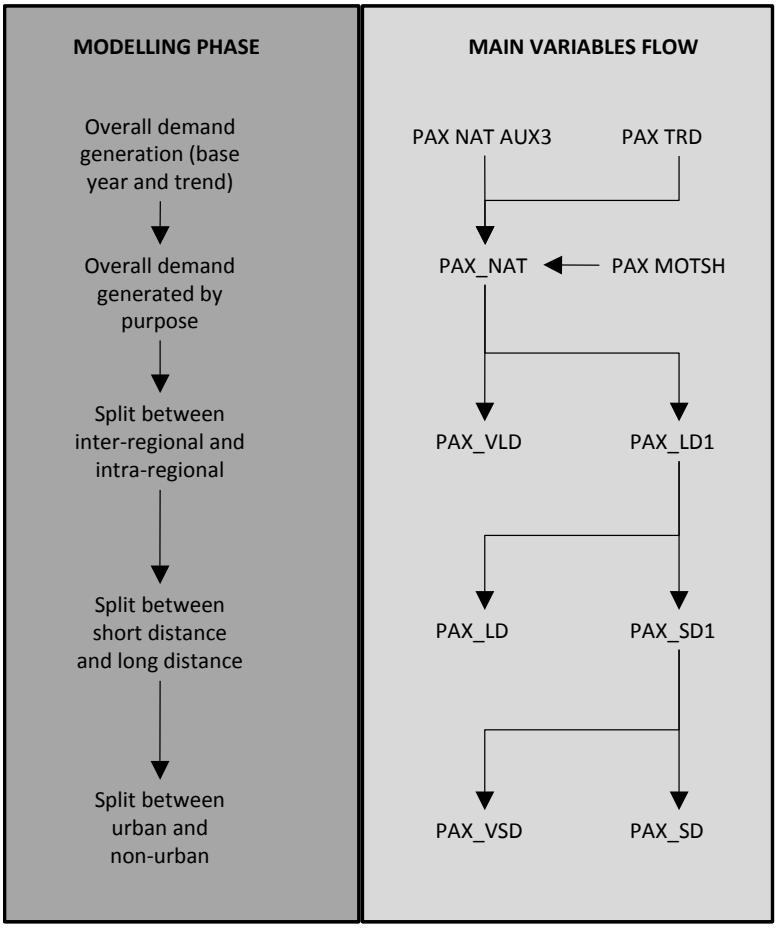


Figure 3 process for passenger demand generation

The equations involved in the procedure are introduced below step by step.

Transport demand split

After demand has been generated according to the "aggregate" dimensions, those aspects that can be interpreted as the result of individual decisions, i.e. the choice of mode and of network type, are modelled.

The equations for mode split can be found in the view **DEM PAX_mode_pkm** and **DEM FRE_mode_tkm** of the Model-T model.

Mode split is based on random utility approach, i.e. it is assumed that the consumer prefers the alternative with the highest utility over the others (utility maximization).

$$U_{nj} = V_{nj} + \varepsilon_{nj}$$

where:

$\boldsymbol{V_{nj}}$= the deterministic part of the utility

$\boldsymbol{\varepsilon_{nj}}$= the random term

A nested logit algorithm is used to compute mode shares. Such algorithm is assumed, i.e. there has not been a process of statistical estimation based on choice data to make a selection between alternative models and alternative specifications. Indeed, this estimation process would need a large amount of data and resources to be carried out. Therefore, also the value of the parameters used in the algorirthm for the various segments come from literature (e.g. value of time) or are the result of a calibration process (see documentation on calibration).

The sequence of choice modelled through the nested logit in the demand model is: first between transport modes and secondly, provided that a road mode is chosen, between road type. An example of the applied two-level nested logit structure is given in the following figure.

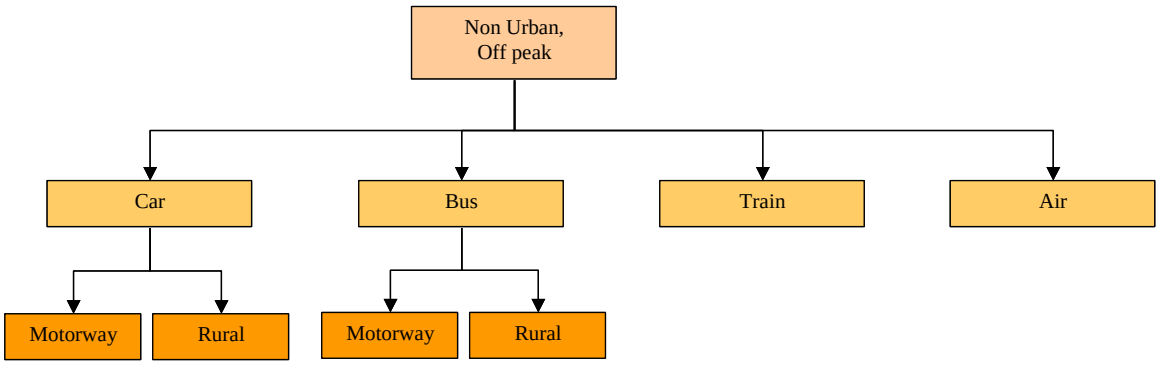


Figure 4 Example nested logit tree structure

The deterministic part of the utility function consists mainly of generalised cost, i.e. transport cost plus time weighted with Value Of Time. An additional term is used, representing reliability and/or extension of transport network and consequent availability of a specific mode. This term has been added to the definition not only for taking into account aspects not covered by the cost and time terms, but also for computational reasons: the value of this terms has been set in order to calibrate the elasticity of the model and to maintain the magnitude of the utility function of the logit model within an acceptable range

for Vensim (which cannot handle too large or too small numbers) and large enough that the inclusive values do not change sign due to the log transformation.

The following tables summarize the parameters added to the generalized cost definition for passengersand freight modes.

Table 1 Additional elements for generalized cost estimation

Passenger variables	Note
PAX RAIL REL$_{allc,dist}$:	reliability of train mode, weighted with a reliability coefficient
PAX AIR REL$_{allc,dist}$:	reliability of air mode, weighted with a reliability coefficient
PAX BUS REL$_{allc,dist,roadtype}$	reliability of bus mode, weighted with a reliability coefficient
PAX TRAM REL$_{allc}$	reliability of tram mode, weighted with a reliability coefficient
PAX CAR DECR$_{allc,dist}$	additional term for car, related to their diffusion and availability
PAX MOTO DECR$_{allc}$	additional term for motorcycle, related to their diffusion and availability

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