Impacts of improving interconnectivity between local and long-distance transport networks in Europe

Conclusions from modelling activities in the INTERCONNECT 7th EU Framework Programme Project (June 2009 – May 2011).

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Abstract

The role of the Trans-European network as an integrated international system is compromised due to poor interconnectivity. Improved interconnections can result in more competitive multi-modal alternatives to uni-modal road transportation and contribute to CO\textsubscript{2} emissions reduction. However, the fact is that nowadays 73% of all kilometres completed through long-distance trips in Europe are made by road. One of INTERCONNECT goals was to investigate to what extent reducing interconnectivity costs (between different modes and between local and long-distance networks) may result in an optimised transport system, induce modal shifts towards rail and contribute to decrease CO\textsubscript{2} emissions. Conclusions indicate that although these impacts are likely to happen, depending on which specific strategies are adopted to reduce interconnectivity costs, rebound effects may also appear, thereby compromising any potential benefits.

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1. Background

In 2006 the mid term review of the EC transport White Paper introduced the concept of co-modality to define a new approach for all transport modes by enforcing the “use of different modes on their own and
in combination” in the aim to obtain “an optimal and sustainable utilisation of resources”. In 2011, the new transport White Paper claims that better modal choices in transport will necessarily result from greater integration of different modal networks, requiring airports, ports, railways, and other public transport systems to be increasingly linked to facilitate multi-modal travel, including the target of all core network airports being connected to the rail network by 2050, preferably on high-speed.

INTERCONNECT research was financed by the 7th European Research Programme aiming to identify and analyse potential solutions to better interconnect transport networks in Europe, as well as providing an overall assessment at the European level by applying new modelling tools able to handle intermodal connections.

This paper is based on the results obtained by applying the new modelling tool developed in INTERCONNECT (IC MSA, InterConnect Modal Split and Assignment module). The IC MSA is based on transport networks and trip matrices generated by the TRANS-TOOLS strategic model, in the second version developed in the frame of the TENCONNECT study (Petersen, M.S. et al., 2009).

TRANS-TOOLS is a classic four-step forecast model developed in the European Research Framework Programme, used for the assessment of European policies at strategic level, such as the TENCONNECT or TRANSVISIONS studies. Because of its sequential four-step structure, TRANS-TOOLS assigns trips mode by mode, after carrying on the modal split process, and does not allow to analyse multi-modal chains.

Modelling multi-modal trips is centred in fact on the issue of how to model (and represent) travellers’ routes and mode choice decisions. According to Fernandez et al. (1994) there are three ways of doing this:

- All relevant combined-mode alternatives are seen as distinct (and artificial) modes (the called extended classical approach);
- All transfer nodes are modelled as a mode alternative (extended classical approach with explicit modelling of transfer nodes and stops);
- All choice decisions emerge from route choice in an integrated multi-modal network (here called the super-network approach).

The IC MSA module integrates modal split and traffic assignment in one so the modes do not compete to carry trips but contribute to form multi-modal chains and modal split is the end result of the process, not the starting point. In this sense, the IC MSA module is based on the super-network approach. The original TRANS-TOOLS transport networks are enhanced to include explicit connections between transport modes and multi-modal transport chains and new routines are programmed integrating modal split and traffic assignment. Results of the IC MSA Module were validated against TRANS-TOOLS second version for 2005.

Even if further work is needed to improve the modelling capability of IC MSA module, especially in relation to how to consider rail and air transport services, as well as to represent local connections, at its current development level the IC MSA module already provides for useful insights concerning the potential impacts of reducing interconnectivity costs in European transport networks. In the next section the IC MSA module is described in more detail.
2. The InterConnect Modal Split and Assignment module (IC MSA)

The IC MSA module has been developed in C++ on top of BridgesNIS. BRIDGES/NIS is a suit of C++ routines developed in the Bridges 4th EU Research Framework by MCRIT (1999), and continuously upgraded since (www.mcrit.com/bridges). The outputs produced by the IC MSA module (16Gb, 450 million registers) are processed by ad-hoc meta-model routines programmed to compute specific indicators measuring interconnection, as well as to carry on sensitivity analyses. The IC MSA module provides for an integrated modal split and traffic assignment procedure based on a multi-class AON algorithm. The module assigns flows searching the cheapest paths according to generalised cost functions.

The model does not take into account congestion in the networks, given that the analysed flows are long distance. Long distance traffic takes place during time periods usually much longer than the peak hours last; travellers tend to avoid these peak hours whenever possible to improve travelling times. The hypothesis of not taking into account the congestion might lead to slightly incorrect results when the long distance traveller has to use networks running around big cities, as congestion might change the shortest path (in time) by using a longer (in distance) by-pass. However, the effect of these route changes has a very low impact on the costs in long distance trips.

The IC MSA assigns flows onto an interconnected network of all transport modes (road, rail, air, ferry). TRANS-TOOLS transport networks were enhanced to model interconnections between long-distance services, and between local networks and long-distance terminals. TRANS-TOOLS’ uni-modal networks were connected by establishing connectors at intermodal transport terminals, and between rail stations and road intersections to nodes representing city centres, and NUTS3 centroids. Airports are accessed only from road and rail networks, and not directly from city centroids, and therefore trips use different transportation means to access airports from cities –road or rail, or combinations of both– depending on the value of time assigned to each trip purpose. The multi-modal graph contains 35,000 nodes and 62,000 links, structured according to a complex network topology able to handle transport services.
Connectors were automatically created using the following criteria: all cities were connected to closest roads, but only to closest rail stations when these were located nearer than 15 kilometres. Airports were connected to the closest rail stations when these were located nearer than 10 kilometres, and to the closest roads when located nearer than 5 kilometres. Rail stations were always connected to roads. Needless to say, this procedure implies a substantial simplification of local and regional networks and was refined manually on a case by case basis.

Average values of time by trip purpose are based on TRANS-TOOLS, ranging from € 7.5 per hour for holiday travellers to € 25.0 per hour for business travellers. As the value of travel time for each traveller also depends on the personal income, average European values have been refined using dispersion coefficients to consider the effect of GDP per capita disparities on travellers depending on their NUTS3 of origin. Average travel fees are also based on TRANS-TOOLS services and refined to consider the effect of GDP per capita disparities in different areas of Europe.

Each transport network has a different travel cost per kilometre ranging for € 0.09 per kilometre for local rail services and € 0.2 per kilometre for long-distance rail services, with € 0.15 per kilometre for road mode. The air mode costs are estimated in function of the size of the airport of departure –directly proportionally- and the relative length of the trip.

The costs of interconnections are calculated based on the costs attached to the intermodal connectors, in euros per kilometre -as a fee ranging € 0.1 per kilometre in city to rail connections, to € 0.25 per kilometre in city to road and road to rail connections-, and the cost of facing increased travel times due to the speed attached to the connector, in euros per hour. Connector speeds aggregates in one parameter both access and waiting times. Additionally, 90 minutes average time is imposed between successive air services. No additional transfer time is considered in connections between long-distance rail networks (TEN-T) and regional or short-distance networks. Aviation is facing much higher interconnection costs than rail, all considered.
All itineraries between centroids representing NUTS3 are finally computed based on lower cost paths by trip purpose. Trips are assigned following an AON multiclass algorithm. A total of 1,441 NUTS3 are considered, generating a total of 8.3 million possible minimum cost itineraries between NUTS3, considering the existence of four different trip purposes with different travel costs. On the other hand, the total number of long-distance trips in Europe is 5,800 million, according to TRANS-TOOLS second version, giving a total of 1,170,000 million trip-kilometres.

Default cost and time impedance parameters in the IC MSA module have been adjusted in a validation process against TRANS-TOOLS results aggregated at European level. The adjustment process was carried out by a process of successive simulations, instead of by an optimisation, given the number of parameters to be adjusted and the need to monitor the process step by step. The final difference in trip-kilometres obtained, after 20 simulations, was considered acceptable: below 0.5% for roads, below 2% for air and 6% for rail, resulting in a weighted error of 1% for all modes, as shown on the next graphic:

Fig. 2. Validation process of the IC MSA module (validation consisted in adjusting the total trips-km of each mode at aggregated level to TRANS-TOOLS figures).

The following facts may directly or indirectly influence the nature and magnitude of the results obtained by applying the IC MSA module. First, the NUTS3 divisions differ between EU27 core regions, EU27 peripheral regions, and other neighbouring regions (Iceland is represented by one NUTS3, Belarus by 6 NUTS3, Spain by 52 NUTS3 and Germany by 439 NUTS3). In peripheral areas beyond the EU, traffic has fewer options to travel from one point to another, since networks are less dense, and this results in fewer transport options. Also, the definition of long-distance travelling by trips originated and bound onto different NUTS3 incorporates a number of relatively short inter NUTS3 trips (e.g. between German NUTS3). Because transport networks and modelling parameters were always defined, and validated, at European level, the IC MSA module at this stage does not guarantee reliable absolute results at national or regional level, and always have to be analysed in relative terms. More than absolute values, it is always the comparison (e.g. between NUTS3, trip lengths and purposes, modes…) in the different scenarios
studied, always at the European scale, that is relevant. Nor are trips from Europe to the rest of the World (not included in the reference area displayed in the following maps) considered.

The following maps illustrate some of these comments for the case of the business trips, represented by trip lengths, for the whole European space considered.

Fig. 3. Modes used in business trips by trip distances (Red represents more multi-modal paths used in business trips originated in the NUTS3 towards all other NUTS3, weighted by the number of travellers in each, while green represents less multi-modal paths)

3. The interconnections on the European transport networks

The IC MSA module was designed to analyse two different interconnectivity costs: costs to get access to long-distance networks from cities, and costs to change service and/or shift mode in the long-distance trips. The overall costs of interconnections are mostly produced by local connections to long-distance networks (about 80%), since all long-distance trips need a local connection, and few long-distance trips use different services or scales, and even fewer trips shift modes.
Relatively few long-distance trips in Europe use multi-modal chains\(^1\) (7% of the total long-distance trips are multi-modal, and long-distance represents 9% of total trips in Europe, so approximately 0.65% of the total trips are long-distance and multi-modal). This relatively small set of multi-modal long-distance trips today represents around 20% of the long-distance trip-kilometres, and 6% of the total amount of kilometres travelled in Europe.

By trip purposes, around 15% and 20% of private and business trips were long-distance and just 6% of holiday trips. In trip-kilometres, all these three trip purposes were in the range between 30% and 40%. Long-distance commuter trips represented no more than 2% of both trips and trip-kilometres.

It is not surprising that the average trip length in long-distance travel is 202 kilometres, since we consider as long-distance trips those trips between NUTS3, and most trips are between large cities at National level (e.g. Lyon-Paris, Milano-Rome, Barcelona-Madrid…) and between large European cities located in the centre (e.g. London-South East, Paris-Île de France, Brussels, Frankfurt…). Trips involving the air mode are the longest, as also expected, being the average air uni-modal trip 1,470 kilometres long and the average air-rail trip 1,366 kilometres long. The average air-road trip is 1,158 kilometres long, while the average train uni-modal trip is 186 kilometres long and the average road uni-modal trip is just 147 kilometres long. Next graphic presents average trip distances for different transport chains.

![Average trip distance for different transport chains](image)

**Fig. 4.** Average trip distance for different transport chains (local interconnections refer to average distances between NUTS3 city capitals and the closest road and rail connections to long-distance networks, and Network interconnections to changes in services and modal shifts).

\(^1\) Uni-modal itineraries, the 93% of long-distance trips, are defined as itineraries where only roads are used, and also those where roads are used in combination with air or rail, as a main modes, and represent less than 15% of the total length of the itinerary. Multi-modal itineraries are all those itineraries that are not uni-modal, and road-rail, road-air, rail-air and road-rail-air multi-modal itineraries are considered.
If displayed in cost or time (following two figures), local connections to long-distance networks and network interconnections will be much more important as interconnections are short in kilometres but substantially slow (involving many delays). In the case of chains involving air, the local and network interconnections may easily represent 50% of the total time of a long-distance trip, and 25% of the total cost. Next figures provide first estimates based on average costs of travel for each mode, and average costs of time for each trip purpose, and waiting times at long-distance transport terminals (assuming 30 minutes rail, 90 minutes air). They take into consideration travellers’ time perception, implying that time spent on access to transport terminals (network and local connectors) is assigned a cost per hour of 1.5 times the cost of time when actually travelling, while waiting times (transport terminals) are assigned a cost per hour of 1.25 times the cost of time when actually travelling. Fees are estimated in the IC MSA module by modes, just using average costs per kilometre.

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![Average cost of trips for different transport chains](image)

Fig. 5. Average cost of trips for different transport chains (local interconnections refer to average distances between NUTS3 city capitals and the closest road and rail connections to long-distance networks, and Network interconnections to changes in services and modal shifts).
European multi-modal long-distance trips are relatively few in number not just because road is the dominant mode in long-distance travel, but because the busiest origin and destinations are naturally served by direct uni-modal services. As the costs providing these direct services grow because of congestion on the terminals on across the links, alternative multi-modal chains begin to be developed in Europe, as it happens in the case of low-cost air carriers using small airports relatively distant from large cities. Long-distance travel, even smaller than short-distance, may need to be segregated in dedicated infrastructure avoiding its over-imposition in already congested local networks.

There is a high potential for new multi-modal long-distance trips in Europe. Even if direct train and air uni-modal services are always more convenient, given the actual layout of transport infrastructure networks in Europe, half of the itineraries between NUTS3 capitals are now better served by multi-modal chains. But itineraries from the periphery to all other regions in Europe have to cope with a relatively larger amount of interruptions than itineraries originated in core regions, as expected. This is not just a geographic question: transport networks are denser and better interconnected in core areas, where there are higher volumes of trips and more frequent services. The most frequented transport relations between NUTS3 cope with a similar number of interruptions all over in Europe. Interconnection rates weighted by trip volumes show similar values for all NUTS3. The complexity of itineraries reduce the volumes of trips, independently of being central or peripheral. Therefore, there is high potential for long-distance multi-modal services to be developed as much as future economic growth may generate more trips across European peripheries, and busier uni-modal routes be more congested and face higher costs.

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2 The recent evolution of the four airports in Catalonia (Barcelona, Reus, Girona and Lleida), shows that due to the constrained capacity of Barcelona’s airport along the 2000s, regional airports substantially grew their traffics in very short periods of time. The Girona airport went from 600,000 passengers in 2000 to 5.2 million in 2009, while Reus went from 700,000 passengers in 2000 to 1.7 million in 2009. However, the finalisation in 2009 of a new 25 million passenger terminal in Barcelona left an important spare capacity in the airport, making it attractive for Ryanair and other LCC to move their bases from the smaller regional airports to Barcelona. Traffics in other regional airports have steadily dropped since then, a monthly 30% on average.
The following maps illustrate the previous arguments.

Fig. 6. Required modal shifts and service changes in lowest paths between NUTS3. For each NUTS3, average number of modal shifts and service changes required to travel to all others NUTS3. Green represents low values and red is for the highest. Peripheral regions require on average more modal or service changes to travel to all other regions.

Fig. 7. For each NUTS3, average number of modal shifts and service changes required to travel to all others NUTS3 weighted by the number of trips associated to each NUTS3-NUTS3 relation. Green represents the lowest interconnectivity rate, red is for the highest. The homogeneity in the figure shows that most relevant flows between NUTS3 require approximately all the same number of breaks.
4. Potential impacts of reducing interconnectivity costs on European transport networks

Three alternative scenarios based on reducing interconnectivity costs were tested using the IC MSA module. The first two (A and B) mostly theoretical, aim to measure the overall impact of just reducing interconnectivity costs in Europe all together:

- Scenario A, which lowers the cost of all interconnections by 50% of today’s values. This reduction affects all connections between all transport modes, regardless of the modes (rail connections to airports, road access to airports and rail stations, road access to cities and rail access to cities).
- Scenario B, which in the same line as previous scenario lowers the cost of all interconnections to zero.
- Scenario C lowers just the costs of access and egress to rail terminals to zero (and thus estimates the maximum impact that may result from reducing costs as indicated in the Transport White Paper - e.g. favouring connections between high-speed train lines and conventional rail and airports, as well as improving access to rail stations).

4.1. Potential impacts on travellers

Upgrading interconnections results in savings for travellers: with general reductions of 50% and 100% in interconnection costs, the overall travel costs may decrease 3.0% and 5.4% respectively, which translates to a € 11,000 million and a theoretical maximum of € 20,000 million savings per year, using average travelling values of time. Considering higher waiting and transfer values of time, this figure will grow substantially. Users have net savings in time and/or infrastructure use costs, which are higher than the interconnection costs applied. This saving mostly results from improving connections to airports (just reducing rail interconnections provides savings of only -0.3%).
Fig. 9. Transport cost of different scenarios with alternative hypotheses on interconnection improvements.

Users that benefit more from reducing the costs of interconnection are those with lower values of time, like tourists. Users with highest values of time, like business travellers, tend to use optimal paths from a time point of view (even if more expensive) and itineraries characterised by a lower amount of interconnections.

Fig. 10. Cost variations by trip purpose

4.2. Potential impacts on modal shares

The reduction of costs of interconnections mostly increases the share of the air mode. Air may increase up to a 7.6%, if all interconnection costs are eliminated. This is expected as aviation suffers from higher interconnectivity costs that rail or, needless to say, road.
The reduction of costs of interconnection increases the share of multi-modal trips and the increase is relatively small, as expected: if costs of interconnections are eliminated all together, multi-modal trips’ share out of long-distance trips increases by 2%, reaching 22%. By selectively reducing the cost of interconnections to favour the increase of rail share, the share of multi-modal trips increases by 3%, reaching 23%, and rail share increases just by 0.3%.

Improving interconnections will likely cause changes in the services provided by air and rail operators, leading to a redefinition of the hub and spoke role of long-distance terminals in the networks. Some small airports may become more accessible and competitive in relation to larger airports. These changes, not included in the modelling exercise carried out but analysed as specific case-studies in INTERCONNECT project, may result in a larger impact of interconnectivity improvements and larger gains of efficiency impossible to measure at this stage.

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1 Improvement of rail-airport interconnection resulted in Frankfurt airport on increased rail demand. This allowed for more efficient use of air and rail infrastructure (co-modality), as the slots no longer needed for the feeder flights were immediately used by the network carriers for additional (long-haul) flights using the full capacity of Frankfurt airport. The use of each mode was therefore optimised.

4 Transport service operators, e.g. rail operators and airlines, can be interested in improving interconnectivity as it helps to make their services more attractive for passengers. In this context, many initiatives arise such as the onboard bus ticket sales by Ryanair, the EasyBus from EasyJet or the many rail-airline operator co-operations such as Airrail by Lufthansa and DB, the TGVAir in France or 50% to 100% ticketing discounts to travel in Scottish railways in combination with flights in Scottish airports. In the case of alliances between different service providers, e.g. in the aviation sector, interconnections between services within companies of the same alliance are promoted, while interconnections with other services are restricted. The planning debate concerning the interconnection between the two terminals in the airport of Barcelona has been deeply influenced by these considerations.
Fig. 11 Improving interconnections: impact on modal split (in trip-kilometres).

The share of the road mode is dominant in long-distance travel. The modal share of road in long distance travel is of 73% (in trip-kilometres), almost 88% in uni-modal chains and approximately 34% in multi-modal chains.

The modal share of the rail mode is very limited in long-distance travel. The modal share of rail in long distance travel is 3% (in trip-kilometres), 1% in uni-modal chains and 13% in multi-modal chains. Most trip-kilometres on rail are allocated in multi-modal chains, approximately 70% of total trip-kilometres for rail mode.

The modal share of the air mode in long-distance travel is 24% (in trip-kilometres), approximately 11% in uni-modal chains and 53% in multi-modal chains. The air mode is mostly used in air uni-modal chains (46% of air trip-kilometres) and air-rail multi-modal chains (36% of air trip-kilometres). Air-train multi-modal chains include all trips using rail to access an airport, regardless of the length of the rail stretch.
4.3. Potential impacts at overall EU level

The reduction of costs of interconnections provides reductions in the overall volume of trip-kilometres travelled, implying that more efficient routes are chosen. With reductions of 50% and 100% in interconnection costs, volumes of trips-km decrease 2.2% and 1.1% respectively (2,600 and 13,000 million passenger-kilometres respectively). The average trip length for each transport chain becomes substantially lower, even if there is a net transfer from shorter transport chains to longer ones (e.g. from road to air).

The reduction of interconnectivity costs may produce a small shift from road to rail, but the most likely impact is the increase in uni-modal air trips (mostly due to the improvement of local connections to airports), and an increase on multi-modal long-distance trips, mostly combinations between air and rail (due to improvements in intermodal connections).

Overall, the reduction of costs of interconnection may cause long-distance traffic CO₂ emissions to increase up to 0.9% (1.9 million tones CO₂) in scenarios with simultaneous reductions of costs of all interconnections, and to decrease 0.5% in scenarios favouring rail. Emission factors per passenger were taken from the TRANSVISION study, in line with TRANS-TOOLS (in grams/passenger-kilometre (or trip-kilometre): Road mode, 115 gr/pax·km; Rail mode, 22 gr/pax·km; Air mode, 130 gr/pax·km).

Upgrading connections between long-distance transportation networks (e.g. linking all high-speed rail lines to core airports) provides network benefits spread to travellers all across Europe, but no direct benefits to local travellers, who are not likely to transfer in their own city. Therefore, improving interconnections between long-distance terminals is more likely to be of European interest than of local or regional or even national interest. It is a genuine European scale policy, since most users will be not just long-distance but also international travellers.

Effective interconnection requires the provision of integrated networks and services and involves close co-operation between a range of authorities and infrastructure and service providers in the public and
private sectors, often with contradictory and competing business and political goals. The creation of effective interconnection may sometimes conflict with the priorities of transport infrastructure managers, service providers and infrastructure planners (and market regulators). Additional to the investment costs, the difficulty is also legal or commercial.

Infrastructure managers, e.g. private airport operators, may have a limited interest in improving interconnections in long-distance networks, being an important part of their business generated in the shopping areas within the terminals and the car parking lots, and their business interest is therefore to maximise the time spent by users within terminals while having important private car access shares to the airport. Only when the traveller’s welfare is obviously reduced or there is a real competition between neighbouring airports, private operators may prefer to improve interconnections onto other transport networks, as happens in the case of Heathrow Express.

Interconnections can provide positive market and regulatory impacts beyond the optimisation of travel times and travel convenience for users, since they often require complex public and private partnership agreements and more advanced cooperation strategies among transport operators and infrastructure managers.

Infrastructure planners are mostly interested in assuring the efficiency of interconnections which are mostly going to be used by travellers in their domain of competence. National planners are mostly concerned about national citizens, while regional administrations are more likely to be concerned about local residents and taxpayers. With the increasing scarcity of budgets, local planners are usually not eager to spend funds on facilities that are not intended to serve local users. Therefore, there is a need for a common European policy to encourage interconnectivity improvements in long-distance networks (this analysis was carried out in the case of the High-speed train connection to the airports of Girona and Reus based on the Rail Pack methodology for assessment developed by the European Investment Bank).

The assessment carried out at the European level proves that interconnectivity improvements can be cost-effective and result in more efficient transport (less trip-km, more time savings for users), if policies target specific missing or poor connections, first in relation to local access to long-distance terminals, then in relation to long-distance terminals, from a bottom-up approach, case by case. If all interconnection costs were reduced by a similar proportion, air trips would increase more than those by other modes since aviation currently faces higher interconnection costs than other modes. If this was to happen it would result in relatively higher CO₂ emissions in the short-term. The application of policies specifically

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5 The case studies of Amsterdam, Lisbon and Helsingborg showed how the collaboration between different stakeholders is crucial to increase the level of interconnectivity, interoperability and integration of different transport systems. In Helsingborg, 10 different institutions and private companies collaborated together, in the view of new Øresund fixed link competition, to make the Knutpunkten intermodal terminal in Helsingborg a reality – rail, bus and ferry. Integration in Amsterdam is driven from a national perspective even at the constraint that such an approach results in the need for a synchronisation between large numbers of parties, whereas in the Lisbon case the approach was a bottom up development, as competing transport operators have agreed to use the OTLIS framework to work in a co-operation environment. The success of non-formalised frameworks of negotiation stands out between state government and the private sector and between central government and regional or local interests. Further investigation, however, is required to determine if optimal interconnectivity is compatible with competitiveness between operators.

6 Heathrow Express is an airport rail link from London Heathrow Airport to London Paddington station in London operated by the Heathrow Express Operating Authority, a wholly owned subsidiary of BAA.
targeting emissions would result in a different outcome, as the reduction of interconnection costs would then be targeted so as to favour the least polluting modes.

For that reason only the improvement of interconnectivity in intermodal trip chains concerning rail transport allows reducing travel-times and costs while simultaneously avoiding increased CO₂ emissions.

5. Conclusions

The results obtained can be summarised as follows:

- Reducing interconnection costs increases the overall efficiency of the transport system (since the total trips-km, all modes considered, diminishes because of the increase on multi-modal trips). 80% of interconnectivity costs are due to local connections, and 20% to changes and modal shifts between transport networks. Major impacts of reducing interconnectivity costs should therefore happen not much on increasing the number of multi-modal long-distance trips but on shifting from road to rail and air trips, as the cost of getting access to rail stations and airports is reduced.
- Reducing intermodal long-distance costs will marginally increase the number of long-distance multi-modal trips, especially in relation to air and rail combined trips.
- Reducing interconnection costs results in significant time savings for users, especially for those with lower value of time and eager to shift to longer multi-modal transport chains.
- Reducing interconnection costs from local connections to long-distance terminals may increase the share of aviation or, more marginally, of railways, depending on which interconnectivity costs are reduced, sometimes leading to an increase on CO₂ emissions.

Given the fact that the cost to access an air service usually is much higher than the cost to get access to a long-distance rail service, it is not surprising that aviation becomes much more competitive and has a relatively higher growth when globally reducing costs of interconnection, in the theoretical scenarios considered.

Savings obtained by travellers are expected to be higher than the interconnectivity cost reductions applied, since they also will be able to pick better modal choices, leading to a reduction of the total trip-kilometres travelled in the system.

Even if these savings may seem marginal in relation to the total costs of travel in Europe, their absolute value is significant, as well as the welfare increase captured by travellers, since waiting and transferring time is valued by them between two and three times more than the time actually spent travelling.

In relation to the cost-effectiveness of the investments required to improve interconnectivity, two conclusions can be presented from both the INTERCONNECT modelling and case-study exercises:
• On the one hand, given the fact that reducing interconnectivity costs may require investments relatively small in the context of long-distance networks, they are expected to have a high positive socioeconomic profitability at European level\(^7\).

• On the other hand, given the fact that costs of interconnections are always allocated locally whereas benefits are spread across the whole transport networks, the socioeconomic profitability may not be necessarily positive at regional or even national scale, especially in the case of improving interconnections between long-distance terminals. The distribution of costs and benefits across stakeholders (e.g. transport service operators, infrastructure managers…) may easily be unbalanced, leading in few occasions to win-win situations and often blocking potential improvements\(^8\).

All considered, results seem in line with the expected goals of European transport policies when promoting interconnectivity, specially favouring rail. At the same time, the likely increase on air trips resulting from general interconnectivity improvements have to be considered. This could be an important rebound effect to be carefully studied: reducing interconnectivity costs in airports and air services may result in a much more competitive sector and, at least in the short term, lead to an increase of CO\(_2\) emissions, even if planes should reduce CO\(_2\) by 50%, and 80% of NOx by 2020.

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\(^7\) The dual-mode railway system of Karlsruhe is widely regarded as the model of a high-quality and well patronised local public transport system. The successful track-sharing experience of the various Karlsruhe rail systems has revolutionised urban and regional public transport: Karlsruhe trams run on the urban light rail system and on the heavy rail tracks of the German Railways. The technical adoptions needed for track sharing of heavy rail trains and tramways are feasible and available for reasonable costs, while these solutions bring important increases in passenger figures, giving an excellent cost-benefit ratio. Although the supply of public transport has increased strongly, the increased revenues from the tickets has resulted in a 20% reduction of the operating deficit.

\(^8\) In the case of the rail connection between Barcelona airport and the high-speed rail line, the connection provides net time savings to travelers transferring from rail to the airport, obviously not residents in Barcelona, but substantial travel time increases to all other users on the high speed rail line. The distribution of costs and benefits among different agents is a critical issue to consider. On another hand, the substitution of bus shuttle services in regional airports by rail connections has a strong positive impact on rail operators, especially if the investment is assumed by the administration, but a very negative impact on bus operators. The question raised here is how should the cost of interconnection be distributed among partners, and what should be the positioning of administrations in order to provide a framework of fair business competition among different transport operators.
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### Appendix A.

#### A.1. Selected case studies for INTERCONNECT project (see the specific deliverables submitted in the project for more information)

Table 1. Selected case studies for INTERCONNECT project

<table>
<thead>
<tr>
<th>Name of Case Study</th>
<th>Modes involved</th>
<th>Countries involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frankfurt airport interconnections (1)</td>
<td>Rail, Air, Bus</td>
<td>DE</td>
</tr>
<tr>
<td>Catalan airport system interconnections (2)</td>
<td>Rail, Air, Tram, Bus</td>
<td>ES</td>
</tr>
<tr>
<td>Milanese airport system interconnections (3)</td>
<td>Rail, Road, Air</td>
<td>IT</td>
</tr>
<tr>
<td>Scottish airport system interconnections (4)</td>
<td>Rail, Air, Bus</td>
<td>UK</td>
</tr>
<tr>
<td>Leeds’ rail station (5)</td>
<td>Rail, Tram, Metro, Bus</td>
<td>Various</td>
</tr>
<tr>
<td>Milan Railways Node (6)</td>
<td>Rail, Metro, Tram, Bus, Air</td>
<td>IT</td>
</tr>
<tr>
<td>The dual-mode railway system: the Karlsruhe model (7)</td>
<td>Rail, Tram, Bus</td>
<td>DE</td>
</tr>
<tr>
<td>Train Taxi and Feeder Bus Services (8)</td>
<td>Rail, Taxi (road)</td>
<td>UK</td>
</tr>
<tr>
<td>Amsterdam ferry services (9)</td>
<td>Rail, Tram, Bus, Ferry</td>
<td>NL</td>
</tr>
<tr>
<td>Lisbon ferry services (10)</td>
<td>Ferry, Rail, Metro, Tram, Bus</td>
<td>PT</td>
</tr>
<tr>
<td>Ferry terminal of Helsingborg (11)</td>
<td>Ferry, rail, bus</td>
<td>DK, SE</td>
</tr>
<tr>
<td>Ferry terminal of Rostock (12)</td>
<td>Ferry, rail, bus</td>
<td>DK, DE</td>
</tr>
<tr>
<td>Tri-city: Gdansk / Sopot / Gdynia transport networks’ interconnectivity (13)</td>
<td>Ferry, rail, tram, bus, air</td>
<td>PL</td>
</tr>
</tbody>
</table>
Fig. 13 Geographic location of case studies
A.2. 2 Stakeholders-Effect matrix. Girona airport interconnection integrated in local tramway network

Fig. 14 Analysis based on the Rail Pack methodology for assessment developed by the European Investment Bank

Stakeholders-Effects matrices are based on the RailPag assessment framework developed by the European Investment Bank (EIB). A Stakeholders-Effects matrix provides the network distribution of economic costs and benefits between territories, modes and actors: users, infrastructure managers, service operators, territory inhabitants and public administrations at all levels.
Each row represents a specific effect or topic of evaluation (e.g. travel cost, travel time). For each row, columns quantify this effect for the different involved stakeholders. Each column represents a specific stakeholder (e.g. users of interconnection, rail operator, regional administration).

- The aggregation of all values in a row provides the economic return for the analysed effect for society in general (e.g. benefits derived from total travel time saved by society). Economic transfers between different actors have neutral balances and show zero economic return (e.g. travel fees paid by users revert as incomes to transport operators and public administrations but provide no global economic benefit to society).

- For each column, rows tell how the stakeholder is affected in the different subjects of analysis. The aggregation of all cells in a column provides the economic benefit or loss for the specific stakeholder.

Matrixes were completed quantitatively (in € million) and in some cases qualitatively ("+" for positive effects; "=" for neutral effect; "+/-" for uncertain effects; and "-" for negative effects).