Is large technological investment really a solution for a major shift to rail? A discussion based on a Mediterranean Freight Corridor Case-Study

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Abstract: The aim of this paper is to assess how the introduction of technological innovations into a capacity constrained rail corridor may increase its ability to capture market share from road transport. The Montpellier-Perpignan section, a bottle-neck in the Mediterranean corridor, is used as a case study for the effects of implementing new rolling stock that allows for freight trains up to 1500 m and a new ballastless track replacing existing one, resilient switched and crossings and monitoring systems that allow for a reduction in maintenance costs and closure times. The results of a cost-benefit analysis show positive net impacts, however the increases in capacity are only enough to maintain current market shares. Evidence suggests that a heavy investment in technology in existing lines is not the most effective way to increase rail market share.

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Keywords: European Rail Freight Corridor; Rail Infrastructure Upgrade; Cost-benefit Analysis

1. Introduction

The European Union (EU) has set very ambitious goals for the increase in rail market-share of both passengers and freight, due to its well-known environmental advantage relative to other modes of transport. The European Commission (EC) set a target of transferring up to 30% of road freight traffic to rail and water transport until 2030 and as much as 50% until 2050 [1]. Still, besides the well-known gains obtained in the development of high-speed passenger corridors, rail has yet to reverse the trend of road dominance.

EU policies for the rail sector have been structured around a set of four legislative packages for the rail sector, aiming to boost competitiveness by setting requirements for free access to the networks in each country to any operator. The expectation is that competition between operators will boost efficiency and drive down costs. However, infrastructure capacity constraints are often an obstacle to the access of new freight or passenger operators, exacerbating other existing barriers and thus to the competition that these policies seek [2]. Due to these difficulties, the kind of open-access envisaged by the legislation has, of yet, only developed in a few countries and in a limited number of routes [3].

Rail transport accounted for only 17% of land-based freight transportation (rail, road and inland waterways; measured in T·km) in the 28 EU countries in 2016, down from a peak of 19% in 2011, with road being the dominant mode with an overwhelming 76% market share [4]. Combining these figures with the EC targets previously mentioned, it is easy to see that they imply a more than 3-fold increase in rail market share in the next 30 years.

The other important European policy mechanism is the Trans-European Networks – Transport (TEN-T), that define a set of corridors for each mode of transport, as well as connections between them. At the outset of the TEN-T initiative, corridor studies have been produced for each of them (e.g. for the Mediterranean Corridor, see Ref. [5], aggregating data and identifying investments. However, these studies are often merely a juxtaposition of fragmented data and proposals. In particular, there was no integrated planning effort in the selection of investments, merely a collection of proposals from each country. The same can be said in the applications for the funding mechanism of the TEN-T corridors; each project is evaluated solely on its own merits and not the context of any integrating planning effort. This shortage of integrated planning has recently been criticised in a report from the European Court of Auditors (ECA) about high-speed rail connections [6]. The ECA has also strongly criticised he performance of the European rail freight sector and called into doubt the outcomes of EU policies [7].

On the research and development side, the EU has supported projects aimed at bringing innovative technologies and methods to the rail sector. The Capacity4Rail (C4R) project was a flagship research project set up with the aim of developing a set of innovations that would dramatically increase capacity throughout the European rail network. This is key in the pursuit of the ambitious objectives established by the EC in terms of rail market share increase, leading to economic, social and environmental benefits.

This paper presents a case study of one of the rail corridors analysed in the context of the C4R project, a highly congested section of a major trans-European rail corridor, the Montpellier – Perpignan section of the Mediterranean corridor. The study on this section of the corridor illustrates some of the main difficulties that the rail sector confronts in its aim to significantly gain market share. It is assessed how the introduction of a set of technological innovations and operational changes may fulfil the immediate objective of increasing capacity and reducing costs, and thus allowing for the capture of more demand and ultimately leading to an increase in rail market share.

2. Background and Objectives

The C4R project was divided into five main sub-projects. The first four were aimed at the development and testing of new technologies, namely, new track systems, new freight rolling-stock, new operational and capacity management concepts, and new monitoring systems. The fifth sub-project (SP5) had the purpose of planning the introduction of these new technologies and concepts developed in the other four sub-projects, aiming for a high capacity rail system, as well as assessing their impacts on the European policy aims mentioned in the introduction.

The first task of within SP5 was to develop a vision for the rail network that would translate the policy aims set out in the EC white-paper [1] into concrete targets. The targets were divided into five key aspects, namely, affordability, adaptability, resilience, automation and high capacity. These targets would then lead to a roadmap for the introduction of the technologies and concepts developed in SP1-4 that would include a set of scenarios for the migration to the new technologies and operational concepts.

Even before any analysis of concrete corridors or networks, a wide gap between the lofting goals set out and the actual possibilities that could plausibly be provided by the new technologies became clear. For example, a shift of half of the current passenger and freight road traffic to rail by 2050, which is far beyond anything that can be achieved with the current and foreseeable rail network, even provided each and every project in TEN-T corridors is fulfilled and the network is fully realised.

However, a detailed analysis would allow one, at least, to identify which combination of technologies and operational changes would be more effective at reaching the targets. To that end, a methodology based on a Cost-Benefit Analysis (CBA) was developed, along with a computational tool that is able to assess multiple investments on corridor or network-wide basis. This CBA-based methodology follows the standard guidelines set out by the (EC) [8], including an incremental approach to the analysis, with the base scenario representing “business-as-usual” or “do-minimum” options, the analysis of multiple alternative scenarios, as well as a sensitivity and probabilistic analysis.

A few candidate corridor sections were identified for analysis, based on data availability and, more importantly, on how critical they might be in limiting rail network capacity. In essence, one was looking for the “bottlenecks” in the network, where the potential benefit of the new technologies and concepts might be greater.

The Montpellier – Perpignan section of the Mediterranean corridor presented itself as a prime example for study. In addition to being currently limited in its growth by capacity constraints, there are already innovative intermodal rail services operating in this section. So-called rolling motorway systems such as “Modalohr” [9] carry freight truck trailers over rail at much lower economic and environmental costs and mitigating the major handicap in flexibility that rail transport has.

The ability of rail transport, and specifically of these new concepts, to compete and gain market share, in line with EU policy goals is dependent on the elimination of bottle-necks throughout the rail network, *i.e.*, a major increase in capacity. The main question that this paper tries to answer is if it is worth investing in technological solutions to (slightly) increase current capacity and what are the limits of this capacity increase and its costs compared to envisaged benefits.

3. Case Study Description

3.1. Route

There are six rail connections between Spain and France. The eastern Pyrenees route, with border crossing at Cerbére–Port Bou, is one of the two main crossing points that carry the vast majority of the rail freight and passengers [10].

The stretch of railway line extending from Montpellier to Perpignan is part of the Mediterranean Corridor of the Trans European Transport Network (TEN-T). This includes a section along the Tarascon to Narbonne line between Montpellier and Narbonne, where the Narbonne to Port-Bou line begins. Of the latter, the portion from Narbonne to Perpignan is included. The corridor section is shown in Figure 1.

North of Montpellier and south of Perpignan the rail corridor forks into high-speed lines that constitute alternatives to the classic line for long distance passenger traffic. In the case of the Perpignan – Figueras high-speed line it is available both for passenger and freight trains.

The A9 AutoRoute between Montpellier and Perpignan constitutes the main road infrastructure along this route, running roughly parallel to the rail line, as shown on the map in Figure 1 (top panel). This is a section of six-lane motorway 148 km length. As in the rail, this road itinerary constitutes one of the two main crossings from Iberia to France.

3.2. Traffic and Capacity

Upon inspection of the timetables, one is able to ascertain that this section of rail has very little remaining capacity, especially between Narbonne and Montpellier. As depicted in Figure 1 (middle and bottom panels), around 150 trains travel on that particular stretch, with around three fifth being passenger trains. The scheduling includes a five-hour nightly closure period for maintenance, visible on the excerpt of timetable diagram on Figure 3, leaving a 19-hour window each day for trains to run.

Another key aspect is the fact that this section has a highly heterogeneous traffic, with high-speed and local passenger, as well as intermodal, train load and wagon load freight trains. Each one of these train categories has vastly different average speeds, stops, and braking and acceleration performance, leading to a necessary increase in the buffer times between them.

Altogether, these circumstances come together to establish this section as the main “bottleneck” in the Mediterranean Corridor, severely constraining the prospects of traffic growth and, as a consequence, market share capture. Indeed, as shall be seen in the results, the current tendency is towards a gradual decline in rail market share, mainly due to capacity shortages. Overall, the issue of capacity is a central one to this case study insomuch as it is a paradigmatic example of the challenge faced by the European rail network.

The capacity occupation was computed according to the guidelines set out by the UIC, the main international railway body [11]. Using the exact track layouts, the exact number of points where overtaking is possible can be identified. Together with the actual number of trains and reliable information on their average speeds, this can be translated into a fairly well calibrated capacity occupation figure.

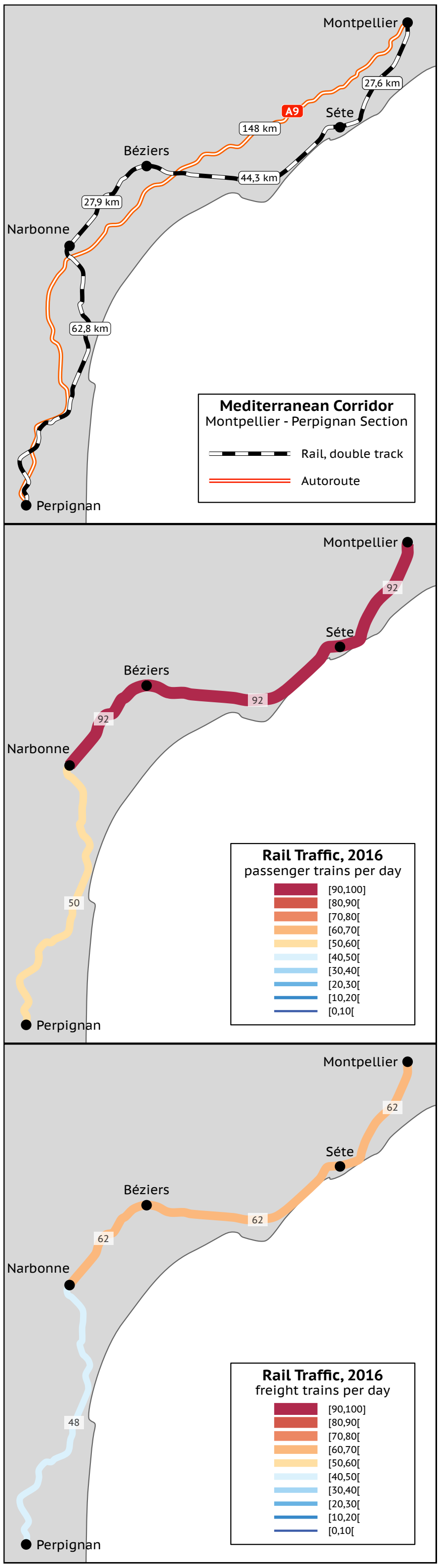

Figure 1. Top panel: Map of the rail and road routes under analysis, connecting Montpellier to Perpignan, with respective distances. The rail route is a double track and the road route is a motorway. Middle and bottom panels: Rail traffic along the corridor in 2016 (year 0), in terms of passenger and freight trains per day.

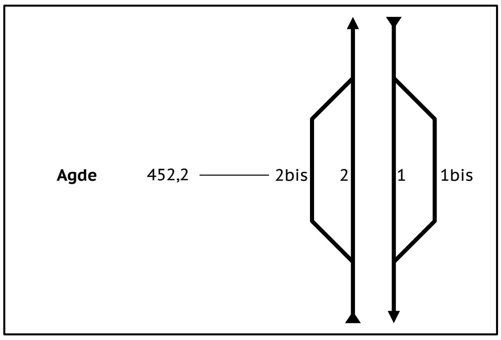

Figure 2. Track layout of Agde station, one of the sets of sidings that limits train length and would need to be extended.

The most congested section between Narbonne and Montpellier is at near full capacity as it is, with the section south of Narbonne connecting to the Spanish border is at around 72% occupation, owing mostly to a much lower passenger train traffic. It is worth recalling that south of Perpignan, outside the scope of this analysis, there is a high-speed line that takes most of the passenger traffic, relieving capacity on the classic line towards Cerbére–Port Bou.

3.3. Infrastructure

The rail infrastructure in the section between Montpellier and Perpignan is a conventional double track rail line with maximum speeds up to 160 km/h for passenger trains, although freight trains run only up to the usual 100 km/h.

This section already complies with the TEN-T standards in terms of axle loads, allowing 22,5 T/axle, and train lengths exceeding the 750 m requirement. This is an operational scenario well beyond the technical standards set out by the EU. The infrastructure currently allows for the running of trains up to 850 m long. This is limited mainly by the sidings at Port-la-Nouvelle and Agde stations; the layout of the latter is depicted in Figure 2.

Concerning the road corridor, no potential capacity limitations were considered. This way, all growth in demand that cannot be met by rail due to lack of capacity is automatically carried to road transport until rail capacity is increased, either by increasing the number of trains or the load capacity of each train. A new high-speed line is proposed for this route, split into two sections: the Montpellier bypass and the connection to Perpignan. This would create a continuous high-speed connection between Paris and Madrid while relieving the congesting section south of Montpellier of a significant number of trains. The construction of the Montpellier bypass had been planned to open in 2018, but it has now been delayed. The connection to Perpignan does not have a concrete time frame for completion. It is thus doubtful when the high-speed alternative will be built, and it is not taken into account in the analysis.

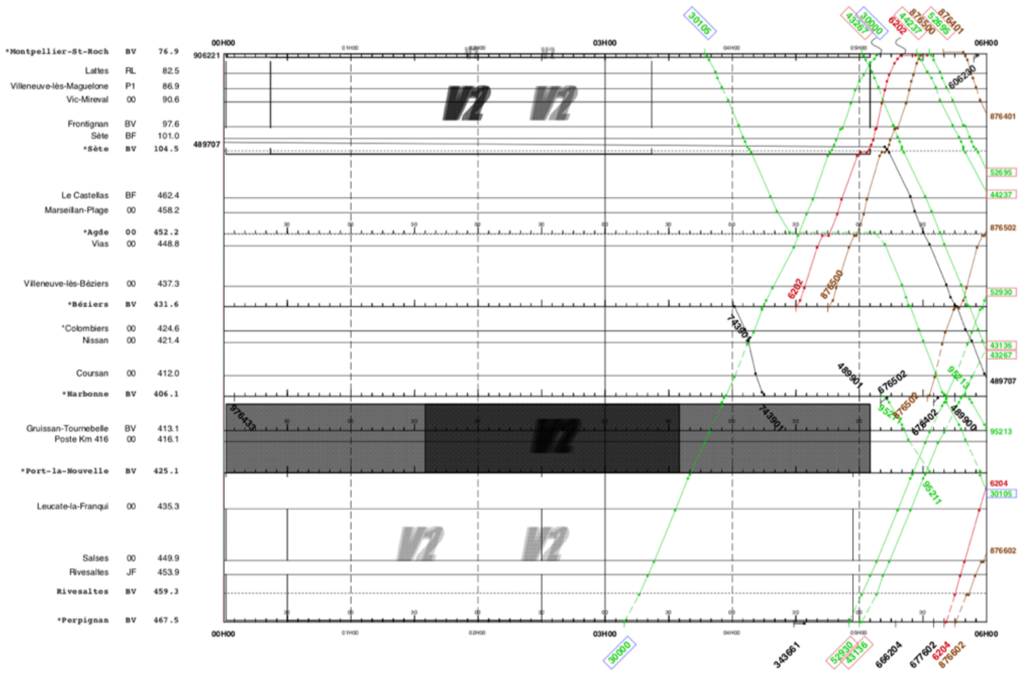

Figure 3. Example timetable diagram for the Montpelier to Perpignan route, with indication of the 5-hour period for maintenance with no trains scheduled.

4. Opportunities for Improvement

4.1. Infrastructure Innovations

One of the main technological innovations developed within the C4R project and tested in this study is a new non-ballasted track concept. The objective of this new slab-track is to provide a lower installation cost when compared with existing designs while retaining the lower maintenance costs usually expected from non-ballasted tracks [12].

At the same time, the new system is intended to be modular, allowing for the replacement or upgrade of one component without the need to rebuild the entire system. This design effort produced two similar but different track designs, one aimed at RAMS optimization and the other aimed at maximum LCC reduction. The former is shown in Figure 4.

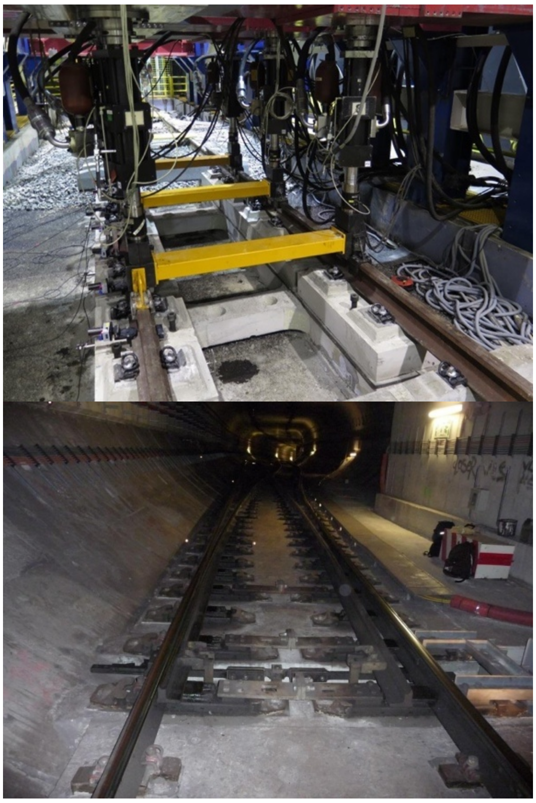

Figure 4. Test setup of one of the slab-track concepts developed on the C4R project (top) [12] and for the selected innovative resilient switch and crossing design (bottom) [13].

It is expected that the elimination of the need for regular tamping operations, regularly required in conventional tracks to keep geometric parameters within tolerances, would have a significant impact on the maintenance costs. The new track systems would also be bundled with an array of sensors that would reduce the need for regular track inspections.

Besides the cost reduction, the reduced number of operations to be performed would desirably free up some of the time reserved for maintenance, during which the infrastructure is unavailable.

The study of the effects of these new track concepts is a key part of this analysis. A target installation cost of 1000€/m was considered, as well as a reduction in unavailability times for maintenance and the elimination of the tamping cycles, with impact on the maintenance costs. Overall, the introduction of this innovative track concept has a major impact on capacity and infrastructure maintenance costs but also with a very significant investment.

In recent years, other solutions offering reduced tamping requirements and maintenance costs relative to conventional track, while also having lower installation costs relative to slab track have been under development, such as the use of a bituminous mix as ballast or sub-ballast [14, 15, 16]. However, these were not within the scope of the C4R project and of this case study.

In order for these benefits to be achieved, new switches and crossing are also being developed with the same focus on reliability and maintainability [13]. Its installation in combination with the new slab-track would be necessary to obtain a similar availability from all elements of the track subsystem.

4.2. Innovative Rolling Stock and Operational Improvements

The innovations on the rolling stock side are all aimed at optimizing freight operations in terms of cost.

An immediate way of increasing capacity while reducing costs is to increase the length of freight trains. Even though the rail corridor section under the scope of this paper already meets and exceeds the European standards in terms of train length, there is certainly room for improvement.

In fact, the required investment in the infrastructure to allow for longer trains is fairly modest. It involves the lengthening of sidings, namely the ones at Agde and Port-la-Nouvelle stations, estimated at 2 M€ apiece to ready them for trains up to 1500 m, and possibly some adjustments to the signalling system.

However, longer freight trains, even when not constrained by locomotive tractive effort or coupling resistance incur in a performance penalty. Acceleration and braking will be slower, as well as brake apply and release times. Overall, this would reduce the train's average speeds and impact capacity in terms of number of trains.

There is a set of technologies that are already being introduced to offset the disadvantages of longer trains [17]. Among these are the so-called End-of-Train device and Electro-pneumatic (EP) brakes which improve braking performance and release speeds. The possibility of using automatic couplers would also allow for the formation longer trains from the coupling of two shorter ones. These coupled trains maintain an acceleration and braking performance similar to the shorter trains and eliminate the need for shunting in this operation.

Other options such as higher axle loads and a wider loading gauge were not considered, since these would require infrastructure investments beyond the corridor section in analysis.

4.3. Migration Scenarios

The main scenario for the introduction of the innovations was setup in two stages.

The first stage, or stage 1, would see the introduction of trains up to 1000 m, with the necessary modifications to the infrastructure and rolling stock, starting in 2020. The migration to longer trains is not uniform in all market segments, with the intermodal trains responsible for most of the migration. By 2025 it is expected that up to half of the intermodal trains would be 1000 m long.

The second stage, or stage 2, extends the train migration period from 2025 to 2035 with the progressive introduction of trains up to 1500 m, also mainly in the intermodal market segments, taking up to one quarter of those segments. Like in stage 1, the train load and wagon load segments are expected to have a much more limited adoption of longer trains, in a large amount, due to their higher load weights.

In addition to longer trains, stage 2 sees the installation of a slab track at the time of the next planned renewal cycle, in 2035. Assuming a period of 2 years for the construction of the new track, this migration produces effects from 2037.

This forms the main scenario for the cost-benefit analysis. In the discussion, a sensitivity analysis and some variations on this scenario are also considered.

5. Modelling Costs and Benefits

5.1. Infrastructure Investment and Maintenance

These sections of track have, as recently as 2015, been subject to a track renewal. The cost-benefit analysis takes into account a 20-year renewal cycle for track and for switches and crossings, with next renewal not expected to take place until 2035.

At the time of the next renewal cycle, two alternatives are considered: to make the standard track renewal or to convert it to the ballast-less track concept described in section 4.1. The latter option presents a heavy investment, even assuming the target cost of 1000 €/m for the system.

This might seem optimistic. However, the literature is clear in showing that the cost of these systems decreases as the length of installed track increases [18]. A review of existing systems has also indicated construction costs 1.3 to 1.5 times that of conventional track, with overall similar LCC, even if pointing out the need for more detailed studies [19, 20]. We thus argue that the assumed target cost is reasonable in the time horizon of this study.

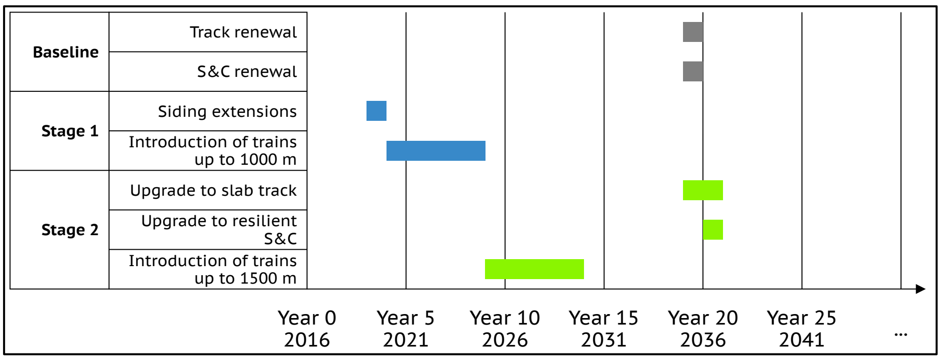

Figure 5. Migration scenario timeline. Baseline includes planned track superstructure renewals at the end of its life-cycle. Stage 1 includes the minimal necessary upgrades to allow trains up to 1000 m. Stage 2 implements innovative infrastructure technologies developed in the C4R project and trains up to 1500 m.

However, the installation of a slab track ensues a dramatic 57% reduction in track maintenance costs, mainly due to the elimination of the need for tamping, as well as cutting the 5 h daily maintenance down-time window to 2 h. It is expected that by 2035 these slab track systems will have achieved the required TRL to be installed. New switches and crossings would be installed at the same time.

5.2. Producer and Consumer Surplus

The modelling of rail and road traffic is at the core of consumer and producer surplus estimations. Since no changes in fares are modelled, the key variables are, respectively, value of time and operating costs.

Modelling the value of time is fairly straightforward. The savings in value of time for existing consumers are modelled simply by comparing the time between origin and destination. When traffic is shifted from road to rail there is a corresponding change, in this case, a negative one in average speeds. This explains why all the results present ahead have a negative consumer surplus. An increase in average freight train speeds would be necessary to mitigate or reverse this relation. The value of time for generated traffic is modelled through the "rule of halves" [21].

The accounting of train operating costs was based on a model developed to test new freight operation concepts such as the introduction of new wagons and specific improvements to terminals aimed at reducing throughput times and costs.

The costs modelling is based on a rail freight market segmentation corresponding to a set of train types, namely, wagon load, train load, intermodal container and intermodal trailer trains. The parameters used for each train market segment are listed in Figure 7.

Reference trains representative of the existing traffic were set up, as well as the expected evolution in 2030 and 2050 horizons. Future trains will be longer, heavier, and have such innovation as better braking technology with Electro-Pneumatic (EP) brakes and automatic couplers.

Train traffic was simulated with a set of reference trains that were constructed based on the actual freight traffic on this section. The reference trains were divided into five market segments: train load, wagon load, intermodal container, intermodal trailer and intermodal trailer with horizontal loading (Figure 6). The schedules allow one to provide the traffic mix of these categories.

Figure 6. Example of intermodal trailer with horizontal loading, the "Modalohr" system currently used in the analysed section of the Mediterranean corridor.

Train length is a key variable in operating costs. At present, trains up to 820 m in length already run on this section, with the intermodal train categories routinely being over 700 m in length. The train load and wagon load, however, are much shorter due to their much higher weigh per unit length and lack of demand. Maximum axle loads are 22,5 T/axle.

When considering the lengthening of trains, the power and maximum tractive effort of the locomotives needs to be taken into account so one can determine when the introduction of a second locomotive is required. In order for train to grow up to 1500 m, a few innovations would need to be introduced in the freight wagons. The introduction of the End-of-Train device and Electro-Pneumatic (EP) brakes allows for a faster brake application and release times. This, in turn, offsets the penalty in average speeds caused by the longer trains.

The introduction of a second locomotive represents a step increase in operating costs. The consequence is that operating costs by unit of freight are not monotonously decreasing as function of train length, as exemplified in Figure 8.

Similarly, a reference road freight was also established as a standard 40 T gross weight European.

Load factors are assumed constant both on road and rail, except in a few special test scenarios that were carried out to test for possible operational optimizations. In any case, improving load factors always has a similar effect to increasing load capacity, by increasing overall load capacity and reducing operating costs per load unit.

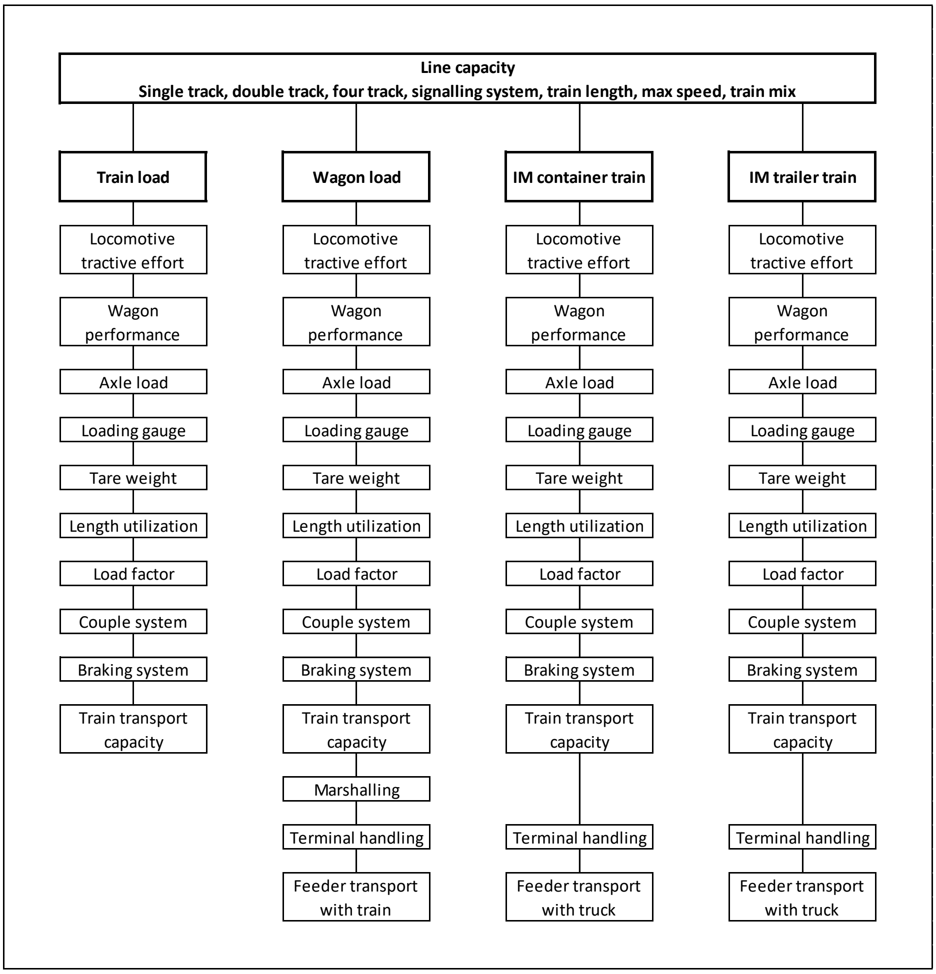

Figure 7. Set of parameters used for rail freight operating costs modelling in the C4R projects. The freight trains are assigned to market segments.

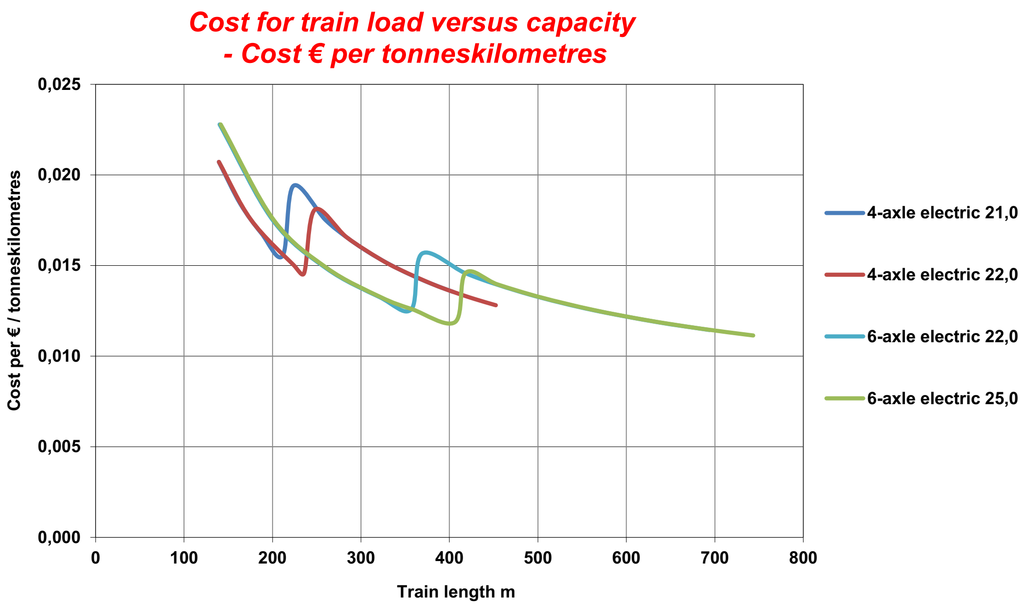

Figure 8. Train operating costs per unit load modelled for heavy Train Load trains by locomotives with different axle load and number of axles. The step jump represents the introduction of the second locomotive. Adapted from Ref. [22].

The evolution of freight traffic demand is predicted using a linear model with a set of elasticities relative to economic output (GDP), price and time. The elasticity of demand with price is itself modelled with an elasticity relative to operating costs, since a reduction in the latter does not often fully translate to the price charged to the user. The assumed values, listed in Table 1, are based on the answers to inquiries made to C4R project partners.

A modest constant GDP growth of 1% per year was assumed for the duration of the scenarios set out for this study. It is also assumed that no further bottlenecks appear upstream or downstream on the corridor due to traffic growth in the 40-year horizon of this analysis.

This study is focused on freight, with passenger traffic taken into account only for the purposes of capacity occupation. Passenger demand is thus assumed constant for the horizon of the analysis. This assumption underestimates the capacity requirements for passenger trains, which would otherwise be expected to grow. Still, one can assume that the Infrastructure Manager has some room to optimise capacity by rearranging the timetable.

Table 1. Main inputs for socio-economic analysis model.

Parameter	Value
Year 0	2016
Time horizon	40 years
Discount rate	4%
Shadow price conversion factor	0.95
Annual GDP growth	1%
Freight transport demand elasticity with GDP	1.5
Freight transport demand elasticity with price	-2.1
Rail freight transport price elasticity with operating costs	0.2
Rail freight transport demand elasticity with operating costs	-0.42
Rail freight value of time	1.66 €/h
Road freight value of time	4.05 €/h

5.3. Externalities

The main external effect considered in the CBA is the emission of Greenhouse Gases (GHG). Of course, rail transport has much lower emissions, especially considering the rail route is full electrified and that France relies little on fossil fuels to produce electricity- These emissions are monetized according to the standard values and considering a steady growth on their unit value.

The value of accidents has not been included but estimates indicated it would have a small impact in the final result.

6. Results

Taking stage 1 and stage 2 incrementally, one finds that both result in a positive Net Present Value (NPV) of the order of 136.1 M€ and 126,2 M€, respectively. The CBAs for both stages can be graphically summarized in Figure 9 and Figure 10.

In both cases, the largest benefit is on the producer surplus category. This accounts for the reduction in operating costs enjoyed by the traffic that would otherwise be forced to run on the road due to lack of rail capacity. It also generates positive externalities from the reduction in greenhouse gas emissions. One should remind that this stretch of rail is fully electrified and that France relies little on fossil fuels to generate electric power.

At the same time, however, the transfer of freight traffic from road to rail generates a negative consumer surplus on account of the lower average speeds on the rail side, even if intermodal trains already have average speeds comparable to road transport. The effects of reliability are not being taken into account, but it is known that they are negative in the transfer from road to rail.

Concerning the investment in the infrastructure, the very modest amount needed for the siding extension, with no further significant investments in stage 1, contrasts with the much higher amount involved for the installation of slab track in stage 2. The investment in rolling stock is diluted into the operating costs as capital costs and thus does not appear directly as investment in the CBA nor in the cash-flows.

The fact that the NPVs are of the same order of magnitude suggests that there is little additional value in stage 2 relative to stage 1. The incremental NPV from stage 1 to stage 2 is, in fact, slightly negative.

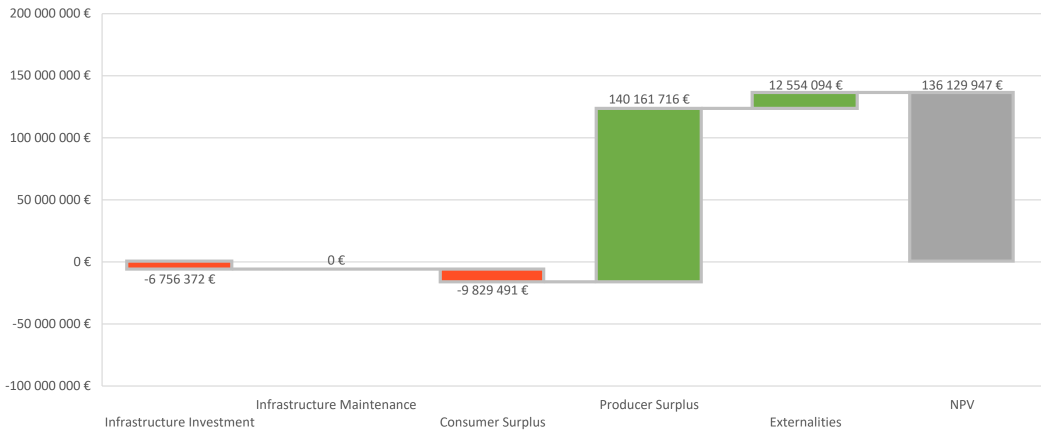

Figure 9. Graphic summary of CBA for stage 1 of the migration scenario. There is a modest investment in the infrastructure, mainly in siding extensions, allowing for trains up to 1000 m, leading to an increase in overall capacity that allows a modal transfer from road to rail relative to the baseline. The negative value in consumer surplus is justified by the lower average speeds of trains relative to trucks and the large producer surplus come from the lower operating costs both for existing and diverted traffic.

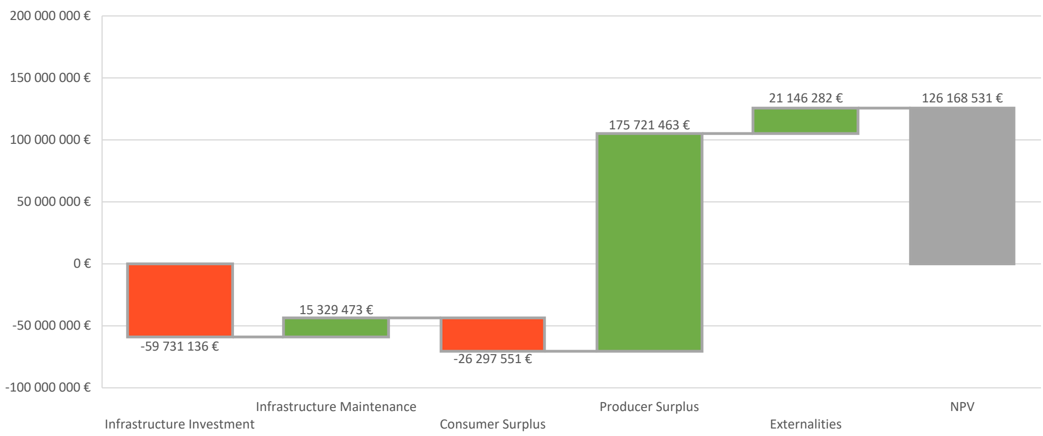

Figure 10. Same as Figure 9 for stage 2 of the migration scenario. There is a significant investment in a new ballast-less track system that leads to savings in maintenance costs. Also, in tandem with trains up to 1500 m, there is a large increase in capacity that manages to offset most of the higher investment via the diversion of traffic from road to rail.

The internal rates of return (IRR) are 44% and 23% for stages 1 and 2, respectively, against the baseline. These unusually high values are justified by the relatively modest investment in infrastructure. The increment from stage 1 to stage 2 turns a much lower but still positive IRR of only 3,2%.

It is worth recalling that only the effects within the Montpellier to Perpignan section are accounted for. An increase in capacity of this section would generate benefits beyond the scope of the section here simulated where there is still available capacity. At most, the same kind of modest investment in siding extensions would need to be made to allow for longer trains. However, it is reasonable to assume that the benefits are being underestimated.

The case of the introduction of slab track is a bit trickier. The reduction in the nightly closure period implies that trains would need to proceed through sections with the same longer availability windows. However, even if one assumes, in the worst case, that the trains would need to wait at Perpignan or Montpellier until the section downstream opens for circulation, there is capacity available in those sections, the trains would always be able to run to their destination. Efficient scheduling would also be able to partially offset this limitation.

The sensitivity analysis identified operating costs, both on road and rail modes, economic growth, demand elasticity and slab-track construction cost as critical variables. That means that when subject to a change of 1% they produce a shift higher than that in the resulting NPV. Bearing this in mind, it was decided to test a few variations on the main scenario. A probabilistic analysis was also performed to test the robustness of the results (*cf.* Ref. [22] for full details).

One of the variations tested was skipping the migration to slab track, while implementing all remaining innovations. This means a significant saving in investment costs, but the daily gain of 3 hours of availability is not possible. In this scenario, the capacity gains are exclusively due to the ability to run innovative trains up to 1500 m. This inability to divert as much traffic from the road leads to a lower NPV, of around 100 M€, but with a slightly higher IRR of 26%, owing to the lower investment costs.

While this study has not looked at the predicted evolution of road transport, basically assuming it will remain static, a scenario was tested where some innovations are applied to road freight. These include an increase in truck length and gross weight up to 34 m and 74 Tons, respectively, and the availability of autonomous driving technology from 2030. Overall, this amounts to an estimated reduction in average road operating costs of around 28%.

It is not surprising that this has a dramatic effect on the ability of the rail sector to compete, reducing by a large fraction the cost advantage of the modal transfer. The average operating costs per freight unit of rail transport remain about half of those of road. For this reason, in our model, most of the diverted traffic in the initial scenario is still diverted in this road positive scenario. However, the producer surplus generated by this modal shift is dramatically reduced, cutting the NPV to a third in stage 1 and by an order of magnitude in stage 2. The IRR's are also much lower, at 15% and 6% in stages 1 and 2, respectively. It is worth recalling that these values of IRR assume that investment in rolling stock is diluted in their operating costs as capital costs, and similarly to road vehicle capital costs.

7. Discussion: Is slab track investment in existing lines the right way for a major shift to rail?

The EU Commission vision for the rail network in 2030/50 sets out very ambition goal for market share capture by rail freight transportation. For that reason, it is at least as important to look at the predicted market share evolution as to the raw CBA values.

The "business-as-usual" presents us with an outlook of progressively declining rail market share of land-based freight transportation. This is, to some extent, due to the very same capacity limitations simulated in this study. The fact that this corridor section is the "bottleneck" curtails further growth, meaning any growth in demand automatically goes to the road. This is the somewhat bleak outlook depicted in Table 2 for the baseline: a decline of a quarter of the current market share by 2050.

The increase in overall load capacity made possible by the longer trains and the increased number of trains running in the extra 3 h made available after the transition to slab track allow for an attenuation of this trend. By 2050, at least 10 additional daily freight trains would be running, as seen in Figure 11.

The results in Table 2 show the incremental effect of each change introduced in the corridor section. The successive implementation of stage 1 and stage 2 of the migration scenario, as described above, allow for the stabilization of the current market share or, at most, a very slight increase in market share.

One the one hand, even though the introduction of the new slab track has a negative effect on the NPV, not even fully offset by the introduction of 1500 m trains, its projected effects appear to be essential to maintain the current market share on the 2050 horizon. On the other hand, the combination of these innovations is not even close to attaining the policy objectives of the, even though they are well beyond the interoperability specifications for the TEN-T corridors. In fact, this scenario includes a significant incorporation of new technology into the rail system.

These results show the limits of capacity increase within the confines of an existing infrastructure where it is the key issue, indeed, a bottleneck for the whole corridor. The investment in novel and very sophisticated technology does allow for a 70% capacity increase in absolute terms, as illustrated in Figure 12, but falls clearly short of the lofty goals set out by policy makers. Still, this assumes that all the capacity made available is actually used, which, in turn, assumes that there is a network-wide compatibilization of train schedules, which is far from guaranteed. It also does not account for potential noise restrictions on running trains during the night.

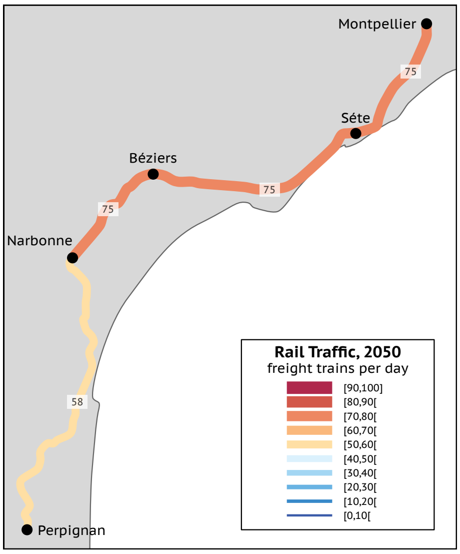

Figure 11. Rail traffic along the corridor in 2050 with stage 2, in terms of freight trains per day. Compare with Figure 1.

Table 2. Predicted rail market share of land-based freight transport in the Montpelier to Perpignan route. The Baseline shows a steady decline in rail market share due to capacity limitations, only partially offset by the lengthening of trains and implementation of slab track.

	2016	2030	2050
Baseline	22,1%	19,5%	16,4%
Stage 1 (1000 m trains)	22,1%	21,7%	18,1%
1500 m trains	22,1%	22,8%	20,0%
Stage 2 (1500 m trains and slab track)	22,1%	22,8%	22,9%

There are other possible measures not taken into account in this analysis. A higher speed for freight trains, 120 km/h in the short term, can increase capacity by harmonizing average speed between freight and passenger trains. ERTMS level 3 with continuous blocks can also increase capacity significant compared with conventional signalling systems or ERTMS level 2.

At this point, it is worth to recall that the figures here presented may be considered optimistic, especially due to the fact that no improvements on rail competitors are modelled, nor any increase in passenger services are foreseen. Furthermore, in a purely theoretical exercise, if all capacity made available with the major investments were to be used by freight trains, considering no capacity and schedule compatibility restrictions on the overall corridor, the maximum modal share for rail freight would still be near 23%, that is 1 percentage point above current figures and still far from EC goals.

The evidence that arises therefore is that, when reaching a capacity limit within a European rail corridor:

- Improvements on the rolling stock side, especially increasing train lengths, should be cost-beneficial if combined with only minor infrastructure improvements (*e.g.* siding extensions);
- Investments in slab track on conventional lines to increase track availability are difficult to justify purely from a cost-benefit viewpoint, even on a favourable scenario, such as this case study;
- In any case, the impact in rail freight market share is almost insignificant in the long run.

Another consideration is about infrastructure access charges: it is assumed that no relative changes in charges are expected to occur in the corridor, *i.e.*, from a financial viewpoint the investments are not be recovered by the Infrastructure Manager through exploiting eventual rail freight market willingness-to-pay.

In fact, it is well known that the rail freight business is heavily sensitive to cost, as well as reliability [23]. Thus, the straightforward solution to reach an effective impact would rather be to invest in increasing capacity by building new High-Speed Lines (HSL) for passenger services, releasing capacity in existing routes. Simulations on the Swedish section of the Scan-Med corridor show that HSL release capacity for 2-3 times more freight trains on daytime on the conventional track [22].

Once the new HSL is in place, the paradigm for the conventional lines could, instead of large technological investments, be shifted towards a "low-cost" (or even "low-tech") infrastructure, since design and operational criteria for dedicated freight are far less demanding (reduced inspection costs, maintenance thresholds and intervals, signalling requirements, etc), also enabling operators to minimize rolling stock capital costs (no need for ETCS/ERTMS, low-noise brakes, axle loads and wheel requirements, etc.). The release from fast passenger traffic alone would potentially still allow for increases in average speed and reliability of freight trains.

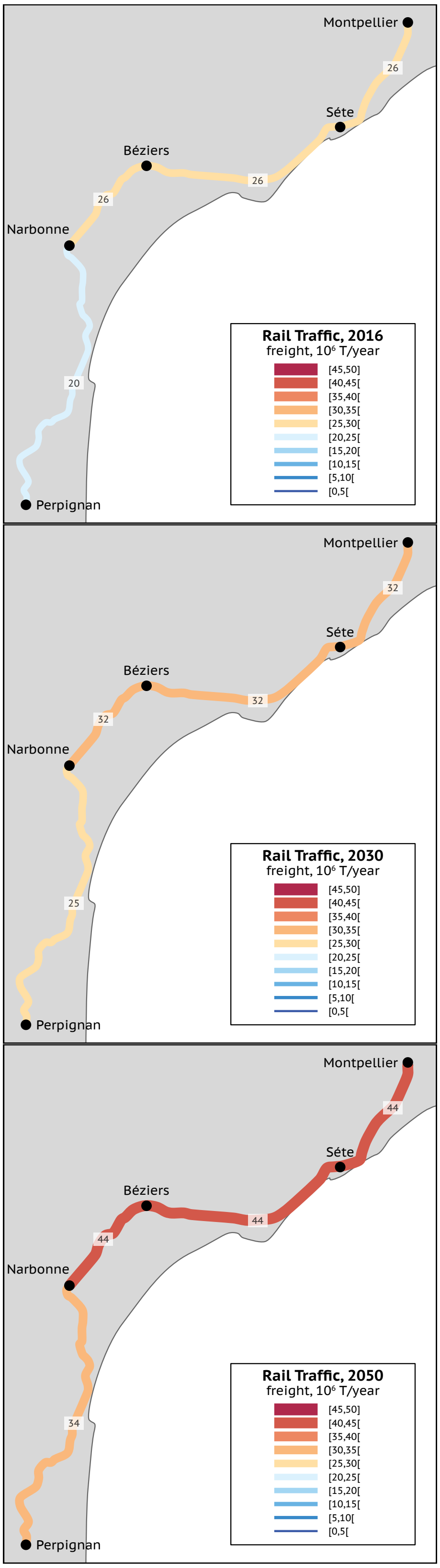

Figure 12. Evolution of freight traffic in terms of T/year from the base year, 2016, to the 2030 with stage 1 and 2050 with stage 2 horizons.

8. Conclusions

In this study, a test of the incremental implementation of a set of modifications to a rail corridor with capacity limitations, as well as the introduction of rolling stock technologies that allow the running of trains up to 1500 m in length, was performed. On the infrastructure side, there is a first stage where there are only siding extensions for longer trains, and a second stage with the installation of slab track and resilient switches and crossing, allowing for a reduction in maintenance costs and in overnight maintenance times, leading to a direct capacity increase.

The results of the CBA analysis show that the projected improvements have a positive economic value as measured by the NPV and IRR. However, the incremental approach, sensitivity analysis and testing of alternative scenarios clearly show that, by far, the largest contribution to the positive NPV comes from the lengthening of freight trains to 1000 m by 2020 and to 1500 m by 2030. In this particular case, it is clear that the replacement of ballasted track by slab track does have a positive effect in every aspect. However, this rests on the key assumption that due to the slab track, an additional 3 hours are available to run trains on each day. In another study that was performed in the context of this project, the advantages of slab track were not so clear [22].

The evolution of market share gives a slightly grimmer picture. Our results show that, at best, a maintenance of the current market share is to be expected, with the scenario where all innovations are implemented on schedule. Baseline and all intermediate scenarios point to a gradual loss of rail freight market share to road. This gets significantly worse when some level of innovation in road transport is considered. The expected arrival of more efficient road vehicles actually has the potential to almost cancel out the benefits achieved on the rail by the introduction of the innovations described.

Overall, this study helps to put in perspective the dissonance between the very ambitious and commendable political goals and what is actually achievable in terms of shift to rail. While there is no doubt about the environmental benefits of rail transport, and the definition of objectives in this regard often generate consensus, the same is not true when actually discussing specific plans, investments and projects. The modernization and increase in sophistication of existing lines is often presented as an alternative to the construction of new lines, that sometimes can become controversial. The public debate leads policy makers to often overestimate both the cost savings and actual benefits of modernization, while underestimating the potential for freight operations of a new high-speed line that takes passengers off the existing one. However, the results of this case-study clearly show the limitations of this approach. In capacity constrained corridors such as the one here analysed, even with some optimistic assumptions, there will not be a significant market share capture.

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