DEVELOPMENT AND EVALUATION OF MIGRATION STRATEGIES FOR ETCS LEVEL 1 APPLIED ON A SYNTHETIC TRACK

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Summary: In the next years the ETCS migration will be a crucial task toward a seamless cross-boarder railway operation in Europe. The right strategy shell minimise the economical effort and the operational restrictions during the long-term migration process. This contribution shows an example appraisal of the cost and the duration of different ETCS Level 1 migration strategies for a synthetic track and rolling stock. The calculation is based on available data as well as the plausible assumptions and estimations. The impact of applying different strategies and the "slow" respectively "fast" alternative is presented.

1. Introduction

Currently approximately 20 different train control systems are in use in Europe. To reduce this number and thus to realise a cost effective and seamless cross-border railway operation, European Train Control System (ETCS) will be implemented in the next years. Therefore the legislative preconditions in the form of EU directives 96/48/EG and 2001/16/EG have been established. Nevertheless besides the political demand the optimal migration of this new system will be a crucial condition for its success.
Based on a consistent methodology for the development and evaluation of migration scenarios [2, 4] a transition from a national system to ETCS Level 1 on an example generic track is given. Thereby different migration scenarios are developed and assessed on the analytical as well as the simulative way. Thus the appropriate strategy for the migration of ETCS on a certain track or corridor can be identified. In order to face the complex multi-dimensional optimisation problem occurring here, following aspects are considered:

- Presentation of a generic state space of the migration process from a national CC-system toward ETCS Level 1
- Requirements on the operational simulation of the migration processes
- Systematic development and assessment of detailed track or corridor specific scenarios

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- Multi-dimensional optimisation with focus on economical and operational criteria considering the relevant technical constraints and possibilities

The methodology aims on optimisation of concrete migration projects for ETCS using figures like costs and duration of the process.

2. Methodology for the Migration of Train Control Systems

The final target of the ETCS migration is not to have one more train control system overlaid to the national systems then to become the only necessary system at least on defined corridors. This should be a requirement on the migration process by having in mind the higher cost of the operation as well as the maintenance in case of the parallel equipment track-side. For the migration of ETCS a few basic strategies have been presented in former publications [1, 2, 5].

2.1. States of the Migration Process

The migration-process can be described as a sequence of states and transitions between them. These possible combinations can be figured as paths through the process (Fig. 1). In the following example the migration from Indusi as an example for an existing national system to ETCS Level 1 is presented. Thereby three basic different Strategies as well as the STM-option are displayed.

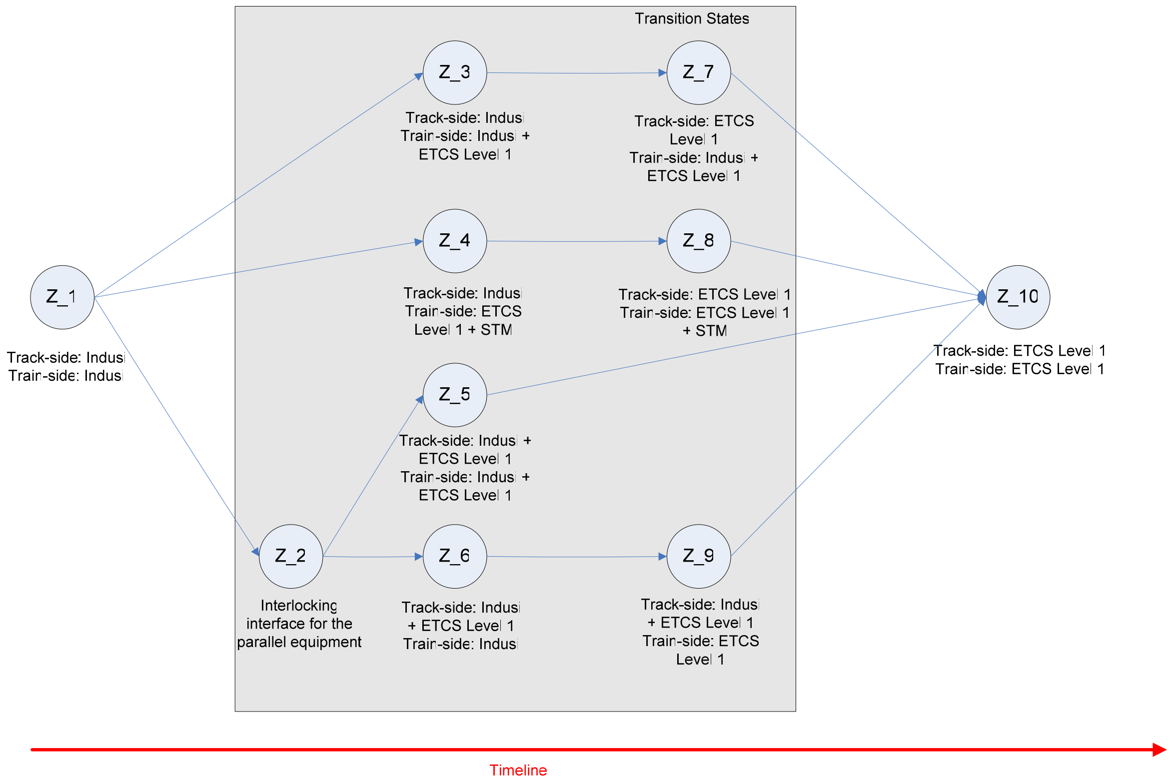

Figure 1: State Space of the ETCS Level 1 Migration

By using mathematical modelling of the transition function the overall migration costs of each scenario can be identified. These costs can be separately analysed for the track-side system components as well as for the rolling stock. Thus the impact on the Infrastructure Managers

(IM) and Operators (TOC) can be identified. In this contribution and especially in the following examples in the Section 6 the migration costs will not be separated regarding IM and TOC then calculated in general.

2.2. Basic Requirements on the Operational Simulation of Migration Scenarios

Migration of train control systems and the requirement to keep up the operation during the process makes parallel equipment train- and / or track-side necessary for a certain period.
In order to be able to model the railway operation during the migration period, different requirements on the simulation can be identified. These are for instance:

- *Simulation of each individual train control system – the current as well as the target state of the migration*
  The ability to model the relevant CC-systems is the basic requirement for each simulation tool. This includes the installation of the track-side components according to the specification as well as the on-board systems with their specific braking curves and the speed restrictions.

- *Ability to implement two systems track-side in parallel*
  Currently, most simulation tools work based on the node-edge model. Thereby, the edges represent track sections with the specified length, maximum speed, radius, gradient etc. The nodes are being used for the separation of sections with different parameters or for placing components of the train control systems. Here we have the requirement to install at least two different systems per node in parallel or otherwise to define different attributes for the same track section.

- *Ability to implement two systems train-side in parallel*
  Analogue to the double equipment track-side, on each vehicle the simulation tool also has to be able to build up at least two different CC-Systems.

- *Section- and train-selective allocation of the active system*
  It has to be ensured that simulated CC-systems can be allocated to each train as well as each track section separately. Thus the mixed operation including trains or track sections equipped with ETCS or with the legacy system can be realised. Separate allocation of the system responsibility during the regular operation and in the fall-back scenario has to be specified.

- *Crosscheck*
  In case of parallel equipment track- OR train-side, the allocation is clear. The CC-System which is active on BOTH sides has the safety responsibility. Therefore a crosscheck is necessary in order to verify the availability of each system. Thus it can be avoided that vehicles without the valid CC-System run over a track section.

- *Prioritisation*
  In case of parallel equipment track- AND track-side the safety responsibility has to be explicitly allocated. It can be realised by using the prioritisation feature for the train-side CC-systems.
  Crosscheck provides a matching function and prioritisation the final selection of the system in the operation on the certain track section.

- *Simulation of different characteristics of the system transition – standstill, on-the-fly*
  This requirement is related to the transition areas between two different CC-systems track-side. Globally there are two possibilities thereby:
  On-the-fly: The switch-over can be realised without the operational brake – no train stop is needed.
  Transition at standstill: In order to shut down the one system and to boot up another one, an operational train stop is necessary.

The crucial target for the design of the migration strategies on the operative level is to provide at least the same operational performance, thus to avoid any restriction during the process. This is one of the boundary condition for the development of migration scenarios.

2.3. Development and Assessment of Migration Scenarios - Methodology

Based on the state space model the migration scenarios – paths through the model – can be developed. For the migration from the national CC-systems to ETCS a few basic scenarios can be identified (Fig. 2). In the next step, these scenarios have to be assessed regarding the defined evaluation criteria. The crucial figures are migration costs and the duration of the migration process. Besides those two figures, the risk related to the stability of the regarding scenarios by changing of boundary conditions is to be determined by using a sensitivity analysis.

		Rolling Stock		
		Retrofit Legacy System -> ETCS	Double Equipment	
			ETCS + Legacy System	ETCS + STM
Track-side Infrastruct	Retrofit Legacy System -> ETCS	*Incompatible*	*Scenario 1*	*Scenario 2*
	ETCS + Legacy System	*Scenario 3*	*Scenario 4*	*Scenario 5*

Figure 2: Basic Scenarios for the ETCS Migration

Due to the restricted availability of the STM-solutions the scenarios 2 and 5 have not been analysed.

The Net Present Value method (NPV) is an approach used in capital budgeting where the present value of cash inflows is subtracted by the present value of cash outflows. NPV is used to analyze the profitability of an investment or project like the ETCS-migration in our case [3]. Instead of an average view in static methods, approaches of the dynamic investment appraisal consider an exact collection or prognosis of the cash flows of the investment and discount them to an imputed interest rate. Thus, the method considers the time value of money. The period, regarded here, refer to the duration of the migration process. The NPV analysis is sensitive to the reliability of future cash flows of the investment or project.
For the evaluation of regarded migration strategies, the net-present-value method is being used.
Since the cleared migration costs are needed, the basic approach is modified due to the determination of cash flows by comparing the payment stream of the regarded migration scenario with the continuation scenario of the current CC-system. Thus the costs the national system would cause without the migration toward ETCS are subtracted. [2]

$$C_0 = \sum_{t=0}^{n} (E_t - A_t) \times \frac{1}{(1+i)^t} + \frac{L_n}{(1+i)^n} \qquad (1)$$

C_0: Migration Costs for the ETCS deployment
E: ETCS - Costs
A: Costs of the reference scenario – continuation of the legacy system
i: Discount Rate
L: Settlement Revenue
0…n: Duration of the Migration Process

By setting the maximal capacities for the installation, retrofitting as well as the removal of the track-side and the on-board CC-system components, the duration of the process can be determined.

3. Assessment of Migration Scenarios – Application on an Example

Based on the publicised data on the one hand and some assumptions on the other hand, being necessary due to the low maturity of the system, in the following section an example calculation regarding the cost and the duration of the ETCS Level 1 migration is given. Besides the overall costs of the complete ETCS migration, costs trend p.a. is presented as well. Thus the identification of the "break-even-date" realising **annual** *(not in general)* benefits of the ETCS migration can be determined.
Therefore we use a synthetic example track with following figures and constraints:

Calculation Basis, Boundary Conditions and Assumptions
Infrastructure: Track-length 500km
Rolling-stock: 500 units
The legacy system track- and train-side is already depreciated.
The methodology includes cost positions for ETCS

1. Invests for the ETCS train- and track-side equipment – facts and assumptions
    a. Train-side asset costs: 250.000 €
    b. Track-side asset costs : 75.000 €/km
2. Cost of operation / maintenance costs
    a. Train-side components: 30.000 €/unit p.a.
    b. Track-side component: 10.000 €/km p.a.
3. Recycling costs for the legacy system: 10.000 €/unit respectively /km

As well as the cost positions for the reference scenario – continuation of the operation with the legacy train control system

- Cost of operation / maintenance costs
    a. Train-side components: 50.000 €/unit p.a.
    b. Track-side components: 20.000 €/km p.a.

Capacities for ETCS-installation, retrofitting and removal of the CC-systems (applied for the first three scenarios):

4. Track-side
    a. Retrofitting and ETCS-installation: 50 km p.a.
    b. Removal: 100km p.a.
5. Train-side
    a. Retrofitting and installation: 1. year 100 units p.a.; else – 50 units p.a.
    b. Removal: 100 units p.a.

Figures in the following sections display the overall status of assets regarding the equipment with ETCS respectively the national system throughout the migration process as well as the trend of the migration costs per year during the process.

3.1. “Slow” Migration

Parallel Equipment Track-side (Scenario 3)

In order to ensure the operational availability in this scenario parallel equipment including ETCS and the national system **track-side** is provided. That implicates the following order of action items during the migration process:

1. Installation of the ETCS track-side component additionally to the existing system
2. Retrofit of the rolling stock
3. Removal of the legacy system track-side

In the Figure 1 it is the transition path:
Z_1; Z_2; Z_6; Z_9; Z_10
During the migration process this strategy allows the operation with ETCS-equipped rolling stock as well as those running with the legacy system.

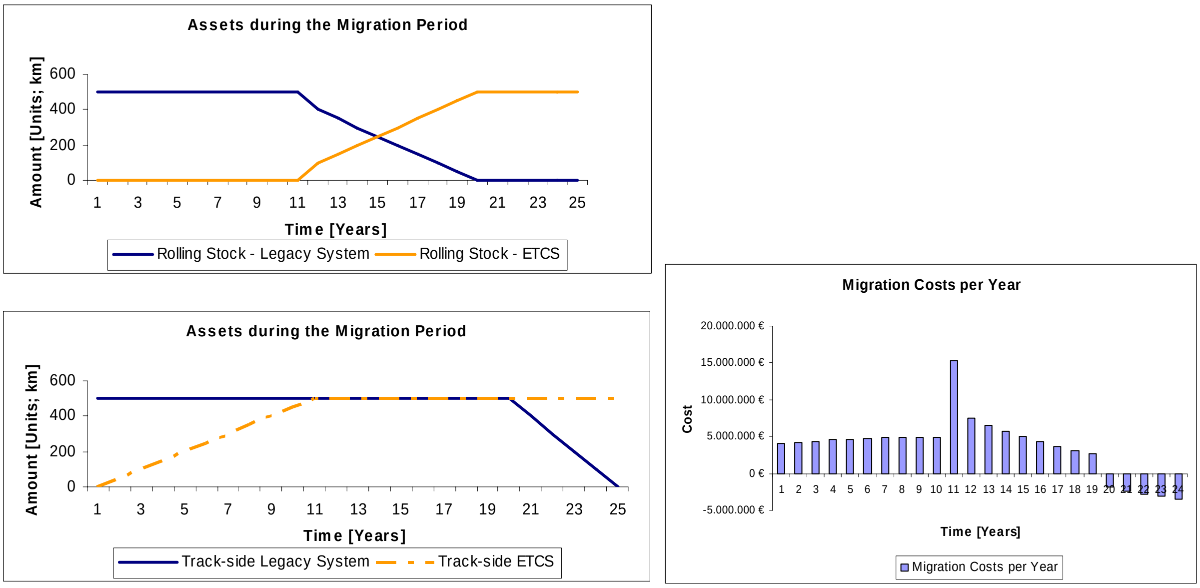

Figure 3: Parallel Equipment Track-side – Assets and Cost Trend

In this scenario the cost peak in the first year of retrofitting the rolling stock (year 11) is significant. From the year 20 on, due to the expected lower operational respectively maintenance costs of ETCS cost savings can be already realised.

Parallel Equipment Train-side (Scenario 1)

Analogue to the scenario above, to ensure the operational availability in this scenario parallel equipment including ETCS and the national system **train-side** is provided. That means the following order of action items:

1. Installation of the ETCS train-side components additionally to the existing system
2. Retrofit of the track-side infrastructure
3. Removal of the legacy system train-side

In the Figure 1 it is the transition path:
Z_1; Z_3; Z_7; Z_10

This strategy allows a flexible circulation of the rolling stock, using track sections already equipped with ETCS as well as those with the national CC-system.

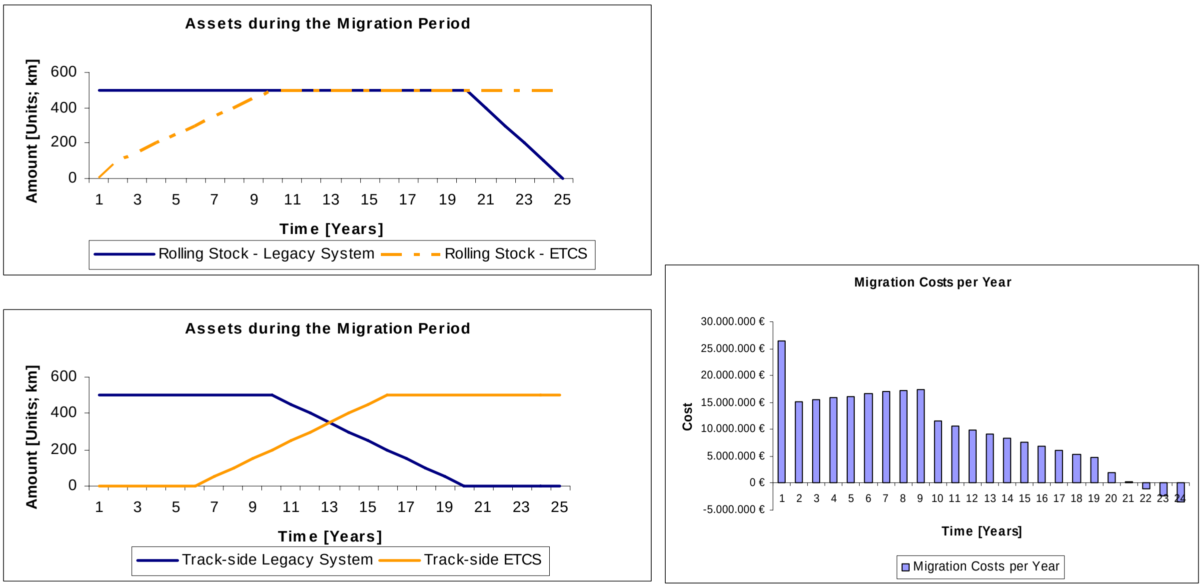

Figure 4: Parallel Equipment Train-side – Assets and Cost Trend

Based on given information as well as the assumptions parallel equipment with ETCS and the national system on rolling stock is the most expensive scenario. High asset costs of the train-side equipment appear at the beginning of the migration period, thus the net present value of the cash outflows is relatively high.

Parallel Equipment on Both Sides (Scenario 4)

Combining the previous scenarios and in order to accelerate the ETCS migration parallel equipment including ETCS and the legacy system **on track as well as the rolling stock** is provided.

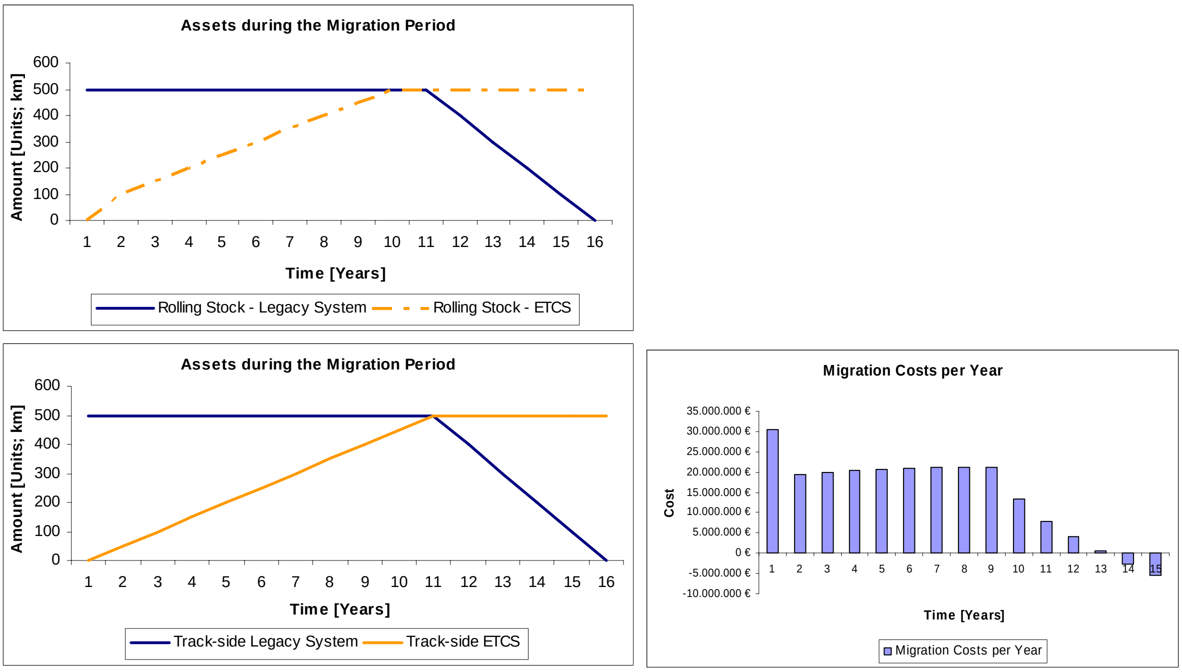

Figure 5: Parallel Equipment on both sides – Assets and Cost Trend

That means the following order of action items (fig. 1):

1. Installation of the ETCS track- AS WELL AS train-side components additionally to the existing system
2. Removal of the legacy system

In the Figure 1 it is the transition path:
Z_1; Z_2; Z_5; Z_10

By applying this migration strategy the process can be shortened. On the other hand additional cost regarding the parallel equipment appears. Based on the assumptions the calculation shows that the positive impact on the duration makes this strategy to a second best solution regarding the migration costs. Regarding the temporal aspects, the crucial advantage of this scenario is the early realisation of the benefits generated by the ETCS migration (year 14).

3.2. "Fast" Migration

In this section the impact of the fast migration on the costs and time is to be analysed. To realise the faster migration the capacities for the ETCS installation, retrofitting as well as the removal process are being defined as a double value compared to the previous settings.

Parallel Equipment Track-side (Scenario 3) - Doubling of Retrofit Capacities

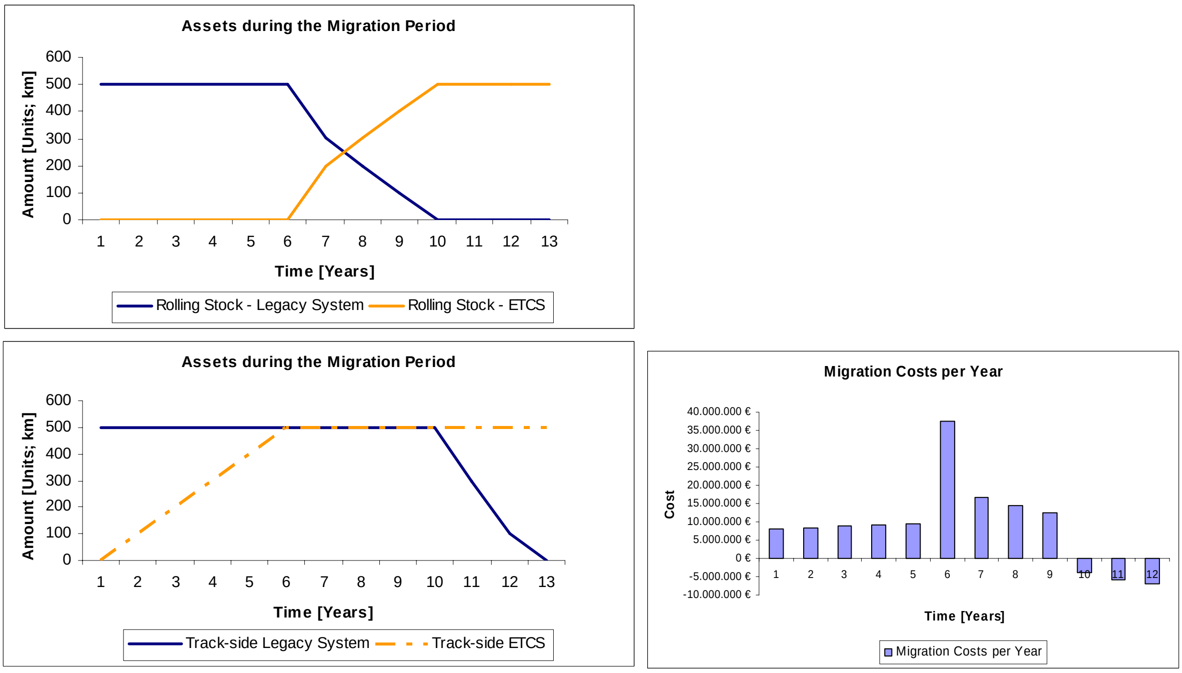

Figure 6: "Fast" Migration / Parallel Equipment Track-side – Assets and Cost Trend

Already up from the year 10 the benefits can be realised, thus the positive impact is visible.

Parallel Equipment Train-side (Scenario 1) – Doubling of Retrofit Capacities

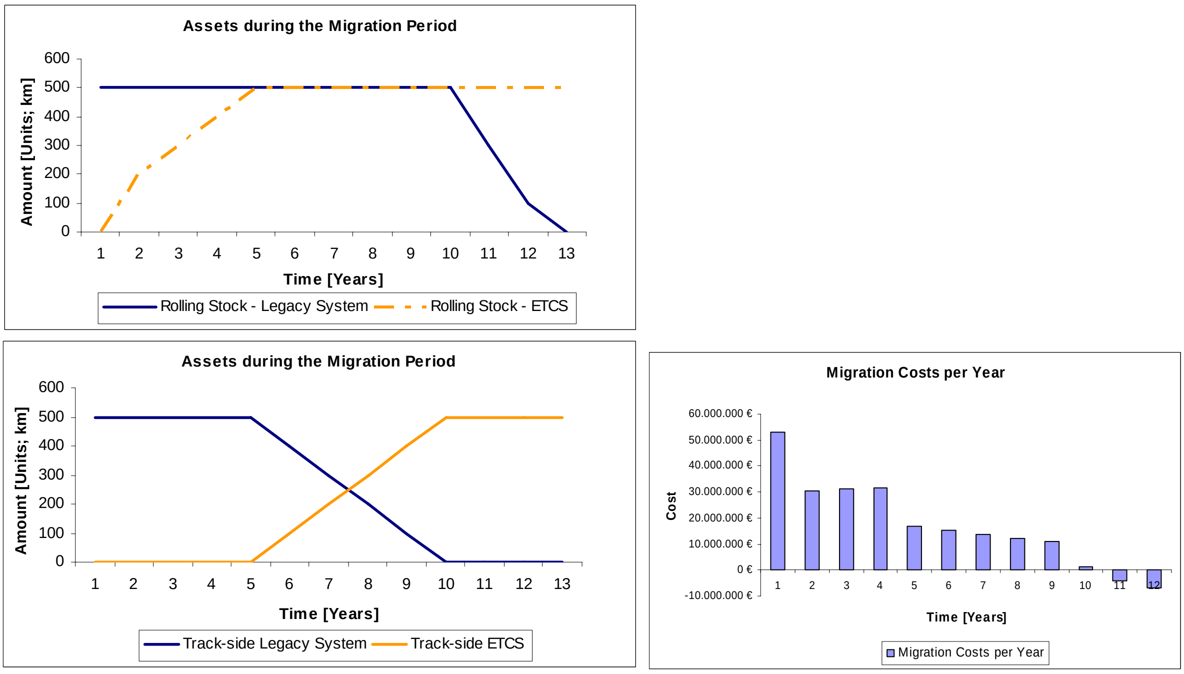

Figure 7: "Fast" Migration / Parallel Equipment Train-side – Assets and Cost Trend

Here we have a similar effect compared to the previous scenario – up from year 11 annual migration costs become negative, thus the benefits are being generated and the break-even is reached.

Parallel Equipment on both sides (Scenario 4) – Doubling of Retrofit Capacities

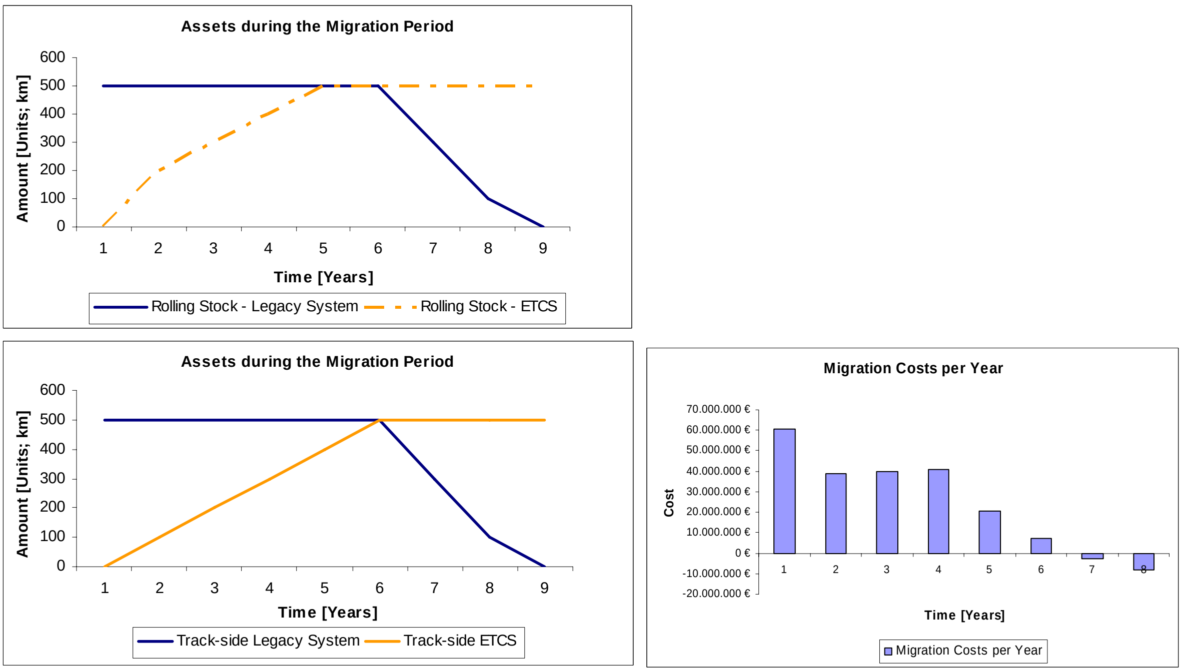

Figure 8: "Fast" Migration / Parallel Equipment Track-side – Assets and Cost Trend

This is the fastest analysed scenario with the break-even of annual costs in the year 7 and the overall duration of 8 years.

3.3. Comparison of the Figures Migration Cost and Time Applying Different Scenarios and Different Capacities

In this section, the final results of different scenarios based on the assumptions as well as the variation of the retrofit capacities and thus accelerating the migration process will be shown.

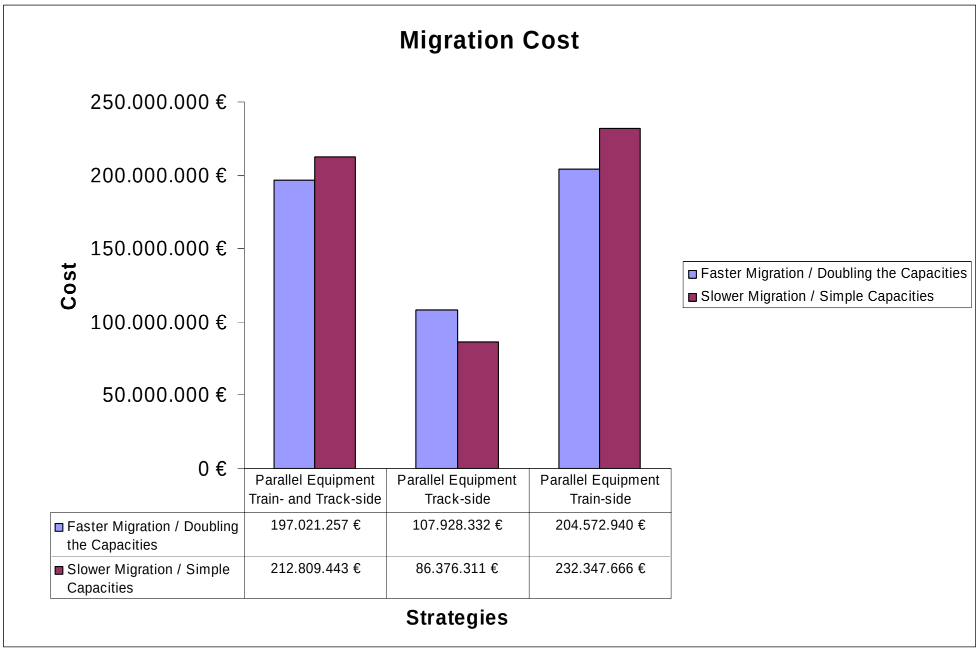

Figure 9: Overview on the Migration Costs of the Scenarios

Based on the used data the parallel equipment track-side is the optimal strategy from the economical point of view. Two of three strategies cause lower migration cost in the "fast" alternative. Based on the assumptions and the calculation carried out, the parallel equipment track-side is the only strategy raising higher migration cost by accelerating the process. Thereby the positive impact of the shorter period the parallel equipment is needed can not compensate the higher invests in the near future with their adequate high net present value. In both other scenarios the effect conducted by using the fast migration leads to lower migration costs.

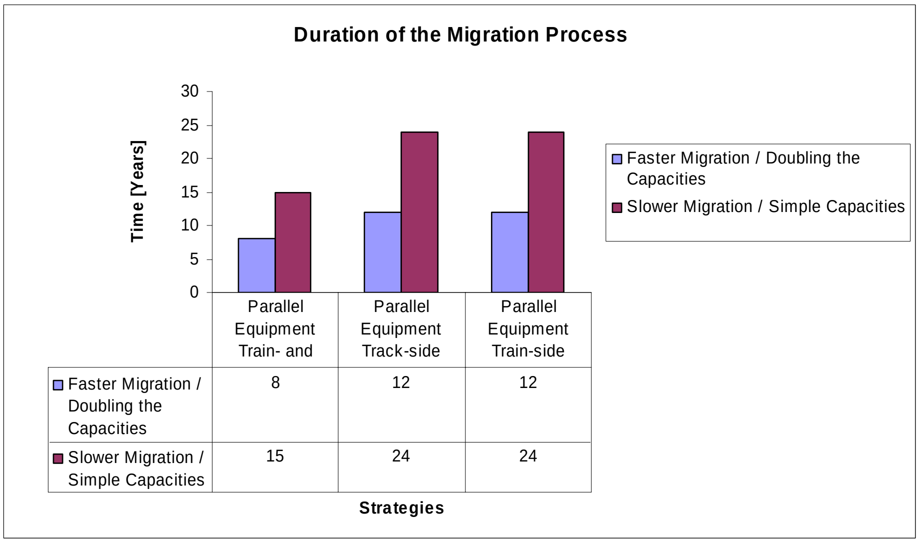

Figure 10: Overview on the Duration of the Migration Process

Figure 10 shows the overview of the impacts of the application of different strategies in the "fast" and the "slow" option on the temporal aspects of the ETCS migration.

4. Conclusions

In this contribution, based on the state space model of the ETCS Level 1 migration process, six different migration scenarios have been assessed with respect to the figures costs and time. These are three basic migration strategies – parallel equipment track-side respectively on-board as well as the parallel equipment with ETCS Level 1 and the national system track- and train-side at the same time – including the two variations in the retrofitting capacities in each case.

Based on the used data as well as the made assumptions regarding the synthetic track, rolling stock as well as the different cost positions, following conclusions can be recognised:

- In both cases – "slow" and "fast" migration the strategy of the *parallel track-side equipment and the retrofit of the on-board systems* is significantly the one with the highest cost effectiveness (low cost strategy). Some disadvantages thereby are the relative long migration period and the lower flexibility regarding the circulation of the rolling stock.
- With the parallel equipment with the national CC-system and ETCS track- and train-side at the same time the duration of the migration process cab be significantly decreased.
- Due to the high investments in the early period – caused by the relative high asset cost for the ETCS on-board equipment – and thus the very high net present value of the cash outflows, the parallel equipment train-side is the most expensive strategy in this appraisal
- Doubling of the retrofitting capacities reduces the duration of the migration process decreasing the cost at the same time. The only exception is the parallel equipment train-side with its higher migration costs in the "fast" alternative. The crucial reason therefore is the high net present value of the asset costs generated in the early period of the migration process

It has to be underlined that other assumptions on the cost positions and especially on the estimated maintenance costs e. g. may lead to another result. Nevertheless this generic application of the methodology for the evaluation of the ETCS migration strategies shows the trend of the cost and time effort by using certain strategies on relevant tracks and corridors. Optimising these figures – time and cost – the deployment of ETCS by choosing the optimal migration strategy will be supported.

5. References

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