Evaluation of economic efficiency of rail operation through simulation

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Abstract

An increasing traffic demand and competition between the traffic modes force the railway operators to improve their economical results. This can be achieved primarily by reducing costs and by keeping a high standard in service and quality whereby an increase of attractiveness for potential customers can be realised. Especially the Deutsche Bahn AG, while preparing itself for going public, demands for a higher relevance of the financial result.

Cost and Benefit are the two factors determining the economic efficiency of rail operations. For both the infrastructure managers and the train operator companies a possible pre-evaluation of imaginable investment scenarios is of high significance when trying to optimise their cost-benefit structure. Helpful hereby can be railway operation simulations which not only consider operative aspects but also economical ones. While there exists quite a bit of supporting software for simulating possible operation scenarios (e.g. RailSys®, OpenTrack®), it is yet not standard to reuse obtained simulation results for an economic evaluation of the considered scenarios. The Institute of Transportation Systems has therefore implemented a software link between the simulation software RailSys® and the in-house created Cost-Benefit Tool. With the latter the cost and revenue positions of the evaluated system and scenario can be calculated. The idea of a link between railway operation simulations and economic efficiency evaluations is discussed in the first part.

In the next step results of first simulations are presented and discussed. Basis for the first examinations is a pre-defined regional railway for which different equipment scenarios were implemented in RailSys®.

Keywords

Railway operation simulation, Economic efficiency, LCC

1. Introduction

The current development on the traffic market forces the two railway operation parties, the infrastructure managers and the train operator companies, to a more economical driven business strategy. In a surrounding of increasing competition between the traffic modes and the governmental demand for a more market oriented behaviour the two parties are forced to improve their price-performance ratio. For being able to offer logistic and transportation services at attractive prices both of them have to cut costs without reducing the system's quality. But when considering different ways for cost reductions, the decision makers have to keep in mind that the long-term effect of made decisions defines whether the overall economical impact is positive or not. This aspect means for the cost perspective that not only the costs generated right with the implementation of the selected strategy have to be considered but also the ones generated in later periods. For this reason Life

Cycle Costs (LCC) as the sum over all costs generated in the life phases development, production, service and disposal of a product or system have been defined [3]. But especially tools for making long-term evaluations of the economic efficiency of different rail operation strategies are missing so far. Therefore the Institute of Transportation Systems started on looking for ways how to give infrastructure managers and rail operation companies likewise a useful instrument when trying to make decisions under consideration of both operative and economical aspects.

New and of scientific and practical interest is the idea of linking railway operation simulations to cost-benefit examinations. With the presented tool link economic efficiency evaluations can be done in an efficient way.

That the idea is of practical use will be proved by presented results received from the inhouse created Cost-Benefit Tool after linking it to the railway operation simulation software RailSys®.

2. Economic efficiency evaluation through tool linking

2.1 Economic Efficiency

Economic Efficiency is defined as the relationship between costs and revenues created by a machine or a system. For investment projects economic efficiency means that its net present value (NPV) is higher than zero.[4]

For the train sector, which is characterized by long economic life-times of the facilities, a lasting optimisation of the cost-benefit structure for the infrastructure managers and the train operator companies can only be achieved by a long-term view on costs and revenues. This means considering the life phases (Fig. 1) of the system and its structure. The vertical line in Figure 1 represents the two perspectives existing in a product life cycle. While the formation cycle is primarily of interest for the product manufacturer, the market cycle determines the economic efficiency relevant for the product user. Hence in practice economic efficiency evaluations mostly never consider the whole life cycle but either cost and revenue positions generated in the formation cycle or in the market cycle.

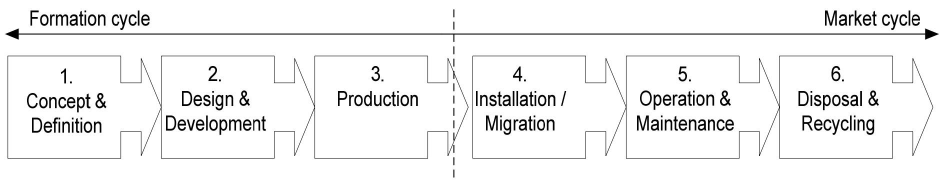


Fig. 1: Product life cycle phases [1]

For the cost perspective the use of the life cycle cost approach is necessary. As defined, life cycle costs are understood as the sum over all costs generated throughout the life cycle phases (procurement, service and disposal) of a product [3]. Accordant various cost components generated during the operation of track and rolling stock and their cause-effect chains have to be considered when setting up the Cost-Benefit Tool and defining the interfaces to the railway operation simulation software. The cost components which define the life cycle costs of a railway operation system are shown in Figure 2. Here the cost positions of the life cycle phases seen from a system user perspective (not customer)

– installation/ migration, operation/ maintenance and disposal/ recycling – are captured in the cost pools purchase expenditure, utilisation costs and disposal costs. In addition there are overhead costs which cannot be attributed to one life cycle phase only. Such are costs generated by an information management system. The cost pools are subdivided into the corresponding cost elements. The cost elements in the cost pools are distinguished between being of recurring, varying amount (orange), recurring, constant amount (grey) or non-recurring amount (green).

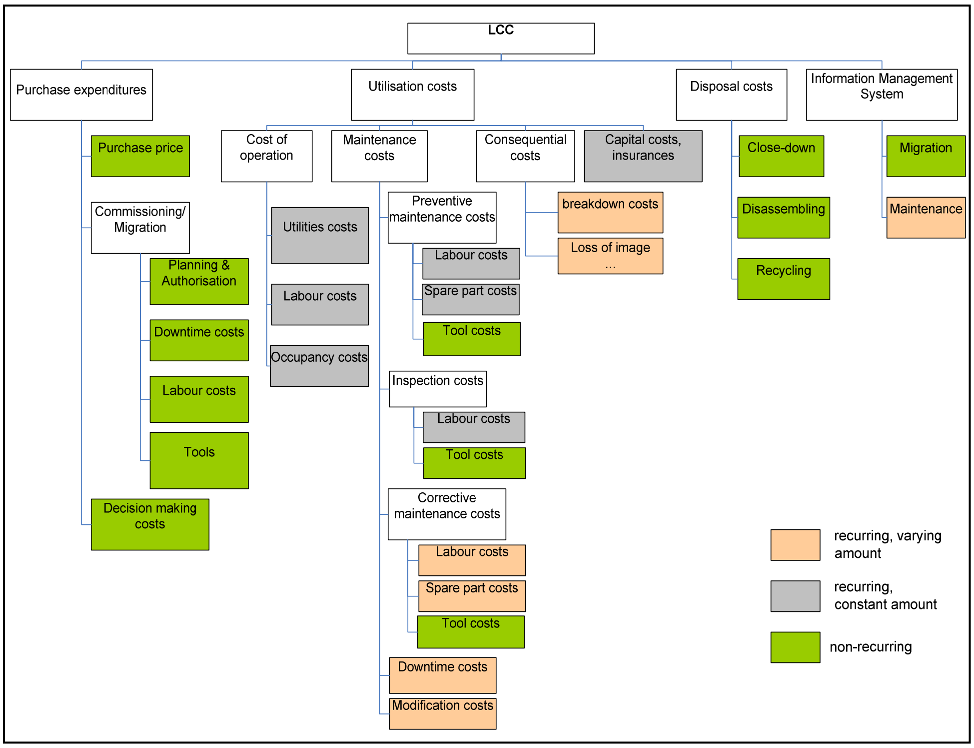


Fig. 2: Life cycle cost components

On the benefit side there are at first the direct benefit factors. They are defined through the revenues out of ticket sales, track access charges, subsidies etc. and therefore comparatively easy to determine. In addition there are indirect revenues such as the level of system security, the system availability etc. which have to be considered as well. The scientific question hereby is if there is a way of expressing these aspects in revenue numbers so they can just as well be entered into the cost-benefit figure.

Such an economic efficiency figure is the Net Present Value (NPV). The NPV is a financial expression for the attractiveness of an investment seen over its entire investment period by considering expenses, revenues, the capital market and time [8]. The NPV can be calculated for the different points of view. NPV figures for the entire analysed track section (infrastructure, vehicles and operation) or just for the infrastructure manager's interest or a NPV figure solely on behalf of the train operators are calculable. In the described evaluation with the NPV method the costs and potential revenues occurring in the disposal phase of the system are not included. Their impact on the overall result is low because of their late occurrence in the analysed life period and therefore a high load reduction factor. The mathematical expression for the NPV shows (1). The revenues (R) and costs (C) per year and the chosen interest rate (i) over the regarded time period (n) are the input variables.

$$C_o = \sum_{t=0}^{n} (R_t - C_t) \times \frac{1}{q^t} \,. \quad (1)$$

2.2 The Link

The systematic approach of evaluating the simulated rail operation with the Cost-Benefit-Tool and the use of the software link is shown in Figure 3.

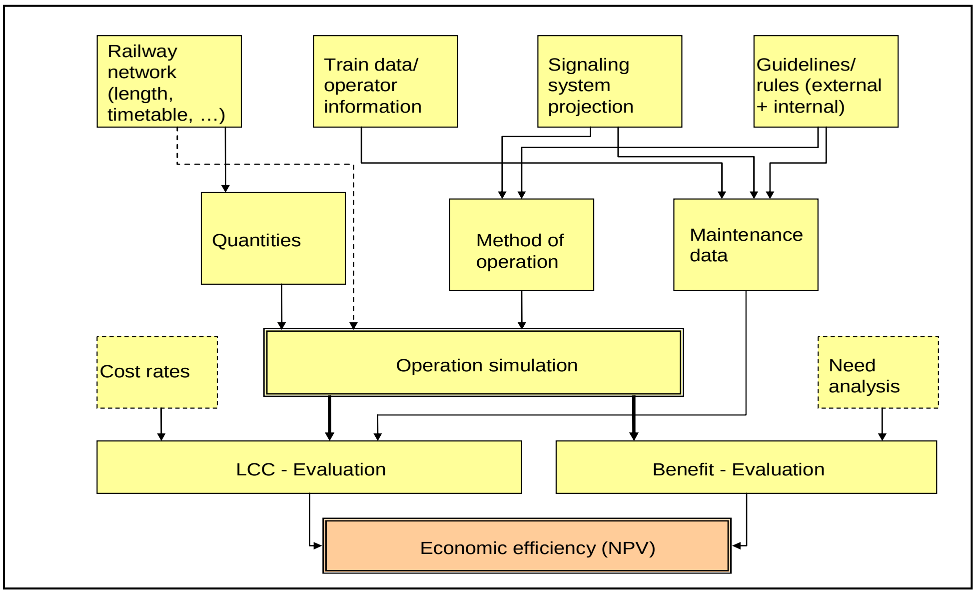


Fig. 3: Systematic approach for tool linking

Above figure indicates the steps of how the economic efficiency evaluations are done with the use of the operation simulation software RailSys®. First of all the scenarios which want to be simulated have to be implemented in RailSys®. This means mapping the track topology, including the timetable and implementing the chosen signalling system projection. Railway network and the method of operation determine the quantities of track infrastructure elements. Timetable and train information set up the time of operation. With this information the operation simulation can be done. The results of the operation simulation do influence the cost side (LCC) as well as the benefit side. For doing efficiency evaluations there are additional information needed. Such are information about the installation and maintenance phase. As described in chapter 3.2. the focus of this paper lies on the utilisation phase. Therefore maintenance data are primarily needed. They are influenced by the rules of the infrastructure manager and the train operator company as well as the signalling system layout and rolling stock and the average load on the infrastructure elements and vehicles. The maintenance information directly influences the LCC-evaluation of the operation phase. Only dynamic figures, which vary with the chosen equipment and method of operation can be obtained from the simulation, e.g. quantity figures, operation time, driven distance. Cost facts and static information, that means data which cannot be received through output files of the operation simulation software (e.g. maintenance intervals) are also needed. The user of the Cost-Benefit Tool has to fill in the additional information, which is detached from the simulation output files, via an entry mask. Therefore it is obvious that the simulation cannot substitute the precise documentation of the relevant static information. The interface between RailSys® and the Cost-Benefit Tool has been realised through Visual Basic for Applications (VBA).

3. Simulative Evaluations

This paper presents the results of simulations of different operating procedures with changing signalling system layouts on a chosen secondary railway line (see 3.1). The reason for doing so is the current economic situation on secondary networks. Here the focus lies more on a cost reduction (by fulfilling the security demands) than on a capacity increase [13].

Starting with a given timetable the simulations are supposed to outline the saving potentials which can be realised by the implementation of different operating procedures and therefore of changing equipment levels. The examinations whose first results are presented in this paper are about a What-if-Simulation [12]. This signifies a comparing study in which some system parameters are changed and there effect on the LCC is analysed.

3.1 Object of Investigation

Within the investigations a single way track, which is built after a real secondary railway line is basis for the investigation. The simulated and analysed track has the following features:

- Single way track
- 2-direction operation
- Maximum speed of 80 km/h
- 10 railway stations
- 11 stopping points

Level crossings will not be part of the examinations.

The line topology how it is implemented in RailSys® is shown in the following figure (Fig. 4). Railway stations A and J are parts of the neighbouring lines with whom the start and end of the trains on the analysed single-way track is realised. Therefore these two stations will not be changed throughout the examinations.

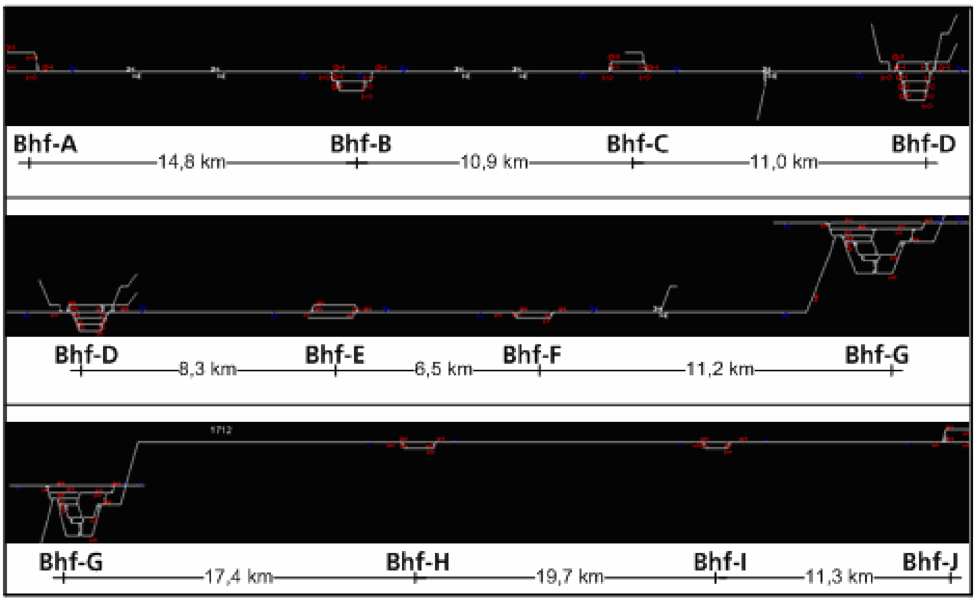


Fig. 4: Line topology

The simulated timetable is constant. Therefore the transport demand is a fix parameter for all scenarios. Trains run from approximately 4 am to 1 am. There are two different trains, passenger trains and freight trains, which are all running on a speed of 80km/h. Therefore there is no overtaking needed. The timetable which is assumed to run 365 days a year includes

- 50 passenger trains and
- 4 freight trains per day.

3.2 Preliminary Considerations

Since different operating procedures on a given track topology and with a constant timetable have been simulated, the focus of the economical evaluations lies on the effect of the different equipment scenarios on the cost-benefit structure during the operation phase. Therefore the analysed question is, what-if we had the simulated operating procedure and what difference would it make on the economic efficiency of the operation phase. The procurement costs are not part of the examination. The LCC analyses have been done on a 20 years basis. This is the minimum expected life time period for railway operations control equipment [6].

Since the track topology and the timetable are constant parameters this examination focuses on the infrastructure manager (IM) and his cost-benefit structure for providing transport capacity. There are no changes for the train operator since the track access charges stay constant for the three operating procedures. Because of the given timetable there are no changes on the benefit side for the infrastructure manager either. Generally the IM’s revenues increase when more routes are sold. The number of sold routes depends on the number of trains running on the track section. The price depends on the length of the used track kilometres and on different parameters of the track section [2].

3.3 Simulated Railway Operating Procedures

The different possible railway operating procedures have a high impact on the operation costs for the railway operation control equipment. As pointed out in the beginning of section 3 for the three simulated operation procedures and the corresponding signalling system layouts the number of control equipment needed differs. Besides the difference in the quantity of needed track equipment there is also a changing operation quality (time margin, safety, etc.) which is realised by the operation procedures. Both infrastructure equipment and operation quality do influence the life cycle costs relevant for an infrastructure manager and therefore have to be considered when doing an economic efficiency evaluation under the restriction of a constant timetable.

The following **operation scenarios** have been defined and simulated. They were chosen under the requirement of fulfilling the timetable and of being feasible (see determination of load profile of a track [10]). How the track parameters differ between the operation scenarios is shown in Table 1.

First scenario (current situation on real railway line):
- mechanical interlocking,
- trackside signalling
- telephone block

Second scenario:
- electronic interlocking,
- telephone block
- unneeded track in stations eliminated

Third scenario:
- train dispatcher [7],
- no interlocking, trackside signalling,
- trailable one way switches,
- unneeded track in stations eliminated

Table 1: Track Parameters

Track parameter	First scenario		Second scenario		Third scenario	
Track length [Km]	126,848		125,798		125,798	
switch	44		42		42	
Caution signal	19		19		2	
Main signal	69		67		57	
stations	10					
stop	11					
Train control system	intermittent automatic train-running control (PZB)					
Interlocking type	7 mechanical	3 electro-mechanical	8 electronic	2 electro-mechanical	1 train dispatcher	2 electro-mechanical
Route formation time	90 s	45 s	12 s	45 s	42 s	45 s
Route release time	25 s	12 s	6 s	12 s	26 s	12 s

3.4 Simulated disturbance scenarios

As mentioned, every operation procedure has its system quality which influences the benefit side and therefore the overall economic efficiency of the system. The two following realistic **disturbance scenarios** on secondary lines have been defined to evaluate the system quality.

First scenario: *Track blocking*	-	Track section between the two stations G and H is blocked because of maintenance work in the early morning,
	-	cancellation of blocking at 4:30 am
Second scenario:	-	Switch failure in station A
Switch failure	-	Failure occurs after a train arrives at station A at 6:27:12 am
	-	Switch repaired at 6:45 am

3.5 Simulative Results

Operation Quality

The effect of the defined disturbance scenarios on the operation quality is measured in delay minutes [1]. Delay minutes are a measure for unscheduled waiting time at the stations. The following delay minutes in the fix timetable for the two disturbance scenarios are the results of simulations in RailSys® (see Table 2). The delay minutes are caused by one disturbance on a chosen day and the series of reactions when one train is delayed and has an effect on the following scheduled trains.

Table 2: Delay minutes

	Scenario 1	Scenario 2	Scenario 3
Track blocking	604 min 36 s	463 min 11 s	528 min 24 s
Switch failure	109 min 39 s	92 min 33 s	91 min 1 s

The explanation for the delay minutes is given in Table 3. Here the number of trains affected by the disturbance scenario 1 and 2 are shown. Since timetable and maximum speed of the trains are constant for the three operation procedures the difference in the number of affected trains is determined by the route formation and route release time (see Table 1).

Table 3: Number of affected trains by a disturbance

	Scenario 1	Scenario 2	Scenario 3
Track blocking	8	5	6
Switch failure	4	3	3

Cost efficiency evaluation

For being able to do the cost efficiency evaluation all relevant information has been exported from the RailSys® simulation into the Cost-Benefit Tool which has been developed at the Institute of Transportation Systems via the tool link (see chapter 2.2). The information exported from RailSys® is:

- Number and kind of track equipment
- Track length
- Operation time
- Timetable with number of trains and train stops
- Delay minutes

As shown in Figure 2 the relevant cost positions in the utilisation phase are

- operation costs and
- maintenance costs.

The *operation costs* are the *product of operation time, number of needed staff and the cost rate for a man-hour*. For an infrastructure manager the labour costs are mainly caused by the staff needed for running the interlockings or for the train dispatcher (see scenario 3). The 8 electronic interlockings in scenario 2 will be run by one person sitting in a control centre. Accordant to the interlockings used in the operation scenarios (see Table 1) the following labour costs (Table 4) are generated in one year.

Table 4: Operation costs for one year of operation

	Scenario 1	Scenario 2	Scenario 3
Operation costs	2.993.446,1 €	898.033,8 €	898.033,8 €

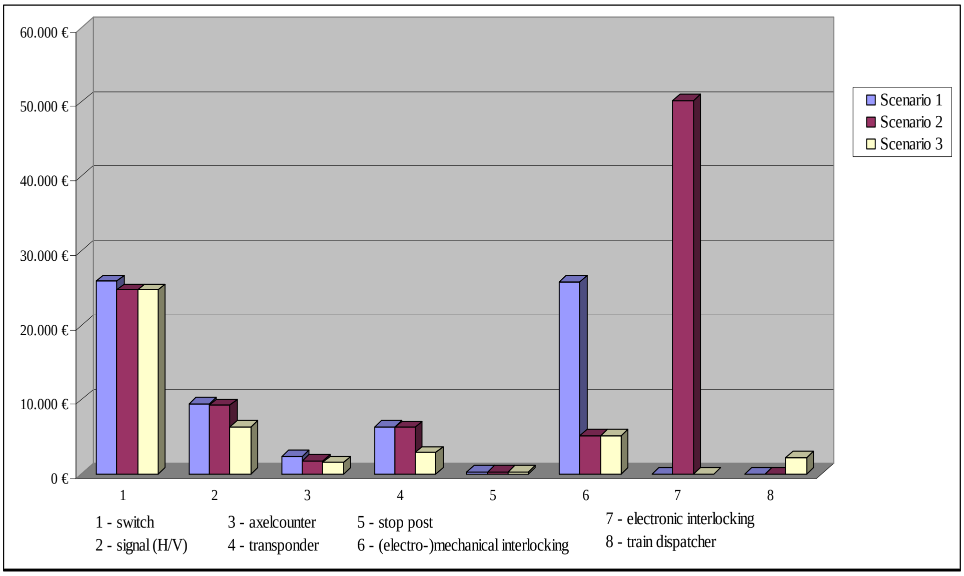
The *maintenance costs* are the second cost position in the utilisation phase. They are mainly caused by labour costs. In addition there are material costs. Within the made examinations the costs for *corrective maintenance* have been calculated with 10% of the overall maintenance costs since detailed failure data (Mean Time To Repair (MTTR), Mean Time Between Failure (MTBF)) about the components was not available and 10% also seems to be a realistic figure as discussions with persons in charge show. For calculating the costs for *preventive maintenance* the controller needs to know the *maintenance intervals, the time and staff needed for the maintenance work and the cost rate for a man-hour*. Since scheduled maintenance (preventive) is done when there are no trains running (generally at night) downtime costs are normally not generated (see disturbance scenario 1). Besides the signalling system components the track itself is also part of the maintenance cost evaluation. This is needed because of the change in track length in scenario 2 and 3 (see Table 1). The following maintenance costs which mature after the interval indicated were calculated with the Cost-Benefit Tool (Table 5).

Table 5: Costs for preventive and corrective maintenance

	Interval [Year]	Scenario 1	Scenario 2	Scenario 3
Track preventive maintenance	4	5.073.920 €	5.031.920 €	5.031.920 €
Track corrective maintenance	4	563.768,9 €	559.102,2 €	559.102,2 €
Operation control system preventive maintenance	1	70.336 €	97.866 €	43.225 €
Operation control system corrective maintenance	1	7.815,1 €	10.874 €	4.802,8

Figure 5 shows the detailed preventive maintenance costs for each control system component per year and operation scenario. It shows where the saving potentials lie. Especially in scenario 3 there is a high saving potential because of the use of a train dispatcher and therefore the abandonment of interlockings and less signalling components because of the use of trailable one way switches. In this study it is assumed that the maintenance work for trailable one way switches is the same as for normal switches. It becomes also clearly that switches are a major cost driver. They represent more than 25% of the maintenance costs for the railway operation control system in all 3 evaluated operation scenarios.
As preventive maintenance intervals for the signalling components are the ones used by the DB Netz (see DB guideline 892) implemented in the Cost-Benefit Tool. The interval of four years between track maintenance works was taken from [5].

Fig. 5: Preventive Maintenance costs per year and operation scenario



Because of a fix timetable there is no direct change in revenues out of track access charges paid by the train operators. But there is a difference in system quality which each operating procedure provides. This has an indirect impact on the revenue side which an infrastructure manager can generate with the track section. Delay minutes will reduce the revenue position because of fines which have to be paid by the IM to the train operator. 15€/min is seen as a realistic figure for delays on secondary lines. [9] [5] With the simulated delay minutes the costs shown in Table 6 are caused during one year of operation. They have been calculated under the assumption that 90% of all trains are on time (figure which is mostly achieved or even outperformed by the DB Regio). It is then further assumed that 25% of primary delays are caused by failures of infrastructure elements (disturbance scenario 2) and 25% by maintenance or construction work (disturbance scenario 1) [1]. In addition Table 7 shows the revenues out of track access charges which are constant for all three operating procedures since the run timetable and therefore the number of sold traces are constant.

Table 6: Fines because of delay minutes in one year

	Scenario 1	Scenario 2	Scenario 3
Fines because of train delays	97.762,97 €	76.066 €	84.782,66 €

Table 7: Revenues through track access charges in one year of operation

	Kilometres of sold traces	Revenues
Passenger trains	1.201.616,5 km	3.489.494,30 €
Freight trains	90.009 km	158.415,80 €
Total	1.291.625,5 km	3.647.910,20 €

The overall result of the three scenarios which have been simulated with RailSys® and then evaluated with the Cost-Benefit-Tool is expressed in the NPV figure for each scenario,

- a 20 years period and
- a discount rate of 8 %.

According to formula 1 the following NPV figures have been calculated (Table 8).

Table 8: NPV of the operating procedures and 20 years of operation

	Scenario 1	Scenario 2	Scenario 3
NPV operation costs	29.390.093,85 €	8.817.027,86 €	8.817.027,86 €
NPV Track maintenance costs	12.283.685,3€	12.182.004,8 €	12.182.004,8 €
NPV Operation control system maintenance costs	767.299 €	1.067.625,3 €	471.544 €
NPV revenues	35.815.718,6 €	35.815.718,6 €	35.815.718,6 €
NPV delay fines	959.851,21 €	746.827,17 €	832.408,58 €
Total NPV	**-7.585.210,76 €**	**13.002.233,47 €**	**13.512.733,36 €**

With scenario 2 and 3 the total NPV which is in the red for the current situation (scenario 1) becomes positive. This means that with operation procedure 2 or 3 the infrastructure company could economically independently act on the transport market and because of a NPV of around 13 million euros there would be no need for subsidies.
Most cost savings can be generated by scenario 2 and 3 because of significantly less costs for operation. With the electronic interlocking or the train dispatcher only 30% of the operation costs with mechanical interlockings are needed. This can be realised because of a reduced number of manned electromechanical or mechanical interlockings and therefore less staff which the IM has to pay for. Because of almost the same track length there are little cost savings on the track side possible. There are cost savings of 13% (scenario 3) to 22% (scenario 2) because of fewer delays. Since only 50% of possible causes for delays have been simulated and evaluated the effect on cost savings because of less delay fines is even higher considering the other 50% of possible disturbance scenarios. All together both scenario 2 and 3 are much better than the current situation expressed in scenario 1. Sce-

nario 3 is better than scenario 1 in every cost position. By an exclusive regard of the utilisation phase there would be no doubt about that the current situation is inefficient and has to be replaced by another signalling system layout.

4. Conclusions and Perspectives

Since neither installation nor deconstruction costs have been considered in this paper the results presented do not mirror reality. Therefore these aspects have to be part of upcoming examinations. Thereby the figures calculated with the Cost-Benefit Tool indicate whether additional costs in the beginning caused by the erection of a new system will be amortised during a 20 years period. So far only directly measurable revenue positions have been included in the economic efficiency evaluation. Next step will be the inclusion of indirect benefit factors such as security and availability. In this regard it has to be checked if these qualitative benefit factors can be expressed in figures or if a combination of quantitative numbers and qualitative expressions such as proposed by the extended profitability analysis [11] is necessary.

As soon as all cost and revenue positions in a product or system life cycle are included the figures given by the Cost-Benefit Tool with its link to the simulation software RailSys® have a high practical relevance. To show that the life cycle cost and benefit approach is of particular importance for the railway system was one intention of this paper. Secondly the authors wanted to show how comfortable economic efficiency evaluations can be done with the developed concept of combining operation studies with economical studies. Technical ideas of how railway operation can be made more attractive for potential customers can be easily evaluated. As a result of a consequential use of this concept, only systems with a positive economical impact will be installed. The concept shows one way of how an increase of the railway modal split can be achieved in the long run.

Besides pure evaluations of given figures also sensitivity analysis [8] are expedient. For example this can be maintenance optimisation consideration with the assumption of different maintenance strategies. It is also conceivable to do examinations with a fix infrastructure instead of, as presented in this paper, with a fix timetable. So the most cost-efficient timetable which fulfils the demand on transportation while having the least impact on the fix infrastructure and operation costs can be determined.

The aim of the integrated tool link is to minimise work when performing an economic efficiency evaluation for railway network sections and their operation. Time consuming recurring data entries are no longer needed. In addition, meaningful and close-to-practice results are generated as soon as the information implemented in the simulation software is accurate. Long term investment decisions are made on a profound basis which can easily be understood by all decision-makers with different background. Comparative studies of different investment opportunities can be conducted for an optimised investment strategy. The cost and benefit structure becomes transparent. The linking to the simulation software RailSys® ensures a realistic data base. Because of its integrated link the presented idea differs from existing LCC evaluation tools. With its global view on time and system structure it is describing the system behaviour as a whole rather than serving for detailed analysis of smaller units and components over their life-time.

Generally speaking, the Cost-Benefit Tool can be used for different tasks. Different applications are conceivable, for example the tool can also be used as a systematic cost-benefit control tool instead of as a decision support tool. Thus it is a support system in modelling, optimising and controlling processes and investment decisions.

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