



ANALYSIS OF DIFFERENT TRACTION SYSTEMS FOR THE ZILLERTALBAHN

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Abstract

The narrow gauge line from Jenbach to Mayrhofen in Austria is still operated by diesel units which are close to the end of their life cycle. New trains shall realize the opportunity of decarbonized services. Therefore, various opportunities of traction and power supply have been investigated and it is a vital example based on several former studies, how the synchronous consideration of vehicles, infrastructure and operation acts gamechanging in aspects of time and costs. The scope of possible solutions is much larger than electrification of the entire infrastructure or hydrogen and battery vehicles only. In this paper a comparison of all investigated solutions is presented with their technical, commercial and time key factors. Their operational performance has been simulated by software OpenTrack to compare running times and traction energy consumption to influence the overall analysis as well as to confirm the required travel time performance of the local mobility plan (minus 18 percent) and to predicted differential life cycle costs. All these results will influence the final authority's system decision.

Keywords: electrification, hybridtraction, hydrogen, Zillertalbahn

1 Introduction

Actually the operation of this railway line is done by loco hauled trains of up to 3 cars, by diesel multiple units DMUSs of three and four car units and - since 2021 again - by loco hauled freight trains, mainly for wood and log transportation to a huge sawmill in approx. 13km distance to the connecting mainline station in Jenbach. During summer on Tuesday till Thursday a nostalgic steam train is operated since more than 30 years, which is a remarkable factor in local tourist industry.

1.1 The route

The route from Jenbach to Mayrhofen is 31.7km long. It is mainly single tracked, but two double track sections of approximately 4km length each has been introduced within the last years. A third one shall be added in 2025. This leads to a higher grade on schedule stability in case of delays on the mainline Vienna – Salzburg – Innsbruck – Zurich.

The line has only gentle gradients, the final destination Mayrhofen is located 97m higher than Jenbach. There is a high number of stations and train-stops, some of them as stop-on-demand, totally 19. Average distance between two stop is 1,76 km, so we can handle it a stop-and-go operation of local mass transit operation.

1.2 The operation and train schedule

Actually the railway operates from 5:45 a.m. to 9:00 p.m. mainly on a periodic 30 min-tact schedule. The travel time is around 51 min in each direction, therefore 4 train sets are required, 5 in operation and a sixth as reserve. The maximum speed is 70 km/h [1]. End of 2024 the operation hours may be extended to 12 p.m., which will cause higher demand in train driver and fuels, but not influence the rolling stock. Former plans (in 2014) to install a 15 min-tact has not been realized because on lack of rolling stock and infrastructure issues (missing crossing station).



Figure 1 Today's ZillertalBahn trains, driven by diesel engines, © ZVB [1]

A new mobility plan, called "Zillertaler Mobilitätsplan" shall be introduced as quick as possible, at least in five years. Therefore the travel time is shortened to 45 min, the top speed raised to 80 km/h (with the option to 100 km/h), bus lines shall be used as feeder lines and several stations shall be re-organized. Because of the age and the technical features of the existing rolling stock, an entire new fleet must be acquired. And this new fleet shall be decarbonised.

1.3 The Future as planned

Because of the gauge of only 760mm no train-sets are available on the market. A brand-new design of trains is required. In 2017 a decision was made, to propel these trains by hydrogen, because of cheap local electric energy during night time, which can be stored as liquid hydrogen. Because of the touristic aspects the people don't appreciate a classical overhead catenary for electric train operation. A lot of synergies with other mobility operators were pushed forward. Offers have been obtained, everything seems on line, but nothing happened. In 2023 a public discussion started about the additional costs for the hydrogen operation (see also [2]) and a scientific study was requested to compare former studies and nowadays opportunities.

2 Scenarios

Six scenarios have been considered as standardized use-cases, based on [3-7]:

0. DEMU new diesel trains (as reference)
1. EMU electric trains – with continuous overhead catenary
2. HEMU hydrogen train – as proposed
3. BEMU battery trains – with charging an one end of line
4. BEMU-hy battery-hybrid trains – with few local catenary sections
5. BEMU-hy-opt battery-hybrid opt. trains – with high level batteries and more short catenary sections

There was no doubt about the fact, that the electro-motoric drives are the best choice. But there is an ongoing discussion, where the electric power shall come from and “which part of the power station” shall be installed inside the train and which part stationary outside the train – which requires either battery packs or hydrogen tanks and a fuel cell pack or local energy transmission to the train by local overhead catenary or a combination of them. Main technical differences are the total mass of the train, the number of remaining seats (means: the capacity), maybe the acceleration rates, the time loss for charging or taking fuel, but also the total costs, the time till availability and the costs of adapted infrastructure.

Table 1 Key parameter of simulated cases

Scenario	DEMU	EMU	HEMU	BEMU	BEMU-hy	BEMU- hy-opt
# cars	4	3*	4	3*	3*	3*
length [m]	68.5	57.8 76.4*	76.4	56 75.5*	56 75.5*	56 75.5*
capacity [seat]	323	303 413*	373	278 392*	278 392*	278 392*
weight [t]	151,4	118,4	164	121,2	122,2	120,3
adhesion weight [t]	58.0	88.0	90.4	86.0	87.0	85,1
speed [km/h]	80	100	100	100	100	100
power/wheel [kW]	500	1400	1400	1400	1400	1400
battery capacity[kWh]	-	-	310	650	325	264
deceleration [m/s ²]	0.8	1.0	1.0	1.0	1.0	1.0
acceleration [m/s ²]	0.65	1.0	1.0	1.0	1.0	1.0

3 Functionality of software OpenTrack

OpenTrack is a microscopic synchronous railroad simulation model. As such it simulates the behaviour of all railway elements (infrastructure network, rolling stock, and timetable) as well as all the processes between them. It can be easily used for many different types of projects including testing the stability of a new timetable, evaluating the benefits of different long-term infrastructure improvement programs, and analyzing the impacts of different rolling stock [8]. Figure 2 illustrates the three main elements of OpenTrack: data input, simulation, and output.

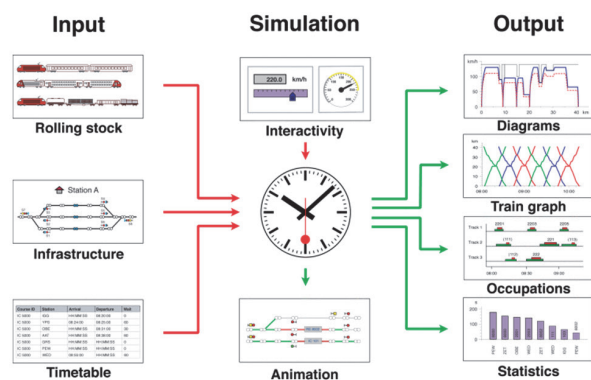


Figure 2 Data flow in a simulation project

For all six scenarios mentioned in section 2 of this paper software OpenTrack was applied to simulate running times and calculate thereby traction energy consumption. The infrastructure model represents the actual state of track speed limits including double track sections and crossing stations. For the simulation of running times only no timetable is required.

4 Results

4.1 Calculations

The calculations of running dynamics and energy consumption has been done in an open-track-environment and also in parallel in a self-made tool, which has been calibrated in former projects. Open-track is calculating the dynamic travel time, considering the infrastructure and train parameter in detail, but it is limited to the energy for traction only on the point of wheel-rail-contact. Recuperation and auxiliary energy consumption is not considered, but this helps for a comparative analysis of the six scenarios. Additional need of specific drives systems like the chiller for battery packs and fuels cells are part of the auxiliary consumers, but the various grades of efficiency are considered.

Table 2 Calculated travel times and traction energy for all cases

Scenario	DEMU	EMU	HEMU	BEMU	BEMU-hy	BEMU- hy-opt
Mayrhofen – Jenbach	50:17	45:33	45:56	45:48	45:34	45:34
Jenbach – Mayrhofen	51:06	45:17	45:47	45:29	45:19	45:19
energy Ma-Je [MJ]	657	620	796	633	634	625
energy Ma-Je [MJ]	835	785	1004	796	801	793
return, on wheel [kWh]	414.4	390.3	500.0	397.0	398.6	793.0
efficiency [%]	45	95	27	89	91	93
costs/year 38x365 [k€]	1565	854	3855	929	912	881
Seats [#]	179	187	2196	187	187	187
costs/seat [k€]	8.74	4.57	19.67	4.97	4.88	4.71
Δ costs/year [k€]	+711	0	+3001	+75	+58	+43

The figures are examples, but not the final last version. Further tables show a deviation of the internal costs of hydrogen for Sz2 HEMU in case of local production and a special contract to promote this technology.

Further calculations have been done for a higher degree in flexibility of the daily operation on working days, but also in a long term evaluation.

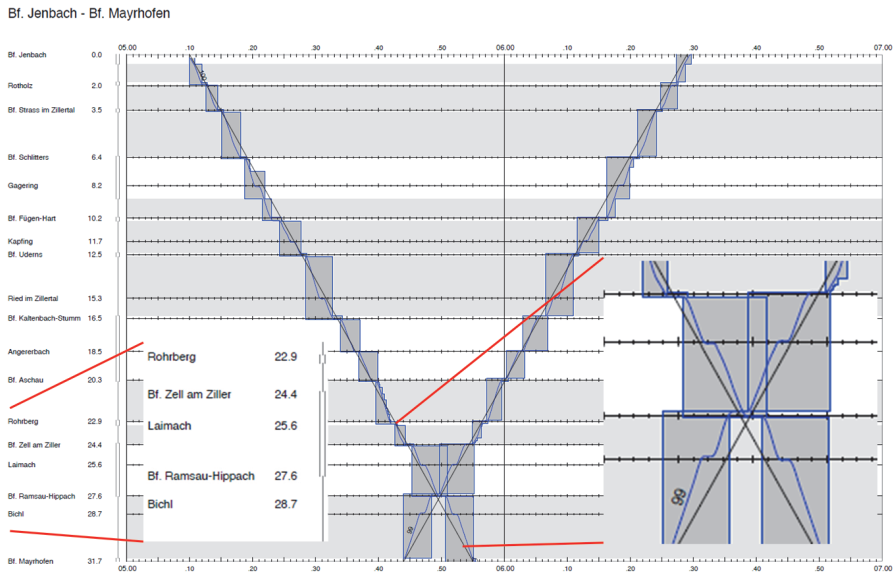


Figure 3 Typical running diagram of a battery-hybrid trainset [1]

4.2 Criteria of assessment

The calculation of the running dynamics of the various train concepts are the base for acceptance. The time schedule is a must have criteria. The traction energy consumption is one indicator of the costs of operation. In this study there are only differential costs considered regarding the uses-cases, but no full costs. Only the effects by different energy supply systems and their different efficient degrees are calculated, not costs for driver, conventional maintenance or cleaning. They are independent on the various train concepts. The main criteria focused on based on [4] and [9] were:

- Invest for rolling stock
- Maintenance of rolling stock
- Invest for infrastructure
- Maintenance of infrastructure
- Costs of Operation

These costs of operation are split in four main groups [1, 4]:

- Prime energy costs
- CO₂-special tax (or equivalent measures)
- Periodically exchange of concept specific components (battery packs, fuel cells, etc.)
- Risk premium by suppliers

The traction energy (and also the specific auxiliary components of traction system) is put into the first bullet – “prime energy costs”. They are an important factor for 30 years of operation, influencing the costs per train-km and therefore the marginal costs for train services at a time with low demand.

The three main assessment criteria in decreasing importance are [11]:

1. Differential costs of operation (in €/train-km),
 2. Differential total costs (in €/train-km),
 3. Differential total costs (in €ct/seat-km),
- whereby the last assessment criteria takes in account the different consumption of space for energy equipment inside the passengers cabinet.

The parameters of this calculation model are subject to sensitivity analysis and average values of these cases form the base of a final ranking, Table 3. EMU is the most efficient concept, followed by BEMU-hybrid concepts.

Table 3 Sample for differential costs as result of the sensitivity analysis in accordance to the assessment criteria 1 [8]

diff. costs of operation [€/train-km]	DEMU	EMU	HEMU	BEMU	BEMU-hy	BEMU-hy-opt
Reference point	2.49	1.09	6.94	1.88	1.43	1.30
Catenary invest (50%)	2.49	1.09	6.94	1.88	1.43	1.30
Primary energy (200%)	2.49	2.17	11.49	3.26	2.70	2.47
Double traction	2.50	1.09	7.09	2.21	1.55	1.41
15 min-tact	2.49	1.09	6.32	1.96	1.47	1.34
H ₂ -special price	2.49	1.09	3.78	1.88	1.43	1.30
60 years view	2.50	1.09	6.94	1.88	1.43	1.30
average	2.49	1.17	7.07	2.13	1.64	1.49
	214%	<u>100%</u>	606%	183%	140%	128%

5 Conclusions

The overall result highlights the fully electrical operation under the dedicated specific schedule condition as the best one. But non-figured parameters as the time of realization cause the situation, that the best solution cannot be implemented immediately.

Under these additional criteria the best solution is one of the battery-hybrid scenarios Sz4 and Sz5, based on the investments and maintenances costs, calculated of 30 and 60 years and the low operations costs per train-km.

The big benefit is the availability of the higher speed and shorter travel time for the passengers. This can be achieved as soon as only few short sections of overhead catenary are installed. Sz5 suggests four sections, Sz4 only two. The gaps in-between are operated by smaller and more agile battery packs (see [6]).

In case, the operation shall be made more dense to a 15 min-tact in future, the costs of operation in €/train-km becomes more and more significant. At any time the gaps of the catenary can be filled without any loss of investment to come closer to the overall best scenario.

The final decision about the locality of the short catenary sections and the type of battery cells shall be done in a second step after the basic decision by government has been done, which system to realize.

Optimization focused either only on rolling stock or only on infrastructure will lead to other results than focussing on both entities at once [2, 10, 11]. The best solution in costs, time, sustainability and operating flexibility for this railway line contains both: battery-hybrid trains and short section of overhead catenary [1].

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