CETRA2020* 20-21 May 2021, Zagreb, Croatia
6th International Conferenceon Road and Rail Infrastructure

HIGHER AUTOMATION - METHODS TO INCREASE ENERGY EFFICIENCY IN RAILWAY OPERATION

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Abstract

Automation is already present in many areas of the railway sector (e.g. computer-aided dispatching or electronic interlockings). In order to achieve climate goals and offer an attractive transport service, it is essential to advance automation and higher grades of automation (GoA). The four levels of automation range from supporting systems (GoA1) to automotive trains (GoA4). This paper summarises a study which outlines the impacts, requirements and potentials of higher GoA within different segments: passenger transport, freight and mixed traffic on mainlines and branch lines. The findings show that energy-efficiency and capacity can already be increased with the first two GoA for both, passenger and mixed traffic. Enhancements have an influence on costs, not to mention the customer satisfaction. The potential in freight transport, e.g. in shunting, can be exploited with intelligent freight trains (GoA4). This leads to improved safety and reduced costs. Within this study a tool to calculate energy consumption is established. It enables the depiction of various scenarios for different trains and driving behaviours. The simulation tool is validated by real measured data. The outcome of the calculation tool underpins the benefits of driver advisory systems (DAS) and automatic train operation (ATO). It can be stated that higher automation, especially on a dispositive level is essential if energy and capacity improvement are to be achieved, regardless of the type of network (electrified or non-electrified). However, operational optimisation has its limits. For non-electrified lines, alternative drives offer the opportunity to further mitigate environmental impacts.

Keywords: automatic train operation, energy efficiency, alternative drives, sustainable railways

1 Introduction

European passenger transport has been constantly increasing for the last decade [1]. By contrast, rail freight is stagnating and has come under pressure due to increasing road freight traffic [1]. To achieve climate goals, remain attractive and competitive, the railway sector needs to focus on a higher capacity throughput, cost reduction and also without a doubt on environmental sustainability. Thus, it is essential to systematically apply higher grades of automation (GoA). Moreover, the implementation of alternative propulsion technologies (considering the significant amount of diesel-powered rolling stock worldwide) can help to further reduce the environmental impact and increase energy-efficiency in railway operation. The aim of this paper is to sharpen our understanding of higher automation in railway operation. It investigates legal, operational and technical requirements and analyses the potentials of higher automation within different systems (cf. Section 2). The importance and

DOI: https://doi.org/10.5592/CO/CETRA.2020.1159

potentials of energy efficient solutions is mirrored by the results of a calculation tool for energy consumption. The paper presents various scenarios for different trains and driving behaviour in Section 3 and gives an insight into alternative propulsion technology in railway operation (cf. Section 4).

2 Higher automation levels in railway operation

2.1 Definition and status quo of higher automation

According to UITP [2] higher automation in railway operation is classified according to four grades of automation (GoA). ATP (automatic train protection) together with DAS (driver advisory systems) are classified as GoA1 and are state-of-theart in railways. ATP is widely used, especially in cases of higher top speeds, and it ensures basic safety (e.g. braking in the event of an emergency). DAS provides the driver with a speed profile in order to arrive on time or to save energy. Automatic train operation (ATO) is considered a subsystem with different functions depending on the GoA and must be combined with ATP to ensure safety. GoA2 combines ATP and ATO, where ATO executes traction and brake commands. Much effort is currently put in field trials for GoA2, albeit existing examples of GoA2 can also be found, such as the Thameslink project in London [3]. In GoA3 the train runs automatically, whereas there is still a train attendant on board to respond in case of a disruptive event. GoA4 corresponds to fully automatically run vehicles without a human railway employee on board. Until now GoA4 has only been applied in urban metro lines, with the exception of Rio Tinto heavy haul freight trains in Australia [4].

2.2 Requirements for higher grades of automation

Railways can be divided into three basic components: infrastructure, vehicle and operation. Norms, rules and regulations ensure secure interaction. It follows that higher automation not only requires a legal and normative framework (safety, security, certification etc.) but also has operational and technical boundary conditions (e.g. specific trackside and trainborne equipment). Since ATP is a safety requirement of GoA2 and to ensure interoperability, many institutions and suppliers support the idea of ATO over ETCS. Efforts are currently being made to incorporate new specifications for GoA1 and 2 in the TSI [5]. Furthermore, adaptions in national legislation, liability issues (of trial runs), certification issues and harmonised authorization processes all need to be considered and solved. To ensure the safe guidance of a train a continuous ATP must be implemented and continuous information, usually known to the driver, needs to be submitted to the ATO. In Europe ETCS Level 2 is regarded as the basis for ATO. However, the current infrastructure and slow migration process of ETCS makes the use of a harmonised, sophisticated ATP unrealistic. ATP solutions based on satellites should thus be examined together with migration concepts in case of ATP other than ETCS [6]. In order to increase energy efficiency and punctuality ATO must be combined with DAS providing an optimised speed profile for one train. To optimise train movements throughout an entire network, ATO must be connected to a cross-network traffic management system (TMS). This implies adapting trajectories continuously to the current traffic to avoid unnecessary stops, reactionary delays or conflicts. One approach is known as dynamic capacity optimisation: it is based on an automatically computed timetable in real-time combined with ATO and can reduce headways (90-100 sec.) [7]. Technical equipment at wayside and trainborne level will need to be adjusted depending on the GoA. As of GoA3, the train must take over the driver's visual functions. For wayside obstacle detection, solutions stem from drone-based cameras to fibre optic sensing [8]. The installation of laser or radar sensors combined with image processing at level crossings or fences at platforms are conceivable solutions [9]. As for onboard obstacle detection the combined installation of radar, infrared, laser or cameras is suggested because of different characteristics in reach and also dependence on the weather [10].

2.3 Benefits of higher grades of automation

Different systems can benefit from increasing automation according to their boundary conditions. Capacity problems are particularly prevalent in passenger transport, especially on mainlines. Solutions as of GoA2 in connection with TMS show great potential in passenger transport and mixed traffic for coping with peak demand in hubs [7]. The need for additional infrastructure (as of GoA3) could therefore be replaced by means of a dispositive level. Comfort can already be achieved as of GoA2, since ATO can balance e.g. aggressive styles of driving. The use of TMS reduces waiting time, increases reliability and punctuality, which has added value for both, freight and passenger transport. In a first step this can already be achieved to a certain degree with DAS. Introducing TMS plus fully automatically run vehicles on branch lines could bring about a cost-effective and demand-based transport service [11]. There is a common understanding that safety increases by taking out the human factor. However, as of GoA3, risks caused by new tech-nologies in terms of cyber security, failures of providers, manufacturers or systems must all in sum be of a lesser character than the human-risk factor. Recently developed “intelligent” vehicles (equipped with a centre buffer coupling and able to perform an automatic brake test) could replace the remaining manual work of coupling processes [12]. Safety in shunting could thus be increased, in particular in the context of the high risk of accidents in this area. A useful way to save energy is to exploit the acceleration, cruising, coasting and braking phase in a more energy efficient manner. In order to show the potential of energy savings due to different driving behaviour and scenarios, a calculation tool was established (refer to Section 3). Energy efficient driving could reduce energy costs by 10 % on average for one train in one year [13]. This could in particular increase the competitiveness of freight traffic. While cost cuts by replacing drivers is a double-sided issue, the economic benefit in shunting is certain (decrease in manual labour) [11].

3 Energy consumption simulation tool

The original calculation tool used in this study (developed in Microsoft Excel by Messner [14], elaborated by [11]) was further improved. Energy consumption can be computed for different driving behaviours and scenarios for various types of rolling stock. The model is based on the total train resistance which occurs in the course of a train journey on a random route and can be expressed in energy needed for that section (cf. Fig. 1). Energy consumed by auxiliary functions is also considered. In order to validate the simulation tool, energy consumption of specific trains and scenarios is compared to real measured data (average deviation of 7 %).

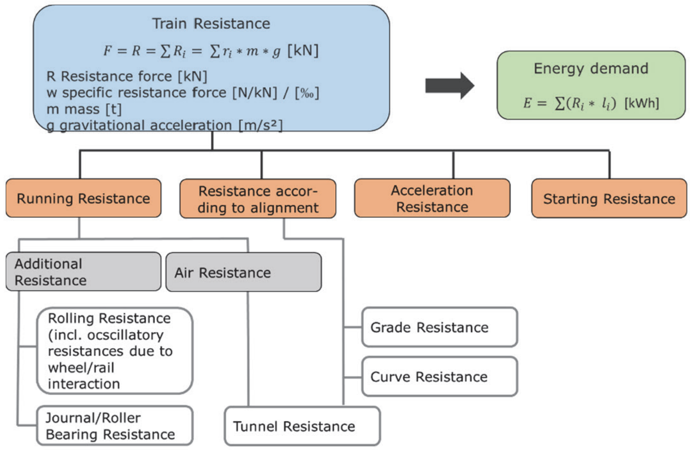

Figure 1 Mathematical model to calculate energy consumption based on [14]

3.1 Results of different driving scenarios for passenger and freight trains

Different driving scenarios and behaviours are computed for a section on an Austrian main-line (approx. 50 km) considering five train types: a long-distance, a regional, a suburban, a light and a heavy (5 and 22 tonnes axle load) freight train. Due to a homogeneous topography (gentle incline) in the chosen section energy recovery remains unconsidered. Fig. 2 and Fig. 3 depict an excerpt of the results.

Case 1 (maximum top speed) demonstrates a tight speed profile which might counteract a reactionary delay, in the event of accumulated delays originating from the point of departure. Stopping points are chosen according to the train type (e.g. the fact that freight trains are often being put aside in railway operation to ensure capacity throughput of passenger transport is also taken into account). Case 2 (no stops) eliminates the stops along the route. Although non-realistic, it serves as a pure comparison between the different train types. Apart from minor differences (e.g. other possible speed limits due to vehicle characteristics), they share the same conditions (i.e. no stops along the route). Case 3 (top speed reduction) shows energy efficient driving for passenger trains by limiting the top speed and yet arriving on time. Buffer time (10 % for long-distance and 5 % for the other two passenger trains) is not reduced. Stopping points are the same as in case 1.

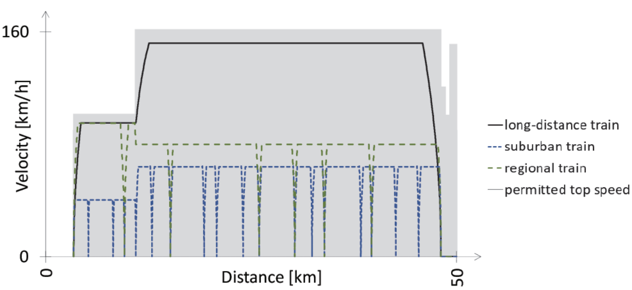

Figure 2 Path-time diagram for passenger trains case 3 (top speed reduction)

The ratio of the train resistances (see Fig. 3) shows that most of the energy con-sumed is related to acceleration resistance. A significant top speed reduction can save up to around 50 % of energy compared to a tight speed profile. The decrease in energy consumption gen-

erates a 35 % higher running time which highlights that the degree of energy reduction is not wedded to the degree of increase in travel time. The results must be treated with caution to a certain extent, since in reality a train will not accelerate up to the permitted top speed every time before a stop. It can be assumed that the energy savings will be lower and correspond more fully to those that can be found in the literature, e.g. [15]. Furthermore, the energy efficient driving profiles only concern the optimisation of one train. It must be assured that the optimisation of one train does not affect other trains negatively. An appropriate TMS is therefore necessary to save energy on a network-wide level. Results of freight trains confirm the need of an improved traffic management. Around 35 % of energy could be saved on the investigated route without putting freight trains aside. Running resistance increases with higher velocities (derived from the fact that air resistance is part of running resistance) compared to other resistances. The long-distance train confirms this fact. Whilst the other two passenger trains have a lot of retardations due to stopping more often, the long-distance train remains in a cruising phase (with a constant, high velocity) for much longer. Train mass influences all resistance forces. The long-distance train is around three times heavier than the regional and suburban train. This is why resistance according to alignment and running resistance (apart from the air and oscillatory resistance which are both dependent on speed) are proportionally higher in the long-distance train. Case 2 highlights the influence of the train mass. The results also show that auxiliary functions consume one sixth of the total energy requirement implying the need for improvements in vehicle technology.
A detailed analysis was performed for long-distance trains. Additional use cases were added, namely a best-case scenario (with coasting phase) and a worst-case scenario (two unexpected stops). The results show the significantly lower energy consumption in the best-case scenario with maximum coasting. By contrast, twice the energy is required in the worst-case scenario (on the route studied). This underlines the effect of conflict management and energy-efficient speed profiles on the energy consumption.

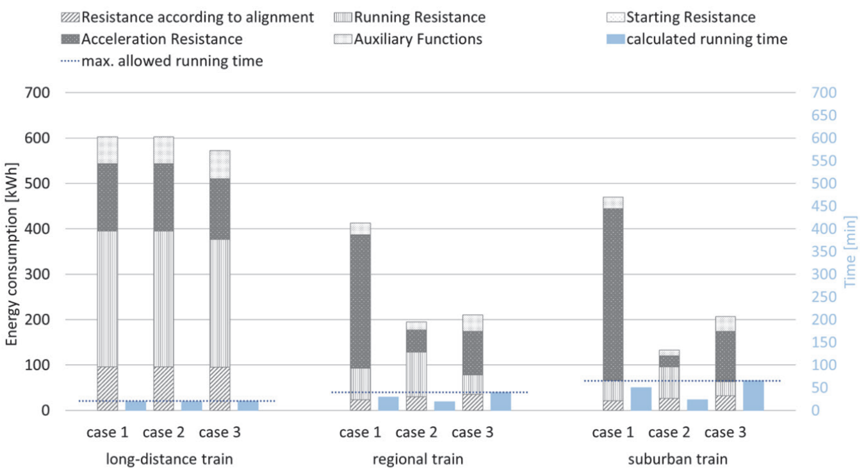

Figure 3 Energy consumption (due to train resistance and auxiliary functions) for different passenger trains and scenarios

4 Alternative drive solutions

It is commonly known that traveling by rail is more eco-friendly compared to other modes of transport. In Austria, a passenger train emits 7,7 grams of CO2 per passenger kilometre [16]. The European average is 28 gCO2/pkm [17]. Reasons for this comparatively low value are as follows: the Austrian Federal Railway (OeBB) network has a high electrification rate of 70 % [18] and OeBB uses 100 % green electricity for railway operation [19]. On the global scale, railway operation is not as sustainable as it is in Austria. More than 60 % of the world's railway network is not electrified [18] and around 70 % of the world's locomotive fleet operates on non-electrified lines [20]. Although higher automation and optimisation in railway operation allows for energy reduction, non-electrified lines need to focus on addi-tional solutions in order to cut emissions. Electrification is not always viable (n)or technically feasible. Thus, alternative drives are considered a sustainable solution, e.g. less direct emissions, less noise pollution and higher efficiency. This concerns segments which tend to be operated with diesel, like branch lines, shunting and freight corridors. Rail traffic on the American continent, in Africa and Australia still relies heavily on diesel traction, which are regions with relevant freight activities. Alternative propulsion technologies in railways are at an early stage of technology development. They currently account "for less than 2 % of all orders" [21]. Available technology, the lack of infrastructure (e.g. recharging, refuelling) and higher costs due to scalability are barriers for the market uptake of alternative drives. Experts expect a "stable market for the next 10-15 years" due to electrification projects, cleaner diesel technologies (considering stage V engine technology being offered on the market) and the lack of incentives in various countries [21]. However, emission targets in rail could change tender conditions in the future. Some European governments or railways have explicit decarbonisation strategies [21],[22],[23]. Most of these aim at the substitution of diesel traction within the next 15-20 years. On-going activities also show a trend towards alternative solutions in the aforementioned segments. The multiple unit segment proves to be the most mature segment for alternative drives. Battery electric multiple units or hydrogen fuel cell trains are currently being implemented and tested on branch lines, especially in Europe [21]. Gas-powered solutions (LNG, CNG) are under consideration and going through trials in North America [21] and in Eastern European countries, notably Russia [24]. It is noteworthy, that the environmental impact of battery and hydrogen applications depends on the electricity mix, the production process and end-of-life of their components. If used with green electricity, they are considered to have a high potential to mitigate environmental impacts for non-electrified lines.

5 Conclusion

The results of the calculation tool for different scenarios highlight the importance of energy efficient driving and conflict management. In reality, DAS (GoA1) can already achieve energy savings by providing energy efficient speed profiles. In a next step, speed profiles could be executed by ATO in GoA2 more precisely. ATO in combination with a traffic management system could prevent conflicts on a network-wide level. Energy savings, along with capacity improvement, increased punctuality and cost-effective offers bring added value to the customer and boost the railway sector. In cases of passenger and mixed traffic operations, energy savings and capacity increases can already be achieved with GoA1 and 2. Nevertheless, technical requirements (e.g. continuous signalling systems, obstacle detection) as well as the lack of regulations and standards are possible barriers for higher automation. Furthermore, there are limits to operational optimisation. Addi-tional measures are required for reducing environmental impacts. This involves improved vehicle technology to reduce energy consumption of auxiliary functions or the introduction of alternative propulsion technologies on non-electrified lines.

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