Answer to Reviewers (Sustainability)

Paper id: Sustainability, 2141400

TITLE: Management of Railway Power System Peaks with Demand-Side Resources: An Application to Periodic Timetables

Cartagena, January 15, 2023

Dear Editors,

Authors thank you and the reviewers for the time dedicated to analyse our paper and for their useful suggestions according to which modifications and additions have been included in the revised version of the paper. A color copy (document sustainability_railways_2002_COLORED.pdf), in which the modifications and the new text have been market with background in yellow (answer to reviewers) or in green (typos, grammar, punctuation...) is enclosed, including the modified version of the paper without marks or background.

Here, we provide responses to the Reviewers' comments, suggestions and mandatory changes. For the sake of clarity, the specific Reviewers' comments appear underlined *and the answers, below in italic, with blue color.*

Also, the original text has been revisited for the improvement of English language and the correction of document editing errors. Authors apologize for some potential mistakes in the revisited version after this review.

COMMENTS FOR THE AUTHORS. Reviewer comments and answers

REVIEWER 2. Comments and Suggestions for Authors

1. The abstract needs to reduce general information but focus on the method and results. For example, the last sentence "which improves the social and economic benefits of railway transportation on the overall energy and environmental objectives for 2050." Some data needs to be used to support the benefits.

On behalf of authors, we thank you very much for the comments about our manuscript. Those comments are all valuable and very helpful for revising and improving the original version of our manuscript

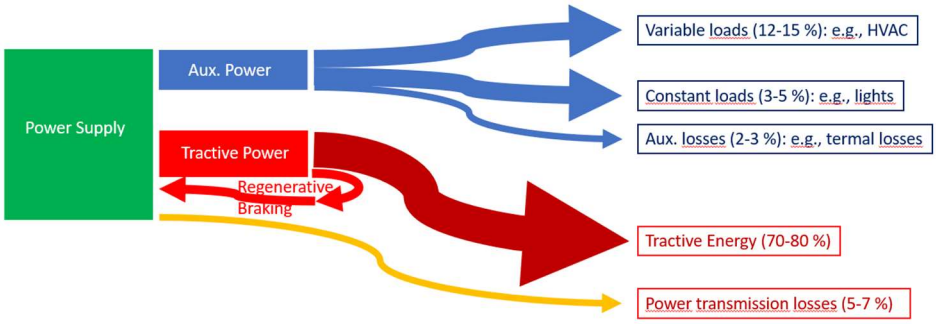
Thanks for this remark. Authors agree with the reviewer. We did not consider the description of main figures from our simulations in the abstract, for this reason we have rewritten the abstract and shortened some of the general information. In this way, we have revisited the abstract and it is more focused on the methodology and main results than in general information. The abstract has been changed to a new version:

> The objective of this paper involves the analysis of opportunities for the management of Railway Systems demand using Physical-Based models and aggregation tools well known in "conventional" Power Systems to develop and enlarge the portfolio of Distributed Energy Resources. This proposed framework would also enable the use of railway flexible resources to their use in Power Systems. The work considers trends for the development of railway transportation units through the adoption of technologies that increase the flexibility of railway units. For instance, we mean a set of resources such as on-board generation in dual units, energy storage and generation in last mile units, and auxiliary loads. Their inherent flexibility can contribute to

increase the management possibilities of the overall net demand. The proposed scenario under study faces to some energy concerns of periodic timetables: fast and high-power peaks in demand unknown in conventional Power Systems. Simulation results present the achieved flexibility and its potential: a decrease in peak demand around 20% and the increase of energy recovery by 10%, lagging new investments in infrastructure. These results improve the social and economic benefits of railway transportation on the overall energy and environmental objectives while reduce energy concerns due to an increasing use of railways and boost the sustainability of the transportation system in next decades.

2. In figure 2, "Train losses (5-7%" it needs some clarifications about the train losses, are these losses due to system friction (mechanical losses?) or due to rolling resistance. It is noted that mechanical friction losses have already, to some extend, been considered in rolling resistance function.

Authors agree with your suggestion and some legend needs a further clarification and a correction. These losses represent losses in the distribution level of the Railway Power System (transformers, converters, feeders, overhead line…). We have revisited legends for a better understanding and to avoid some mistake. Figure 2 is now:



3. "These resistance forces can be examined in detail with different models [20, 21] but they are not the objective of this paper." It is understandable that rolling resistance is not the focus of the paper, however, it is key for energy calculations. It is noted that train starting resistance is significantly higher than the resistance formula Equation (3) as discussed in the paper "Hill-starting a heavy haul train with a 24-axle locomotive". Some discussions and acknowledge of the starting resistance can be useful. Meanwhile, curving resistance formula is also regarded as in accurate as discussed in "Curving resistance from wheel-rail interface" some discussions and acknowledgment is also useful.

Thanks for this relevant remark and for providing us these insights. Both papers are of interest, but we did not know this research (unfortunately, because our University has limited the license to Taylor&Francis journals). We have achieved access from other sources and thanks to some authors of these papers, and we are very grateful for this help. We have included these interesting references to enlarge and improve the development of the model for resistance forces:

Qing Wu, Bo Wang, Maksym Spiryagin & Colin Cole (2022) Curving resistance from wheel-rail interface, Vehicle System Dynamics, 60:3, 1018-1036, DOI: 10.1080/00423114.2020.1843689]

Qing Wu, Xiangjian Yang, and Xihong Jin, "Hill-starting a heavy haul train with a 24-axle locomotive". Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 2021 236:3, 201-211

Wu, Q., Spiryagin, M. & Cole, C. Train energy simulation with locomotive adhesion model. *Rail. Eng. Science* **28**, 75–84 (2020). https://doi.org/10.1007/s40534-020-00202-1

*With respect to starting resistance we did not include it in the model description (a too short description, and obviously an error), but it was included in simulations, according to the expression found in Kaller; Fa=7.5*10^{-3}mg; which is around 3-5 times (for the different EMUs being considered) the value of equation (3) for v=0; and 2.5-3.5 times the value for v=10 km/h. Also, we included the starting force for speeds between 0 and 15 km/h. With your appointment we have changed this value to 3 times the value in v= 10 km/h, lineal between 0 and 1 km/h and for the rest of speeds*

the value in v=10 km/h. But the changes in results are not significant because we have considered Fa and our main energy demand appears in the two acceleration periods to reach 70 and 100 km/h.

With respect to curving resistance, we have changed the equation, including the radio R of the curve for the sake of simplicity, and we have included the two expressions that is discussed in "Curving resistance from wheel-rail interface". For simulations we have not included curves because we have not accurate data of curves in this track section. New expressions are:

*Fc= 0.001*mg*198/R*

Also, we have acknowledged the abovementioned references and we foresee that they can be very important for future works. The new text is:

Curve resistance is found by means of empirical formulae. Some expressions in literature are different for different curve radius, but this has not much sense. New and interesting approximations and equations for this force can be found in [29]. For instance, and according to [29]:

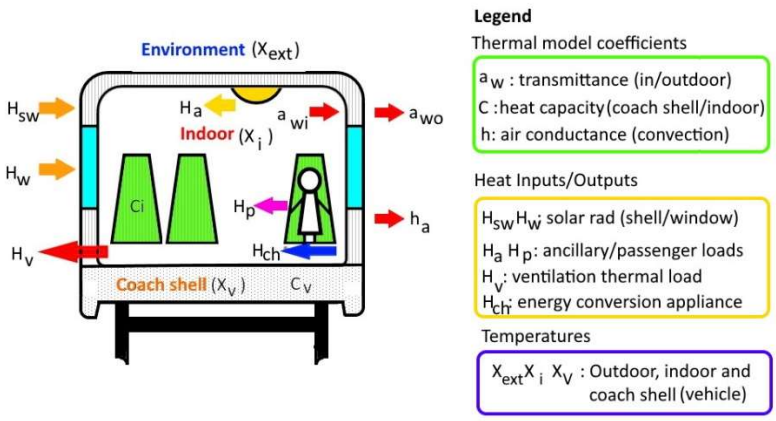
$$F_c = 0.001mg * 198/r_c \quad (5)$$

Where r_c is the curve radius.

With respect to starting force F_s, there have been very limited studies in this topic. An accurate approximation of the main interest for haulage is the approach proposed in reference [30], especially in freight trains. In this model, when the vehicle has zero speed the value of starting resistance is assumed three times the value for v=10 km/h in equation (3); when the speed is between v=1 and v=10 km/h equals the value of (3) in v=10 km/h. Finally, it linearly decreases between the values v= 0 and v=1 km/h.

4. Figure 8 a seems to be incomplete, please adjust the figure. Meanwhile, it is better to explain the notations used in this figure in the captions. Or replace the notations but text descriptions. Otherwise, it is inconvenient to read the figure. Also, Figure 8b probably not contributing a lot to the paper. You can mention that the couch studies is Talgo VI coaches, this is sufficient. Figure 8c also looks incomplete.

We have included in figure 8a the convection coefficient (ha). According to your suggestion, we have included a short legend in this figure to enhance the information and usefulness for the reader (from the point of view of thermal modelling). With respect to figure 8b, you are right. The initial reason was that Talgo coaches are not a standard class of coaches for main railways outside Spain (lack of bogies, length, height …) or Europe. Now, we have included the manufacturer web page as a reference for the reader. With respect to figure 8c, it is complete, for the second order model being considered (a simplified thermal model also used by the Vienna Arsenal Lab). We present the new figure 8a



5. In figure 9 a, measured data and simulated data have general agreement. However, there are some obvious differences near 35 min and after 45 min. explanations need to be added about the reasons behind the differences. One of the possible reason can be your air brake model, it seems your braking is shaper than the measured date. In realty air brake acts slowly due to pressurised air.

Thanks for this remark. We agree with you to the need of a more detailed explanation for this figure and the differences between real and simulated data. Of course, one of the reasons can be the model of pneumatic brake because dynamic braking was more familiar for us. We have considered that in many MU trains, with many powered axles thorough the unit, regenerative (or resistive) braking is usually sufficient for braking (and our model tries to brake first with this option, and it establishes braking distances with this premise above 20-30 km/h). Obviously, this is not right considering the behavior of train drivers). Another problem can be the pressure of air in this unit (the hybrid unit, which can change according to service mode. Note that it can reach 250 km/h at 25 kV). We will ask about this question in a next meeting with Patentes Talgo, in the future. Another problem (minute 30 to 40) is the poor maintenance of the infrastructure because the Spanish Railway policy is to develop high-speed tracks (a big infrastructure in km in comparison with "large gauge" lines, 1667 mm). In this section of the track (a trenched stretch) there are many problems in the track with ballast and sub-ballast sections due to heavy rain episodes (very frequent in our county) and poor maintenance (lack of investments). This causes the regular use of temporary speed restrictions that change speed limits (unknown and variable) with respect to our database for this section. Finally, fourth TS is a junction station with double track but not "banalized" and this causes congestion when train is near this zone, and signals can force speeds under the maximum speed limit. Specifically, in this comparison the real unit was delayed about 3-4 minutes. We have changed the text:

This can be due to driver's behavior or due to some temporary speed restrictions in the stretch (the same problem arises in MT, a trenched track with problems in sub-ballast due to periodic heavy rain episodes). This is difficult to know "a priori". Also, the model fails in the acceleration before fourth TS, and in some braking periods and, specially, after 45 min. This can be due because this TS is a junction station and traffic increases near TS, and also because our braking model prioritizes dynamic braking (for energy targets) whereas the unit also uses air brake which acts slowly due to pressurized air.

References you have also proposed in comments 3&6 are very interesting to improve air brake models in our "in-home" models, specially, for freight trains. We are very grateful to you for this remark and the valuable information provided with those works. A future objective of our research is the valorization through OESS of refurbished freight and passenger diesel-electrical units (based on GM and Nohab designs, rebuilt on 2000-2006). They can represent an opportunity to increase freight in low traffic non-electrified lines, a transportation problem in Spain where railway freight is testimonial.

6. "increment of mass due to rotating inertia, a coefficient in the range [0, 0.30] depending on the type of vehicle. Usually in the range [0.06, 0.10] for a complete train." It is better to be more accurate about the parameter as presented by equation (1) and discussed in "Train braking simulation with wheel-rail adhesion model". This parameter would have significant influences on your results, for example 0.06 and 0.10 would give you 4% differences in your final results, this is considered to be quite obvious difference.

Thanks again for this remark. The problem is the same than in previous comments: a scarce and incomplete explanation of general equations of motion, we are very sorry for this lack, and some important mistakes you have found. For this parameter we have considered the values from the book by Prof. Allenbach and Prof. Kaller which help us in our first steps in this area, and some papers, we have found during the development of the simulation models. For instance, papers from Ogawa et al (Vehicle Control Technology Division, Railway Technical Research Institute, Japan). They report values for Japanese EMU commuter of 0.08 for motor and 0.06 for trailer units and we chose those as a reference for some units (S-Bahn services). For conventional trains (locomotive + coaches) we chose 0.22 and 0.06. For dual-units, some data from qualification tests developed by Patentes Talgo with S250 BHEMU.

Tomoyuki OGAWA, Shinichi MANABE, Gaku YOSHIKAWA, Yoichi IMAMURA, Masahisa KAGEYAMA, Method of Calculating Running Resistance by the Use of the Train Data Collection Device, Quarterly Report of RTRI, 2017, Volume 58, Issue 1, Pages 21-27, Released on J-STAGE March 09, 2017,

We have added some of this information in the description in the model and the paragraph has been rewritten and modified.

In this model, k is the increment of mass due to rotating inertia (Equivalent Rotational Mass) that ranges from 0 to 0.30, depending on the type of vehicle. Usually in the range [0.06, 0.10] for a complete train according to [24]. For specific units, a more accurate value must be used from specific sources (manufacturers, tests and literature) to reduce the error. For example, in [26] k=0.08 is reported for commuter motor units and 0.06 for trailer units. Some additional discussion and values can be found in [25]. In [27], for conventional trains in some intercity services (locomotive and coaches), k=0.22 and k=0.06 have been used in equation (2).

7. The starting resistance is also important for your acceleration and braking energy calculations in Table 4. Therefore, some discussions about the starting resistance is needed.

Thanks for this remark. As we have explained in the response to comment 3, we use a rough value of starting resistance for simulations. The change you have proposed does not change very much the data in table 4. When the train leaves station because our original starting resistance (and speed range to consider this value in the model) was bigger, and in the braking process because, in our model, the pneumatic braking is basically in charge for speeds under 25 km/h, the usual speed when trains reach track points and platforms of the terminus station.

With respect to starting resistance, we have included your suggestion in the description of the model, as explained in response to comment 3.

8. Some numbers, values are needed in your conclusions to show the significance of your statements.

Some changes have been included in the conclusion section according to the reviewers' comments. The changes in this section have been marked in yellow. For instance:

This paper entails and simulates how the introduction of new technologies in railways, mainly explained by decarbonization and sustainability policies, can afford the application of new resources and policies in Power Systems. Energy Storage, Mobile Distributed Generation and Demand Response that are similar to conventional DER in PPS, have been identified and simulated for RPS to make easier the implementation of periodic timetables. The use of flexible resources reduces the stress of present infrastructures, allowing the lagging of new resources and the introduction of storage in electric and diesel units which limits environmental impacts and improves energy efficiency through an increase of regenerative braking (10% in the simulation scenario). To perform this objective, physical-based train models (locomotives and EMUs with LM options), "hotel/comfort load"and ESS models have been revisited and linked to improve the usefulness of simulations results. Braking energy can therefore be harvested by ESS and energy efficiency improved both in the RPS and PPS. Moreover, the use of load management (during time dwellings) and ESS avoids at some extend the problems related with high ramps experienced by demand in RPS systems because of periodic timetables. As conclusion, the proposed policies in the

simulation scenario achieve around 25% reduction in peak demand and around 30% reduction in demand fluctuations considering 15-minute demand curve (RPS and PPS). Moreover, the paper demonstrates that flexible railway resources can an interesting potential to balance unpredictability of renewable generation (photovoltaic) in this case, enabling balance strategies foreseen in the future development of energy markets.

The achievable flexibility of railway loads discussed in this work can be also used in the integration of renewable in Public Power Systems through the enlargement of responsible customer segments. Finally, these alternatives appear as cost-effective considering the cost of ESS with respect to the cost of locomotives and EMUs, and this result can catalyse the increase od share of railway transportation in EU and other countries (for passenger but also for freight services). It is worth to note the proposed alternatives have considerable synergies in railway systems with partially electrified routes or many different voltages and frequency (e.g., Europe) where the presented alternatives give some additional advantages to ESS systems and their management.

Obviously, the problem of planning timetables is very complex, but the management of demand must be considered as a main factor and this new flexibility can give new opportunities to reduce potential issues dealing with the implementation of periodic timetables.

9. In figure 10, it is good to see that you've considered fuel cell, battery and supercapacitors. However, it is not clear what are the percentages of these ESS, different ESS have different characteristics, the final combined characteristics are also different.

We have considered different options for the hybridization. Obviously, fuel cells have an interesting potential. For this reason, we have underlined this possibility in figure 10. Unfortunately, from a practical point of view, we were unable to found specific data of European units developed by Alstom (Coradia, now in service in non-electrified sections of Germany) and from other manufacturers working with prototypes. We have got more information and valuable feedback from the Rolling Stock Engineering Centre, SNCF (Le Mans, France) dealing with "Regiolis" DBEMU, and specially from some tests and characteristics of dual-hybrid units and coaches manufactured by Patentes Talgo (Spain, under confidentiality agreements). For this lack of knowledge and limited feedback from manufacturers and railway operators, we have restricted our simulations to batteries, ultracapacitors and diesel (dual) units, but our interest in fuel cells remains active.

With respect to percentages, and after a review of the literature and data from some manufacturers depicted in table 3, this database (table 3) and simulations were considered as a framework of storage capacities of hybrid prototypes in EU. For this reason, we have proposed 6 kWh for ultracapacitors (comparing tramways and EMUs requirements) and 100 kWh for batteries. We have underlined and revisited these percentages (1:16) in the text.

10. "However, hybrid units DHMEU, in the diesel mode of operation, have several advantages to be discussed later in this work, for example, a high traction effort (figure 5b)." an example application of ESS locomotive can be found in "Comparison of locomotive energy storage systems for heavy-haul operation".

Thanks for this interesting remark for our future research. We agree with you, despite of the fact that passenger trains have more limitations that freight trains to include on board ESS systems. According to manufactures' data, the values of storage systems do not reach the values proposed in "Comparison of locomotive energy storage systems for heavy-haul operation" because the ESS systems developed for passenger services in the EU are limited to 30-80 km of autonomy. Nevertheless, we proposed in a previous paper the use of Talgo technical coaches in the rake (1 in Talgo VI, in the old picture 8b; and 2 coaches in dual unit S250) to be used for energy storage too (e.g., a coach with the 1,3 MW diesel unit and the other with ESS systems). Now, S250 has two

diesel-electric groups only for reliability reasons. This is like B-units with ESS proposed in the abovementioned paper by Wu et al. This simulation can be very interesting for future developments, discussion with Spanish manufacturers and the consideration in more detail of the development of ultracapacitor tram systems in conventional railway units. We have included this interesting reference (now [33]) and some comments, for example in page 9

However, hybrid units DHMEU, in the diesel mode of operation, have several advantages to be discussed later in this work, for example, a high traction effort (figure 5b). Specific characteristics for diesel and electric units with high storage requirements (i.e., around some MWh) for heavy haul operation, B unit ESS powered locomotives, (without cab, used in Australian and US railways) can be found in [33].

And in page 19

Figure 13d describes the same simulation for a dual unit (DHEMU) in IR26 duty (in diesel-electric mode, for simulation, the commercial unit S250 [40]). This is an unlikely option in Swiss Rails (electrified tracks account for 99% of Swiss system) but, in this case, first and second peaks disappear (the second because DHEMU supplies power with half of its generation capacity) but the breaking energy is not fully recovered unless the unit endows an ESS (as proposed with other vehicles in [27] and [33]).

11. Examples need to be given for hotel loads, what are the typical types of hotel loads.

We agree with you and the term hotel loads is confusing for the reader in the first version. The problem is that we used in the paper the terms ancillary, auxiliary and hotel loads with respect to energy demand of coaches. Perhaps this nomenclature is confusing. In the new version, the term "auxiliary comfort loads" has been applied because it seems more appropriate and understandable. With "hotel loads" we mean heat/cool appliances, ventilation, lighting, water heaters (in some cases), seat sockets and some other electronic devices (WiFi, TV or information screens, etc). Some lines have been included in the paper.