# A Green Markup for the Assessment of Optimized Circulation Plans ⋆


**Matthias Rößler** * **Daniele Giannandrea** ** **Niki Popper** *,**

* *DWH Simulation Services, Neustiftgasse 57-59, 1070 Vienna, Austria (e-mail: matthias.roessler@dwh.at).*
** *TU Wien, Institute of Information Systems Engineering, Favoritenstraße 9-11, 1040 Vienna, Austria*


## 1. INTRODUCTION

Due to the climate crisis, reducing energy consumption and greenhouse gas emissions has gained more and more relevance in railway traffic over the past years. While many studies propose optimization methods that consider energy consumption during circulation planning directly (Fernández et al., 2019), there is still an abundance of other methods (Piu and Speranza, 2014) that do not take energy consumption into account, especially for real-world applications. We propose a simulation-based approach to assess the quality of such circulation plans from an energy consumption and a robustness perspective, the *Green Markup*, which enables comparison of circulation plans and may be considered for optimization within a feedback loop.

## 2. DEFINITION

For a markup we want to compare the effects of a certain circulation plan (circulation scenario; $cs$) to an idealized base scenario ($bs$) where traction units are available if needed, in a realistic setting. For that, we use a simulation model that calculates the delay propagation within a time table based on injected primary delays (Rößler et al., 2020). In both scenarios, the same trains are simulated using the same primary delays. In the circulation scenario, additional empty runs are introduced through the circulation plan, for which no primary delays are added.

A green markup should indicate the performance of circulation plans both in terms of the corresponding energy consumption as well as their robustness against delays. For each of the two characteristics, robustness and energy consumption, we define a separate markup, in which we compare the two scenarios.

The markups can be calculated for different subsets within the time table. While in principle all possible subsets are feasible, the following are the most reasonable:

- *Global Markup*: sums up all relevant values for the whole time table.
- *Circulation Markup*: sums up all relevant values for the tasks used in the circulation plan.
- *Train Markup*: sums up all relevant values for the tasks driven by a certain train.

While Global Markup and Circulation Markup may be used to assess the overall quality of a circulation plan, the Train Markup can be used within a feedback loop with an optimization algorithm.

### 2.1 Delay Markup

The delay markup was already introduced in Rößler et al. (2020) and is defined as

$$m_d := \frac{\sum_{t \in T} SD_{t;cs}}{\sum_{t \in T} SD_{t;bs}}, \tag{1}$$

with $SD_{t;cs}$ and $SD_{t;bs}$ referring to the secondary delays of a task $t$ for the circulation scenario and the base scenario, respectively. The set $T$ depends on which type of markup should be calculated.

As delayed empty runs only impact the quality of a circulation plan if they affect other trains, their secondary delays are not directly considered in the markup calculation.

### 2.2 Energy Markup

Analogously, we define the energy markup:

$$m_e := \frac{\sum_{t \in T} EC_{t;cs} + \sum_{r \in ER} EC_{r;cs}}{\sum_{t \in T} EC_{t;bs} + \sum_{r \in ER} \tilde{EC}_r} \tag{2}$$

with $EC_{cs}$ and $EC_{bs}$ denoting the energy consumption (also including recuperation) of the circulation scenario and the base scenario, respectively. Again, the set T depends on the type of markup to be calculated. Additionally, for the energy markup the energy consumption of the empty runs ($ER$) in the circulation scenario ($EC_{r;cs}$) contributes to the markup. It is compared to an idealized energy consumption value, that the empty run would need with no interference from the rest of the time table ($\tilde{EC}_r$).

The energy consumption values are approximated based on historical energy data from the Austrian railway system. For the calculation, geographical information of the tracks, travel times, weight and length of the train, technical data of the locomotives, and also planned (i.e. given in the time table) and unplanned (i.e. made necessary during simulation) stops during a trip are taken into account.


⋆ This research was funded through the Green-TrAIn-Plan project (FFG project number 892235) by the Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology (BMK) as part of the IKT der Zukunft initiative AI for Green. We thank ÖBB and its digitalisation program ARP for providing the data and valuable insights used in this study.


DOI: 10.34726/9008

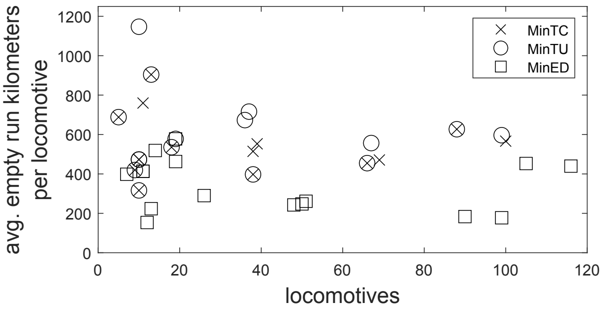


Fig. 1. Number of locomotives and average empty run kilometers per locomotive of different circulation plans

### *2.3 Green Markup*

Finally, we define the green markup as the weighted sum of the delay and energy markups $m_d$ and $m_e$, namely

$$m := \frac{w_d m_d + w_e m_e}{w_d + w_e} = \frac{m_d + \lambda m_e}{1 + \lambda} \tag{3}$$

where $w_d$ and $w_e$ are the corresponding weights which can also be consolidated in the single parameter $\lambda = w_e/w_d$. Evaluating several circulation plans in terms of their energy and delay markups will give us a sense of the magnitudes of the markups, which in turn will allow us to choose a suitable value $\lambda$ for the green markup.

All three markups are defined such that they are equal to or greater than 1, taking the value 1 for a circulation plan that does not lead to additional energy consumption or delay compared to the base scenario. A meaningful comparison of markups is only possible for evaluations based on the same time tables and primary delay distributions.

## 3. EXPERIMENTS

The circulation plans are created using the optimization approach presented in Frisch et al. (2021). The objective function is a weighted sum of the number of locomotives ($l$) and the total amount of empty run kilometers ($km$)

$$\min \quad w_l \cdot l + w_{km} \cdot km, \tag{4}$$

with weights $w_l$ and $w_{km}$. We vary the weights to achieve different results, that mimic different requirements.

- MinTC: Minimize total costs.
- MinTU: Minimize the number of used traction units.
- MinED: Minimize empty run distance.

The weights for MinTC are chosen to roughly reflect the cost difference between a locomotive and a driven empty run kilometer, for MinTU and MinED the weight for the not-prioritized component is multiplied by a small $\varepsilon > 0$ to limit the respective usage.

The circulation plans are based on real-world time tables for a reference week, that contain both passenger and freight traffic. For the analyzed instances we only use freight trains, as the amount and distribution of energy consumption for freight and passenger traffic is vastly different. We create instances for several traction unit classes using different additional filters to gather a variety of circulation plans with different sizes. Figure 1 shows an overview of the KPIs for the different circulation plans.

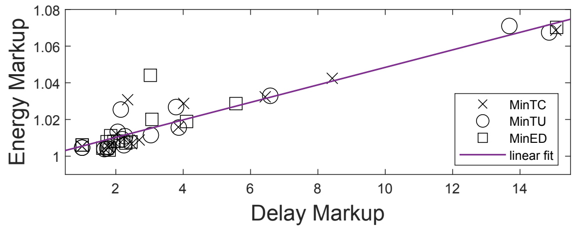


Fig. 2. Energy Markup plotted against Delay Markup

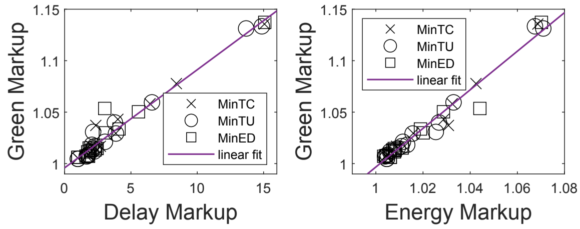


Fig. 3. Green Markup plotted against Delay Markup and Energy Markup

For the simulation, all trains present in the time tables are used to create a realistic model of the railway traffic. Each circulation plan instance is simulated on its own, and the delay and energy markup are calculated separately.

## 4. RESULTS

As Figure 2 shows, the delay markup for the chosen circulation plans lies in the range $[1, 16]$ whereas the energy markup lies within $[1, 1.08]$. The plot indicates a linear relation between the two values, and a group of slightly deviating values where the energy markups are greater (or delay markups smaller) than the linear fit would suggest.

The selection of $\lambda$ must take into account the variations of the markups. Choosing

$$\lambda = \frac{\max(m_d) - \min(m_d)}{\max(m_e) - \min(m_e)} = 208 \tag{5}$$

yields the green markup presented in Figure 3. As can be seen, the relation between the delay and energy markups is preserved in the green markup, as the group of values deviating from the linear relation is visible in all plots.

## REFERENCES


Fernández, P.M., Sanchís, I.V., Yepes, V., and Franco, R.I. (2019). A review of modelling and optimisation methods applied to railways energy consumption. *Journal of Cleaner Production*, 222, 153–162.

Frisch, S., Hungerländer, P., Jellen, A., Primas, B., Steininger, S., and Weinberger, D. (2021). Solving a real-world locomotive scheduling problem with maintenance constraints. *Transportation Research Part B: Methodological*, 150, 386–409.

Piu, F. and Speranza, M.G. (2014). The locomotive assignment problem: a survey on optimization models. *International Transactions in Operational Research*, 21(3), 327–352.

Rößler, M., Wastian, M., Jellen, A., Frisch, S., Weinberger, D., Hungerländer, P., Bicher, M., and Popper, N. (2020). Simulation and optimization of traction unit circulations. In *2020 Winter Simulation Conference (WSC)*, 90–101. doi:10.1109/WSC48552.2020.9383926.