Determination of the Most Energy-saving Traction Speed Based on UAS Simulation

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Abstract. During the operation of EMU, the power supply network will be cut off and the train power will be lost due to bad weather, high voltage cable dropping off, catenary failure and power supply system failure, which will cause the whole train line to be stopped and a large number of passengers to be detained, causing serious harm. Therefore, the Emergency Guidance (UAS) simulation software for EMU is developed based on the QT platform, and a lot of simulations are carried out under different initial battery power, different traction constant speed and different operation modes. Based on the simulation data, the main energy consumption models of trains and the models of total operation energy consumption and traction constant speed under time-first operation mode are established, which can be found from the models. The constant speed of traction with the least energy consumption can help the driver to drive energy-saving and reduce unnecessary energy consumption. Finally, the model is validated and evaluated, which can be well applied to general situations. The simulation has good application prospects in the construction of energy-saving intelligent high-speed railway in the future.

1. Foreword [13]

In recent years, the construction of Intelligent Beijing Zhangjiakou High-speed Railway has begun, aiming at creating a safer, more intelligent, more reliable and more comfortable high-speed train system. One of the important tasks in the construction of this project is to use on-board energy storage device to realize emergency self-running of trains after the loss of power from traction network, so that trains can arrive a nearby station, keeping passengers safe.

When EMU is in an emergency state, all the energy of the train is provided by the on-board energy storage device. During the whole process of emergency disposal, not only the electric energy needed for air conditioning (ventilation) and lighting, but also for traction transmission system. However, due to the limitation of installation space and energy density, the capacity of on-board energy storage devices is limited. So the energy consumption of auxiliary system and emergency traction operation put forward the demand for energy management from two dimensions of time and space respectively. In this study, a reasonable train emergency running strategy is planned by considering the geographical conditions, two-way arrival distance, train parameters and characteristics, energy management strategy of auxiliary system and capacity of on-board energy storage system, so as to achieve the optimal parking guidance.
Optimized emergency travel plan can not only avoid subjective decision-making errors caused by driver's artificial estimation, but also improve the life of energy storage devices directly benefiting from energy-saving operation. With the construction of Sichuan Tibet Railway, trains will pass through countless tunnels, mountainous areas, no man's land and many harsh terrain. Once the train loses power from traction network unexpectedly, the emergency self-running of trains becomes extremely important.

2. UAS introduction [13]
UAS [1,2,3,4,5,6,7,8,9,10,11,12] refers to the driver's guidance device for emergency operation of EMU, which is called Urgent Operation Assistant System. It is an intelligent control guidance device that prompts the driver's best emergency response plan in an appropriate way when the traction network fails. Considering that it is impossible to guarantee the full power reserve of on-board energy storage batteries at any time in actual operation, and in extreme cases the battery power is less. Therefore, four different groups of initial battery capacity are selected for simulation. Due to the loss of traction network power supply and the limited power of on-board batteries, the stable traction speed of emergency train is low; In order to meet different needs, the simulation model is divided into several parts, and the specific conditions are shown in Table 1.

### Table 1. Simulation conditions.

| Railway                              | Initial battery capacity(percentage) | Stable traction speed | Simulation mode                        |
|--------------------------------------|-------------------------------------|-----------------------|----------------------------------------|
| Intelligent Beijing Zhangjiakou High-speed Railway | 60%, 70%, 80%, 90%                   | 30km/h, 35km/h, 40km/h | Mode1-Forward driving priority Mode2-Energy conservation priority Mode3-Time priority |

3. Energy Consumption-Speed Model with Time Priority
When using UAS to simulate running, this study defaults that the shortest running time (mode 3) is needed to get the passengers on the train to the nearest station as soon as possible, and then consider the least energy used in the driving process. According to the actual road conditions, the fault parking point is selected at a distance of 18.414 km between Beijing and Qinghe River, that contains comprehensive road conditions such as ramp and big bend. In mode 3, the change rule of total energy consumption is explored when the initial power of the system is 90% and the set speed limit is changed.
Through UAS platform, 31 sets of data of total energy consumption and set speed limit were obtained, and the traction speed changed steadily from 20 km/h to 50 km/h.
Figure 1. Total operation energy consumption-stable traction speed scatter chart.

The data points of 20 km/h-26 km/h and 30 km/h-32 km/h of the stable traction speed range are the results of reverse operation. The data points of 27 km/h-30 km/h and 33 km/h-50 km/h of the stable traction speed range are the results of forward operation. When the speed limit range is greater than 48 km/h, the obvious change law is quite different from that of forward operation.

The influencing factors of total operation energy consumption can be roughly divided into three aspects: energy consumption to overcome resistance work in driving process; traction work of train traction motor; auxiliary energy consumption caused by running time, etc.

Overcoming resistance energy consumption satisfies the following equation:

\[
Q_r = f \times s \\
\begin{align*}
f \propto v^2
\end{align*}
\]

(1)

The conclusion can be drawn from the equation (1):

\[
W_1 \propto v^2
\]

(2)

The energy consumption of traction motor meets the following equation:

\[
\begin{align*}
P &= T\Omega \\
\Omega &\propto v^2
\end{align*}
\]

(3)

The conclusion can be drawn from the equation (3):

\[
W_2 \propto v^2
\]

(4)

Time causes energy consumption to satisfy the following equation:
\[ t = \frac{s}{v} \]  \hspace{1cm} (5)

The conclusion can be drawn from the equation (5):

\[ W_3 \propto \frac{1}{v} \]  \hspace{1cm} (6)

Based on the above factors, it can be concluded that the relationship between total operating energy consumption and stable traction speed of EMU is as follows:

\[ Q_{Tal} = av^2 + bv + c - \frac{1}{v} + d \]  \hspace{1cm} (7)

According to the changing trend between speed and energy consumption shown in Figure 1, equation can be divided into three-stage functions to solve the problem. The results are as follows:

\[
\begin{cases}
Q_{Tal,-1} = -0.038v^2 + 3.071v + 553.890 - 18.631 \\
[20, 26] \cup [30, 32] \\
Q_{Tal,-1} = 0.001v^2 + 0.491v + 250.623 - 19.715 \\
[27, 29] \cup [31, 47] \\
Q_{Tal,-1} = 0.039v^2 - 2.865v + 1280.370 - 63.436 \\
[48, 50]
\end{cases}
\]  \hspace{1cm} (8)

The fitting curve and confidence interval of the model are as follows:
It can be seen that the models obtained by formula (8) all fall within their confidence intervals, and the model has greater reliability.

When the stable traction speed is greater than 48 km/h, the data is less, so it is not universal. The simulation results show that the maximum speed of the train is less than 40 km/h in the whole driving process. The real-time speed data with the set speed limits of 48 km/h, 75 km/h and 100 km/h are taken as follows, as shown in Table 2.
### Table 2. Simulation data.

| Position (km) | Speed (km/h) | Time(s) | Position (km) | Speed (km/h) | Time(s) | Position (km) | Speed (km/h) | Time(s) |
|---------------|--------------|---------|---------------|--------------|---------|---------------|--------------|---------|
| 18.414        | 0            |         | 18.414        | 0            |         | 18.414        | 0            |         |
| 19.014        | 32.934       | 97      | 19.014        | 29.637       | 98      | 19.014        | 29.637       | 98      |
| 19.614        | 27.524       | 163     | 19.614        | 23.215       | 176     | 19.614        | 23.215       | 176     |
| 20.214        | 36.958       | 242     | 20.214        | 30.942       | 265     | 20.214        | 30.942       | 265     |
| 20.924        | 47.091       | 301     | 20.924        | 39.275       | 338     | 20.924        | 39.275       | 338     |
| 21.524        | 38.243       | 350     | 21.524        | 28.842       | 399     | 21.524        | 28.842       | 399     |
| 22.124        | 30.144       | 413     | 22.124        | 28.842       | 474     | 22.124        | 28.842       | 474     |
| 22.724        | 24.155       | 498     | 22.724        | 28.511       | 549     | 22.724        | 28.511       | 549     |
| 23.204        | 22.638       | 572     | 23.204        | 27.144       | 611     | 23.204        | 27.144       | 611     |
| 23.444        | 21.713       | 610     | 23.444        | 26.33        | 644     | 23.444        | 26.33        | 644     |
| 23.564        | 21.24        | 631     | 23.564        | 16.873       | 661     | 23.564        | 16.873       | 661     |

From Table 2, it can be concluded that when the constant speed traction speed is too high, the train does not have the ability to drive at high speed because of the limited power of the on-board energy storage device. At this time, the simulation data of the three kinds of constant speed traction speed are almost the same, and the maximum speed in the simulation data is far from the set constant speed traction speed. It can be inferred that when the constant speed traction speed is too high, it has little influence on the recommended driving scheme of the train.

### 4. Universality and Reliability Assessment of the Model

The data used in the 4 models are substituted into the neural network fitting toolbox for training. As shown in Figure 3, most of the errors are concentrated near 0.3, which is very small, and in Figure 4, the training quantity, correction quantity, inspection quantity and comprehensive quantity R value are relatively large, which shows that the model has universality and reliability.

![Error Histogram with 20 Bins](image)
5. Conclusion
In summary, the reliability of the model is very high through fitting curve and error analysis. At the same time, the model has universality on other railways similar to Intelligent Beijing-Zhangjiakou Intercity Railway. Moreover, UAS and the model obtained by simulation data are helpful for driver's driving operation in emergency phase, reasonable allocation and utilization of energy of on-board energy storage batteries, reducing unnecessary energy consumption and ensuring passenger safety.

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