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Elektrotechnik und Informationstechnik**

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**Der Titel der Arbeit
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Aachen, March 31, 2020

Danksagung

Danke.

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Abstract Modern day railway system operations require automated train control mechanisms, e.g. European Train Control System ETCS, to maximize efficiency, which is often times limited by outdated infrastructure, as well as safety of operations. One way to achieve this is by lowering the required distance between two trains on the same track, which in turn demands a reliable method of predicting the braking distance at any given moment.

While determination of the necessary braking curves is feasible for a limited number of train formations, the large diversity of vehicles in freight operations poses an issue. One approach for a solution would be using Big Data, which would be able to process the required amounts of data to calculate reliable braking curves even for freight operations.

The problem here is there is simply not enough data available since freight trains usually don't have the sensory equipment needed. To circumvent that obstacle, this work proposes generation of artificial data via white box modeling to be then used in further big data operations.

Introduction

Introduction This section describes the background and motivation of the research (Sect. 1.1), the problem to be addressed (Sect. 1.2) and the proposed solution (Sect. 1.3)

1.1 Background

1.1.1 Railway Vehicle Operations

1.1.2 Train Protection Systems

1.1.3 Braking Curves

1.2 Problem

As has been shown, to predict the braking behavior of trains, readings of wagons and locomotives are needed. Unfortunately, freight vehicles do not currently possess the sensory equipment that would be necessary to obtain such data in an adequate quantity and quality, especially in regards to *big data processing*. Although it has been proposed to equip freight wagons accordingly <TODO: ref zu wagon4.0>, it will be years before enough rolling stock has been retrofitted as to make it possible to obtain the desired data.

1.3 Solution

This work proposes to circumvent the problem described above by creation of an artificial data set. The set must replicate the actual distribution of braking behavior as close as possible. It is therefore necessary to first create a model encompassing the braking process of a freight train. This model will be discussed in depth in chapter 3. It can then, once finished, be also used to generate the data set by simulation. This process will be discussed in chapter 4.

As real life operations would yield very high quantities of data, the simulation output must be stored in a data structure which is suitable for big data processing. This structure will also be discussed in chapter 4.

Fundamentals of Railway Vehicle Engineering

Modeling of Train Operations

Introduction As has been noted in 1.3, it is necessary to model the braking process of freight trains. All modeling work has been performed with Matlab Simulink.

3.1 Initial Model

The initial model to be expanded upon describes a single braking process. It's sole input, apart from some constants, is pressure over time, meaning a distinct value ranging between 5 and 3.5 bar for every timestamp. For visualization, please refer to B. Let's take a look at the whole model first.

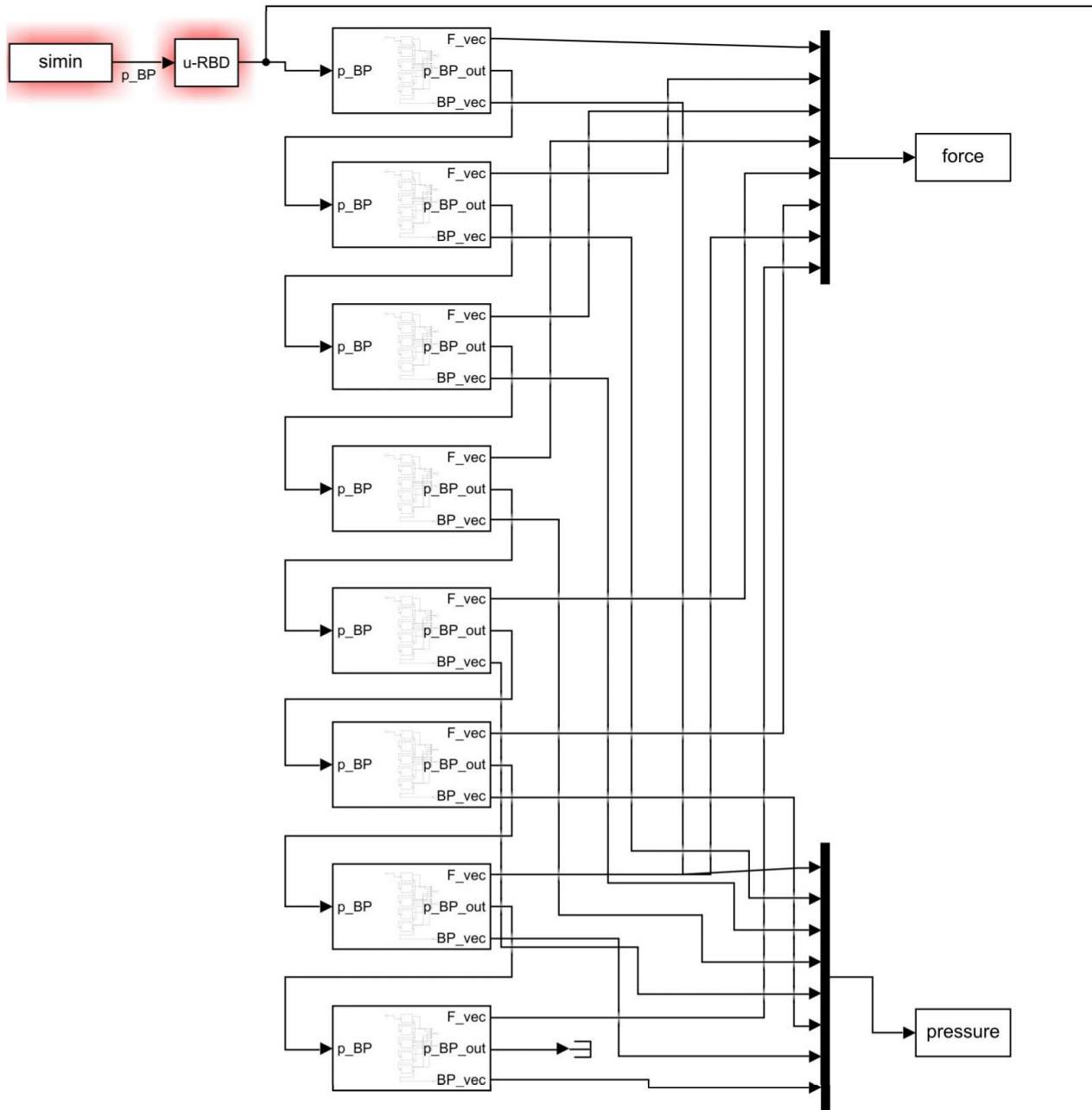


Figure 3.1: Initial Model

Here we see a model of a freight train of fixed length, consisting of 40 wagons, which are, for better readability, further condensed to subsystems of five wagons each, so there are eight of these subsystems. They are interconnected via braking pipe, which is also the sole input to each system. Outputs are braking pressure and braking force. We will take a look at the actual wagon model next.

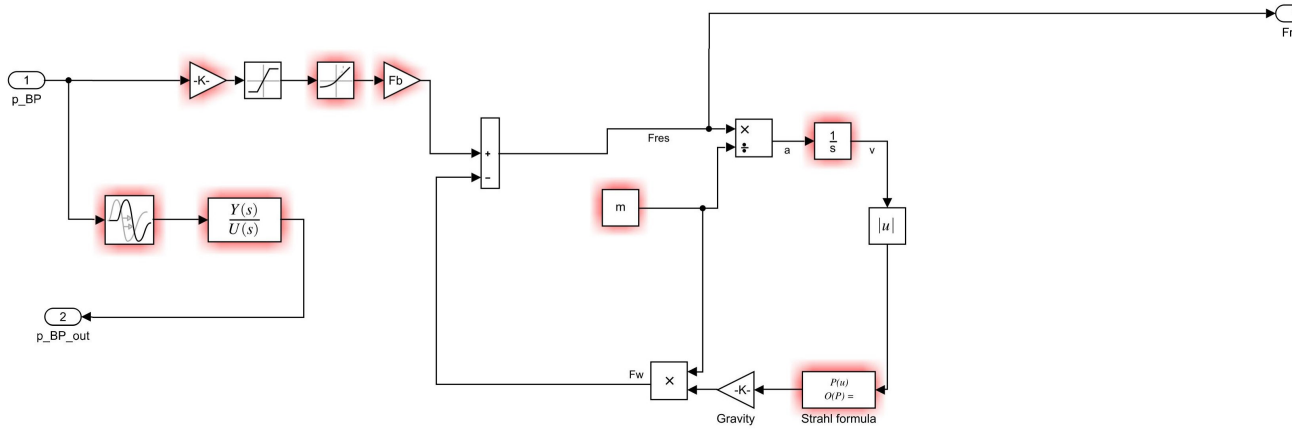


Figure 3.2: Initial Model - Wagon

Above is the initial wagon model. **NOTE: All 40 wagon models are identical here. This will be addressed in section 3.2.** It consists of three main components.

In the upper left corner is the input, which is the current pressure in the braking pipe. In the lower left corner, the propagation delay of the braking pipe is calculated. This is done by **<TODO: >**. Top center describes the calculation of the actual braking force, which is achieved by **<TODO: >**. Finally, the **<TODO: Formulieren: Fahrzeugwiderstand>**.

3.2 Model Expansion

This initial model is however not of sufficient detail. Where it merely describes one single braking process, we need to simulate a whole ride, with alternating phases of braking and accelerating. For that purpose, the simulation input has to be adjusted accordingly. Where previously it was only one braking process, using braking pressure as input was the obvious choice, whereas now the idea is to use a kind of track profile, which shall describe the maximum allowed velocity over time, of a notional track. For visualization, please refer to B. The simulation then only needs to brake or accelerate depending on train velocity versus maximum velocity at the current time.

Accordingly, the first expansion step is to create a mechanism to control the train so to speak. For this purpose, the system simply checks for each timestamp whether the current velocity of the train is greater than the maximum allowed velocity at the current time, according to simulation input. If this is the case, a braking pressure is applied to the pipe, scaling with the difference between v_{max} and v_{real} , $vdiff$. This means the higher $vdiff$ is, the more braking pressure gets applied. This more or less covers the braking part of the system.

The model however also needs a component for acceleration. To simplify things, the logic here is that if the train is not braking, it is accelerating, which actually works out pretty well. To accelerate, a traction force is applied, which also scales with $vdiff$, so the higher $vdiff$, the higher the applied traction force.

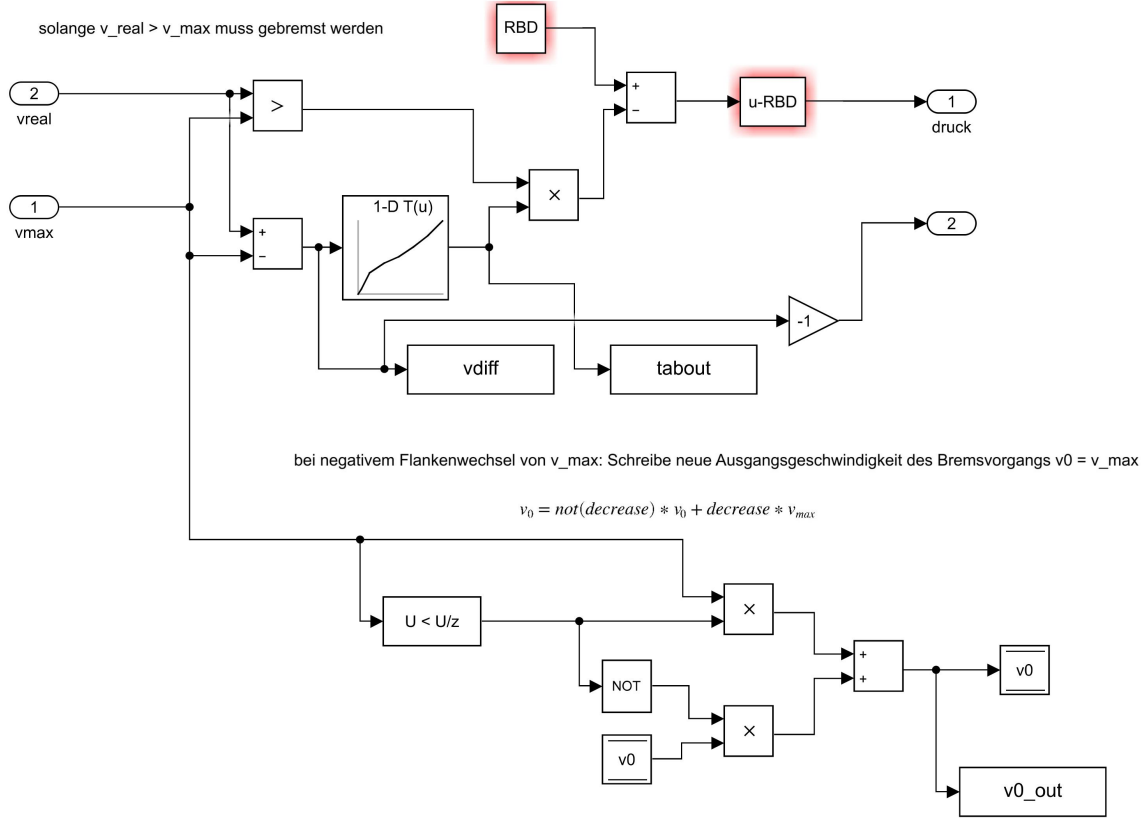


Figure 3.3: Expanded model - Pressure Calculation

Depicted above is the system which determines braking pressure to apply. It calculates v_{diff} by subtracting v_{max} from v_{real} , which is then fed into a one-dimensional lookup table. The table is a sampled representation of a function with fixed breakpoints, mapping one function value to each breakpoint, like so

$$H(n) = \begin{cases} 0.1 & \text{if } n = 1 \\ 0.7 & \text{if } n = 15 \\ 0.8 & \text{if } n = 20 \\ \dots & \end{cases}$$

where n are the breakpoints of v_{diff} . Since the pressure should only be applied if v_{real} is greater than v_{max} , the ultimate result follows the logic of the following equation

$$f(n) = H(n) * (v_{real} > v_{max})$$

where $v_{real} > v_{max}$ is either 1 or 0.

3.3 Further Expansion

Data Generation

4.1 Data Structure

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Performance Analysis

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Quellcode

1. Source 1
2. Source 2

Data visualization

<TODO: Visualisierungen einfügen>

Initial model - simulation input Expanded model - simulation input