Methods to obtain reliable car body load assumptions for light rail vehicles using multibody simulations based on measured input

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Abstract
The development towards higher energy efficiency, transportation capacity, safety, accessibility, and comfort has made modern light rail vehicles much more complex than their predecessors. To provide a high ratio of low floor passenger area, equipment of considerable weight was shifted to the roof. The need for portals between cars, large windows, and a maximised number of doors made it difficult to laterally support the resulting inertia loads. At the same time, new bogie concepts with stiffer suspension and less degrees of freedom between bogie and car body increased loads further, as track displacements are more directly applied to the car body structure. The length of the vehicles combined with an often demanding urban topography require well-adjusted articulation systems.
Besides some non-linear components, it is the large angles in these articulations that turn the vehicles into fundamentally non-linear systems and the determination of reliable load assumptions into a major challenge. Although these loads form the basis of the structural design, conventional analytic methods using superposition of acceleration based load cases have shown large gaps to reality in the past. This paper demonstrates how multibody systems (MBS) of the relevant load cases solved in the time-domain can help to fill these blind spots. They require the use of increasingly detailed models of vehicles and tracks, as shown in Figure 1. Their input can be obtained from and their output has to be verified with measurements of existing tracks, similar vehicles in service, or prototype vehicles.

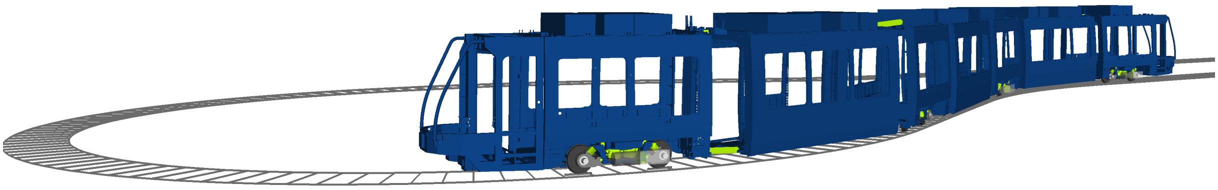

Figure 1: MBS model featuring flexible car body structures with measured speed on measured track.

While the integration of measured track is well-known [1], the usage of vehicle data like measured speed profiles requires the synchronisation of way-dependant track and time-dependant vehicle data from different sources. To do so, a cross-correlation method is formulated to align track-side curvature and vehicle-side yaw rate. To pin long-term measurements like [2] precisely to the track, a system-theoretical approach is shown. Describing the track network as a finite-state machine, with track segments forming states and switches forming transitions, a global optimisation method can be demonstrated. Taking different directions on a single track into account by doubling the amount of states, the search space for the most likely track sequence covers exactly all possible sequences. A recursive correlation algorithm is shown to correct the measured speed so that even for long distances an accurate distance to time relation between the vehicle measurement and the track sequence is reached.
Regarding the vehicle model, different ways to model the car body structures are discussed. Because quasi-static loads like low-frequency twisting show such a large impact, it is crucial to match the car body stiffness between all of its interfaces. This can be achieved by applying model order reduction methods to the according finite element (FE) models [3]. Key steps of this modelling process are demonstrated.

The paper details how to create close to reality simulation scenarios by using measured or synthetic tracks as well as measured or synthetic vehicle speed profiles. In addition, the simulation of exceptional, light rail specific load cases, like discussed in [4], will be taken into consideration.

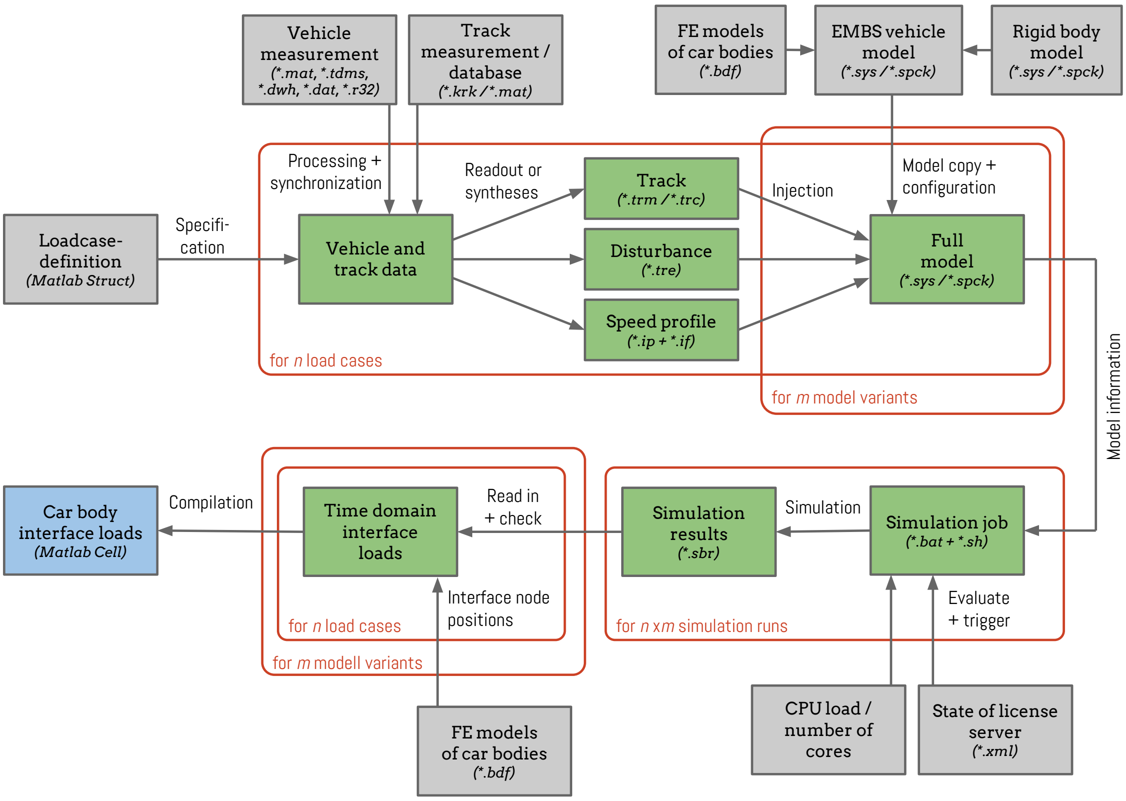

Figure 2: Fully automated simulation process to maximise the number of regarded load cases.

As the non-linearity rules out the superposition of load cases, O^n load cases have to be taken into account to cover n factors of influence. To cope with this high number of simulation runs, it is shown how the process can be fully automated, as summarised in Figure 2. Keeping the vehicle measurement, synthesised data, and simulation results in the same reference system and side-by-side in software becomes an advantage in post-processing. It is shown how it can be used to find correlations, dependencies, causes, and effects between all available data. A method to compile relevant load cards is presented. As an alternative approach to existing works on track-dependant fatigue evaluation methods [5], a modified rainflow counting-method is shown, that is based on lossless rainflow tables.

References

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