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Modeling, simulation and validation of material flow on conveyor belts

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ABSTRACT

In this paper a model comparison approach based on material flow systems is investigated that is divided into a microscopic and a macroscopic model scale. On the microscopic model scale particles are simulated using a model based on Newton dynamics borrowed from the engineering literature. Phenomenological observations lead to a hyperbolic partial differential equation on the macroscopic model scale. Suitable numerical algorithms are presented and both models are compared numerically and validated against real-data test settings.

1. Introduction

Reduction of cost for transportation, storage and handling as well as reduction of processing time with the help of mechatronic product innovations are the main objectives in planning of in-company material flow systems. To fulfill these requirements, the VDI-guideline 2206 [1] proposes a multi-stage design concept based on the V-model, see Fig. 1. It is thereby recommended to support the different design stages by virtual prototypes, thus reducing design times, securing design goals and enabling interdisciplinary cooperations of mechanical and electrical engineers as well as computer scientists.

The amount of details included in the virtual prototypes increases hereby from one design stage to the next. The first phase, called the preparation stage, aims at estimating the theoretical material flow in order to get a first insight into material distribution, material density and material storage. The focus of the following conception and detailed planning phases is to test concrete design alternatives using different material flow elements. To this end, the concrete design alternatives such as material branching, separation and sorting or inclination of transportation devices have to be modeled in the virtual prototype. The requirements for virtual prototypes are therefore:

- The model has to be able to predict the space- and time evolution of material flow and material density. This is ideally not done at isolated points in space but continuously over the whole spacial domain of the material flow system.
- At the preparatory stage, the material flow should be characterized through rough parameters and properties, while the virtual prototypes of the coarse and fine planning phases have to account for concrete design strategies.

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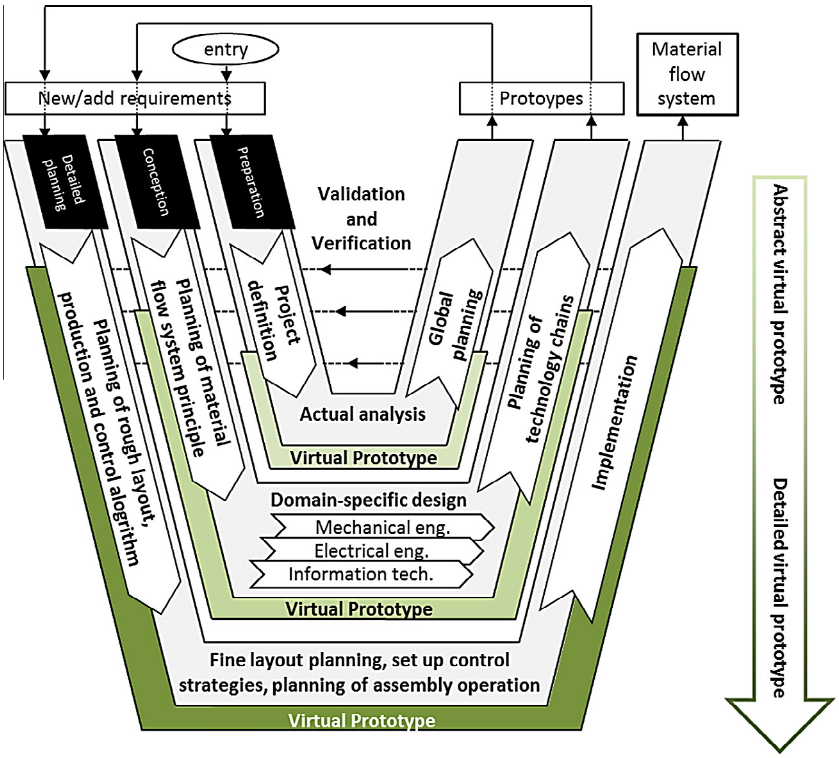

Fig. 1. Interactive design process based on the V-model, see [1].

In this paper, we focus therefore on two models for material flow. The microscopic model, especially suitable for the conception and detailed planning phases, is reviewed in Section 2. This model tracks each part in the material flow system and uses Newton's law together with a detailed description of the acting forces to simulate the evolution of material distribution and density. This modeling approach is well known from molecular simulations, see e.g. [2] for a recent review. In the engineering community, models based on this or similar principles are state of the art for material flow simulation in the planning phases, see e.g. [3–5] as well as for other applications such as granular flow [6,7], computer graphics [8,9] or traffic flow [10].

In Section 3, motivated by [11,12], a phenomenological study of the model in Section 2 yields a macroscopic model, based on a two-dimensional nonlocal hyperbolic partial differential equation (see [13] and the references therein for an overview), that is designed to fulfill the requirements of the preparation phase. This model is especially suitable to provide first estimates on the material flow and throughput rate of the production line. Similar ideas are used to rigorously derive macroscopic models from microscopic ones via kinetic models, see [14–16]. In Section 4, we explain the numerical implementation of the two proposed material flow models and discuss numerical issues such as computation time. The presentation concludes with Section 5 devoted to a detailed comparison of the microscopic and macroscopic model with experimental data. The results of this section show very promising agreement of the models with the experiments in terms of throughput rate and material flow.

2. Microscopic modeling

In the microscopic material flow model the physical movement of each single particle or cargo on material flow elements is studied in a general setting, i.e. a 3-dimensional space. Each cargo is described as an unbounded rigid body with the corresponding mass and moment of inertia. The interactions between the cargo among themselves or cargo and conveyor belt are presented through the physical laws of contact mechanics [17]. This approach is mainly used in material sciences (see e.g. [18,19]) or granular flow (see e.g. [20]). In the following, we review the well-established microscopic model in its standard formulation as it applies to the transport of cylindrical cargo on a conveyor belt (see Fig. 2), where the cargo is separated by a rigid singularizer.

The material flow process is described as the sum of the unbounded movable cargo and the contact between other cargo and the material flow elements. The equation of motion for the movement of the cargo i is derived by means of Newton's law of motion: