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Digital Engineering tools in designing parcel distribution centers: Introducing a multidimensional classification model

Herramientas de Ingeniería Digital en Centros de Distribución de Paquetes: Introducción a un Modelo de Clasificación Multidimensional

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Abstract: Parcel distribution centers have been facing the challenge of efficiently sorting a growing number of shipments in recent years. In addition to this trend, constant changes in the shipment spectrum, shifting consumer behavior, and seasonal fluctuations require efficient design of distribution centers and flexibility in process strategies, while also considering sustainability aspects.

Digital Engineering offers various solutions to meet these requirements. As the variety of methods and tools of Digital Engineering is steadily growing, this study presents a methodology to choose the most appropriate in the context of the development and optimization of a parcel distribution center. The methodology’s core is a multidimensional classification model that summarizes a parcel distribution center, allowing the representation of its inherent information and interconnections. This, in turn, enables the allocation of the most appropriate Digital Engineering solution. The primary emphasis is on solutions that the authors categorize under the domain of "Design and Simulation", encompassing techniques such as material flow simulations and Multibody Simulations.

Initially, different levels[1] of the parcel distribution center are investigated independently, focusing on methods, tools, influences, and outcomes. Subsequently, the connections between these levels are established to obtain a holistic view of the distribution center, highlighting the interactions between the approaches. Finally, future challenges and opportunities are discussed.

Furthermore, the paper outlines the allocation of Digital Engineering tools throughout the product lifecycle. These tools are assessed with respect to sustainability goals, covering ecological, economic, and social aspects.

In conclusion, this publication demonstrates the significant potential of Digital Engineering tools in enhancing the design, operation, and sustainability of parcel distribution centers by using a multidimensional classification model.

Keywords: Parcel distribution centers, CEP, Digital Engineering, multidimensional classification model, CAE, material flow simulation, sustainability

Palabras Claves: *Centros de Distribución de Paquetes, CEP, Ingeniería Digital, Modelo de Clasificación Multidimensional, CAE, Simulación del Flujo de Materiales, Sostenibilidad.*

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[1] Level means in this context a layer of abstraction within the classification model..

1. Introduction

1.1 Trends in the Courier, Express and Parcel Industry

For many years, the Courier, Express, and Parcel (CEP) industry has been experiencing a steady upward trend, manifested in increasing shipment volumes. This upswing is primarily attributed to the growing prevalence of E-commerce in the Business-to-Consumer (B2C) sector. Particularly notable dynamics were observed in the years 2020 and 2021, marked by the Covid-19 pandemic, leading to unforeseen surges in growth [1] [2].

In addition to the sheer volume of parcel shipments, distinct seasonal fluctuations in business operations are characteristic, driven by shifting consumer behavior, especially during holidays [3].

Furthermore, the spectrum of goods dispatched within the CEP industry is heterogeneous and subject to continuous change. Especially with regard to the packaging of the parcels, a dynamic change is evident. Studies like [4] try to identify the current situation, changes and future trends.

1.2 Challenges in the Parcel Distribution Process

The distribution of these shipments is carried out through multi-stage transportation networks. These nodes include regional depots for the collection and sorting of shipments on one hand, and hubs that serve as central sorting facilities on the other [5].

Hubs are typically designed as cross-docking transfer points, i.e. no storage of shipments takes place [6]. The core element of these hubs is the sorting system, which receives incoming shipments from various suppliers, identifies them, and assigns them to their destinations (which is in this case mostly the following shipment vehicle) and distributes them accordingly [7]. The structure and process flow of such a system is explained in Fig. 1. Due to significant variations in terms of mass, shape, and mechanical properties of the shipments, sorting systems in hubs face high demands. The distribution conveyor which is the centerpiece of a sorting system must be capable of handling all these variations [4]. The same sorting system might be loaded with heavy, voluminous shipments in the morning and process light shipments weighing only a few grams in the evening.

As the sorting system needs to be designed according to the maximum throughput (at maximum shipment mass), which is also influenced by seasonal fluctuations (e.g. Christmas or Black Friday), challenges arise in the planning process to find the most suitable design and strategic solutions that enable efficient operations under these varying loads.

Another significant factor lies in the necessity to achieve a high degree of automation in these hubs to efficiently manage large shipment volumes. While sorting at the distribution conveyor meets these requirements as they are mostly fully automated, the loading and unloading processes of the sorting system are mainly carried out manually, which is a significant concern that needs to be investigated, as these manual processes can cause bottlenecks in the workflow [8] [9].

1.3 Practices in Parcel Hub Planning and Design

The design and conception of such hubs encompass a multitude of objectives (e.g. sustainability, economic efficiency, delivery capability) as outlined in [10]. This study focuses on two primary planning aspects of this variety. The first aspect pertains to material flow planning, in which the design of the conveying system is determined. Essential for the design is the calculation of the material flow system throughput. [7] distinguishes between the technical maximum throughput and the operational throughput of the distribution conveyor. The former describes the system's maximum achievable performance and can be determined using analytical methods. The operational throughput reflects a more realistic perspective as it accounts for unforeseen disruptions during the process. Due to the stochastic nature and the arising complexity, this throughput determination is only feasible through numeric simulation, as described by [11].

The second planning aspect involves the structural dimensioning of the mechanical components used in the system such as sorting systems and distribution conveyors. This is primarily based on empirically derived schematics (guidelines and standards) and the development is driven by experiments. The application of simulation models in this area has not yet found significant use [12].

For effective and efficient planning, detailed knowledge of the processes within a hub is essential. Various approaches for depicting intra-company material flow processes are documented in the literature, presenting potential process sequences. A comprehensive representation of these approaches is shown in Fig. 1.

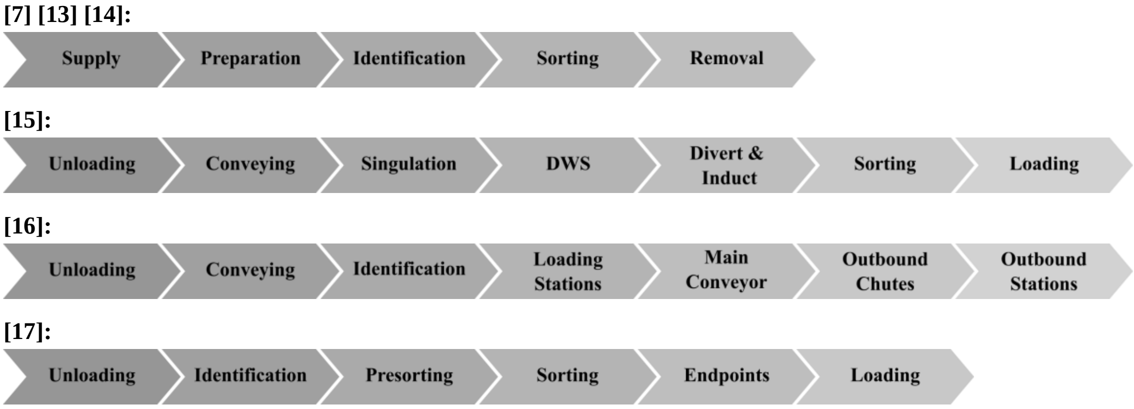

Fig. 1. Different approaches of process sequences

It should be noted that [7], [13] and [14] address sorting systems in general. [7] provides further detailed descriptions and classifications of sorting facilities by examining the process steps more closely and integrating the sorting system into an overall system.

It becomes apparent that there is a necessity for the application of virtual methods in the design process, which can be attributed to Digital Engineering. These methods offer the potential to enhance efficiency, accuracy, and innovation by simulating and analyzing various design scenarios in a controlled digital environment. Digital Engineering involves the continuous utilization of digital methods and tools throughout the entire product lifecycle [18]. This leads to enhanced product quality, shortened development times, and innovative solutions through the integration of virtual in real systems. An exemplary list of various methods and tools has been compiled in Table 1 from [19], [20], [21] and [22][2]. The table exemplary classifies tools and methods and does not claim to be complete.

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[2] The mentioned tools are attributed to the sources of "virtual product development," which, however, is regarded as a precursor to Digital Engineering [18].

Table 1 Examples for Digital Engineering tools

Simulation and Design	Data Visualization	Data Management	Internet of Things	Virtual Commissioning
Process Simulation	Virtual Reality (VR)	Knowledge management	Big Data	Production Data Acquisition (PDA)
Finite Element Analysis (FEA)	Augmented Reality (AR)	Product Lifecycle Management (PLM)	Digital assistance	Manufacturing Execution System (MES)
Discrete Element Method (DEM)	Digital Mock-Up (DMU)	Enterprise Resource Planning (ERP)	Artificial Intelligence	Computer-Aided Quality Assurance (CAQ)
Multibody Simulation (MBS)		Process Data Management (PDM)	Cloud services	Computer-Aided Manufacturing (CAM)
System Simulation (SS)			Cyber Physical Systems (CPS)	
Computer-Aided Design (CAD)				

1.4 Aim of the Study

This scientific contribution highlights the potential of Digital Engineering in the strategic planning, design, and optimization of processes and facilities in parcel distribution centers to achieve sustainability objectives. An integrative model is presented, illustrating the diversity of possibilities offered by Digital Engineering for these tasks. The emphasis lies in optimization as an integrated process, not solely in planning. A central guiding principle is the holistic consideration of the entire product lifecycle for effective and sustainable solutions.

This study showcases a selection of utilized Digital Engineering tools, focusing on CAx (CAx is the acronym for computer-aided x, where x can be e.g. design, engineering) and material flow simulations, and allocates them to different hierarchical levels of a parcel distribution center while demonstrating potential starting points through exemplary instances. The ongoing dissertations of three of the authors further contribute to the advancement of this field.

2. Methodology

The following section introduces a conceptual classification model, which serves as the central methodological framework for further investigations. This section is conducted in two consecutive steps: firstly, the overall model is introduced, providing a comprehensive view of the interconnections among the different levels (section 2.1). Subsequently, a detailed explanation of the individual levels follows to illustrate the origins of the specific flows within the model (sections 2.2 – 2.5). In section 3, an allocation of Digital Engineering tools to these levels takes place, including the current state of technology and ongoing research.

2.1 The Classification Model

The model, as shown in Fig. 2, is structured into four levels (strategical, material flow, plants and components) that encompass the areas of analysis and planning within hubs. The structural arrangement and content of the presented levels are deduced from the combination of established representations of hubs as found in relevant literature sources (e.g. [7], [14]).

In this section, the basic structure of the individual levels is depicted. Exemplarily, possible information flows between the levels are also indicated. The flow of information across the different levels offers a significant advantage in terms of utilizing Digital Engineering tools. Examples show in which context simulation outcomes can serve as aids for strategic decision-making or as data foundations for simulations in different domains.

By integrating data and outcomes of analyses from other levels, investigations are enabled, whose input parameters cannot be derived directly from available information and therefore would require separate simulations. For instance, the establishment of simulation groundwork for level 4 can be achieved by using outcomes from level 3. Consider a scenario where an emergency stop of a conveyor induces mechanical stress on the gear, a calculation of this is unattainable. However, through the exchange of information between level 3 (calculating the loads induced by the inertial reaction of the emergency stop) and level 4 (using the calculated loads and calculating the mechanical stress), it becomes feasible to compute the effects on the gear. Something like the information exchange from this example could be used to facilitate a comprehensive analysis of an entire hub.

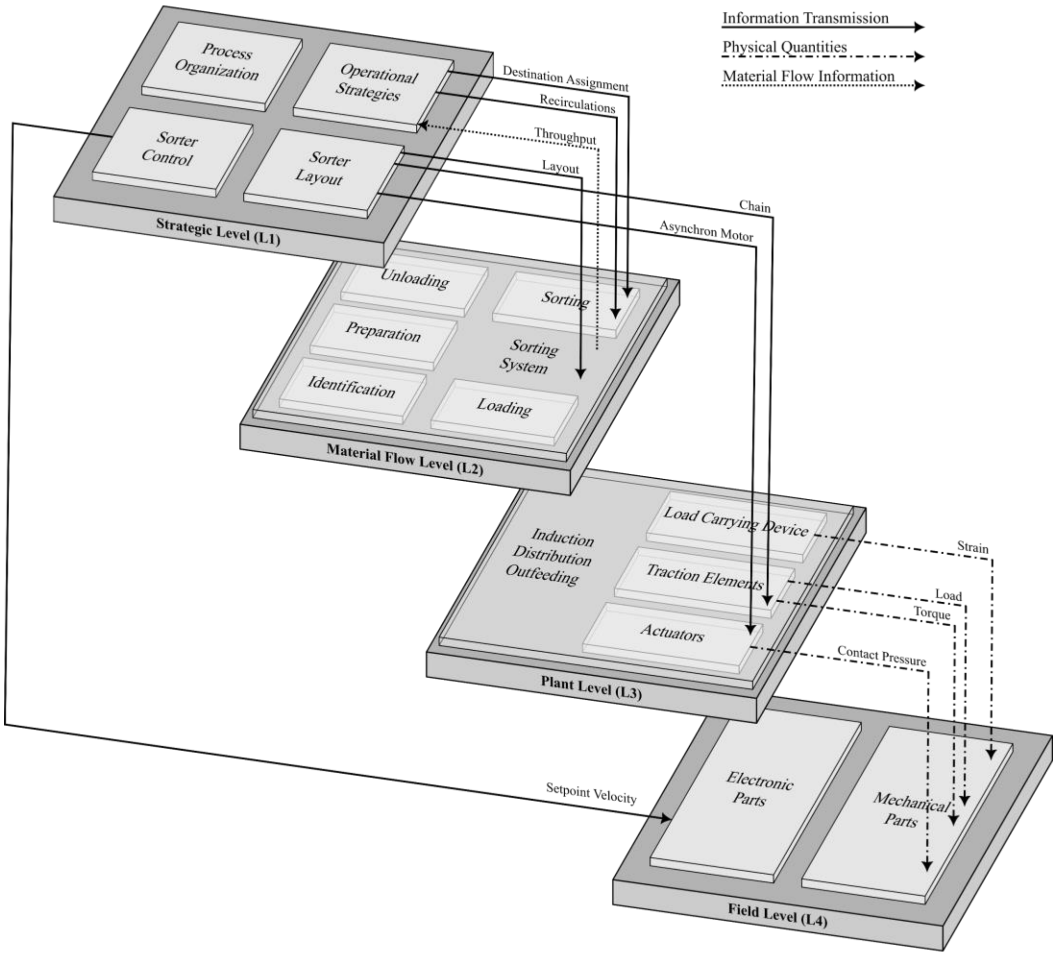

Fig. 2. Classification Model

2.2 Strategic Level (L1)

This level determines the design of the sorting system and processes within a hub. The system boundaries are defined in such a way that only the sorting system itself is considered[3]. Therefore, the components are aligned with the construction of a sorting system according to [7]. These components encompass architectural aspects, such as

[3] Future advancements of the classification model may expand the current system boundaries, such as by considering trucks, which deliver or pick up the shipments at the gates of the hub.

determining the layout, the sorting technology, and the sorter control. Moreover, this level also encompasses process organization, for instance, the handling of non-conveyable goods, as well as the implementation of various operational strategies.

For the selection and design of the aforementioned components, decision support is indispensable. An example of this is the throughput calculated at level 2, which can be examined both for the overall system and for individual subsections. This is an initial example of the connections between the levels: Information calculated at level 2 serves as a basis for decisions at the first level.

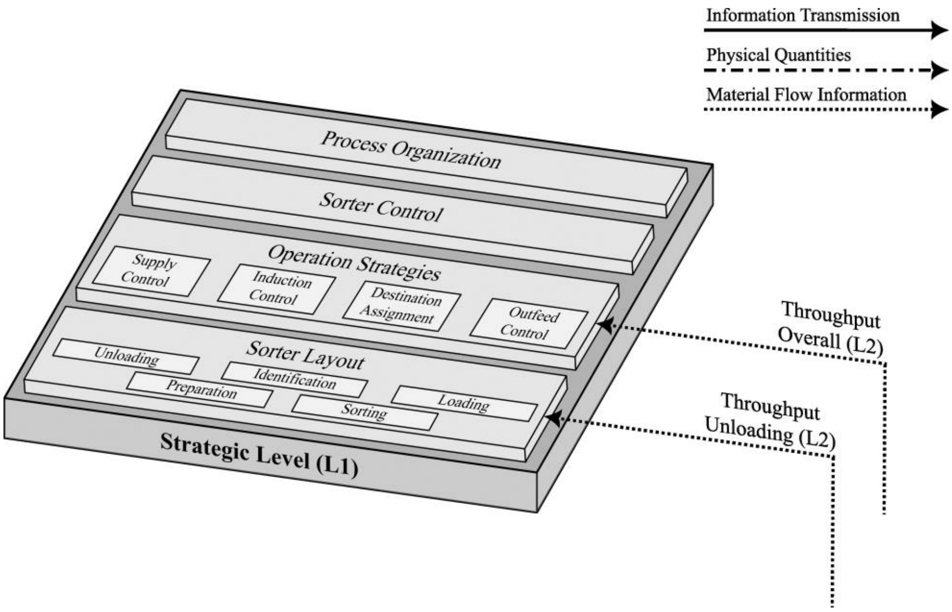

Fig. 3. Strategic Level (L1)

2.3 Material Flow Level (L2)

Level 2 encompasses the analysis of material flow within the sorting process. This level primarily involves throughput analysis to assess the performance of the system. Additionally, the examination of shipment movement behaviors falls under the purview of this level, aiding in the analysis of, for instance, sorting errors. The structure of this level is based on the individual stations within the sorting process, derived from the overview depicted in Fig. 1. Specifically, it consists of five main process components: unloading, preparation, identification, sorting, and loading. For a detailed examination, sub-processes have also been defined.

An instance of interaction with other levels was already mentioned in section 2.2. The exchange occurs bidirectionally here (e.g. the layout information held in level 1 affects the material flow calculation in level 2, which in turn influences the design of the layout again). To determine the throughput, the layout of the sorting system and the parameters of the strategy under investigation needs to be inherited from level 1. Examples of such strategy parameters are shown in Fig. 4.

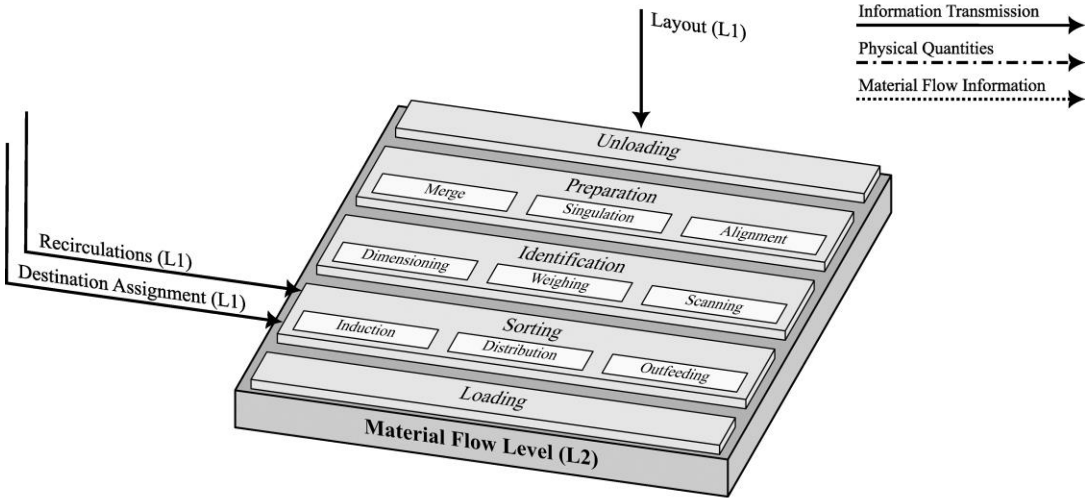

Fig. 4. Material Flow Level (L2)

2.4 Plant Level (L3)

The plant level focuses on the specific conveying equipment used within distribution centers. This conveying equipment can be divided into two main categories: continuous conveyors and discontinuous conveyors. Sorting systems are assigned to continuous conveyors, while novel technologies like Automated Guided Vehicles (AGVs) are classified as discontinuous conveyors according to [14].

Within this work, the focus is placed on the field of continuous conveying technology, deliberately excluding the relatively new realm of AGVs to address the current state of the art. The presented approaches are equally applicable to the areas of induction, distribution, and outfeeding, as these areas can be broken down into fundamental components: load carrying device, traction elements, and actuators [7]. Information regarding their structural design is sourced from the overarching level 1. Once the layout is established, using information about the loading of the conveying equipment (L2), the respective loads occurring in the aforementioned components can be determined. The identified loads on the carrying device serve as the basis for further investigations conducted in level 4.

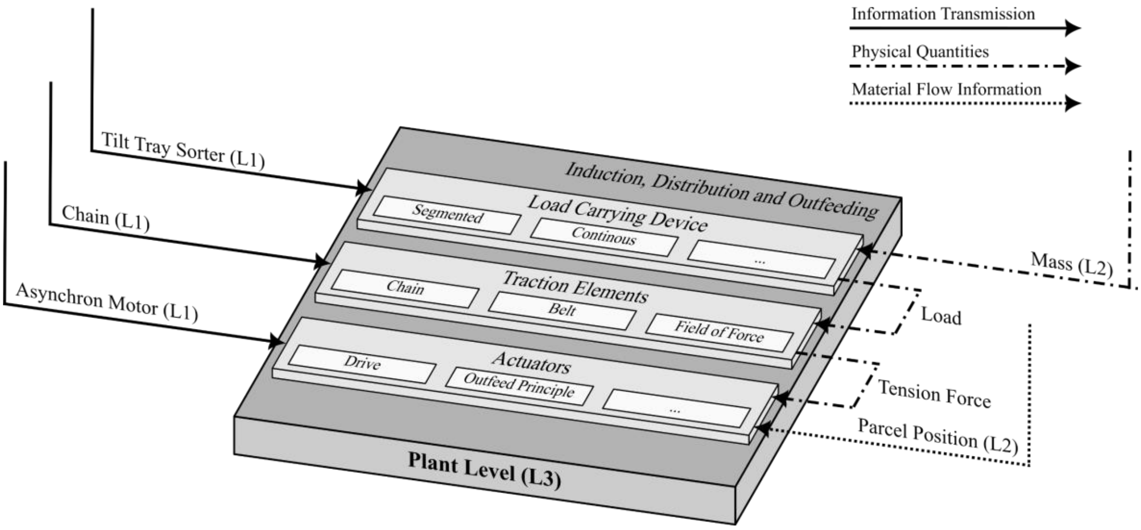

Fig. 5. Plant Level (L3)

2.5 Field Level (L4)

The field level or component level within the classification model encompasses the physical components and parts involved in the sorting system on the lowest level. These can include elements such as support rails, housings, or connecting elements. Alternatively, components for power transmission such as drive wheels, chain wheels, or gears can be assigned to this level [7]. The system boundary here defines a division between the utilized individual parts and their internal structures. Information regarding their structural design is, once again, derived from the layout definition in level 1. Additionally, sensors for process monitoring and control, as well as potential scanner or verification systems, are also part of this level.

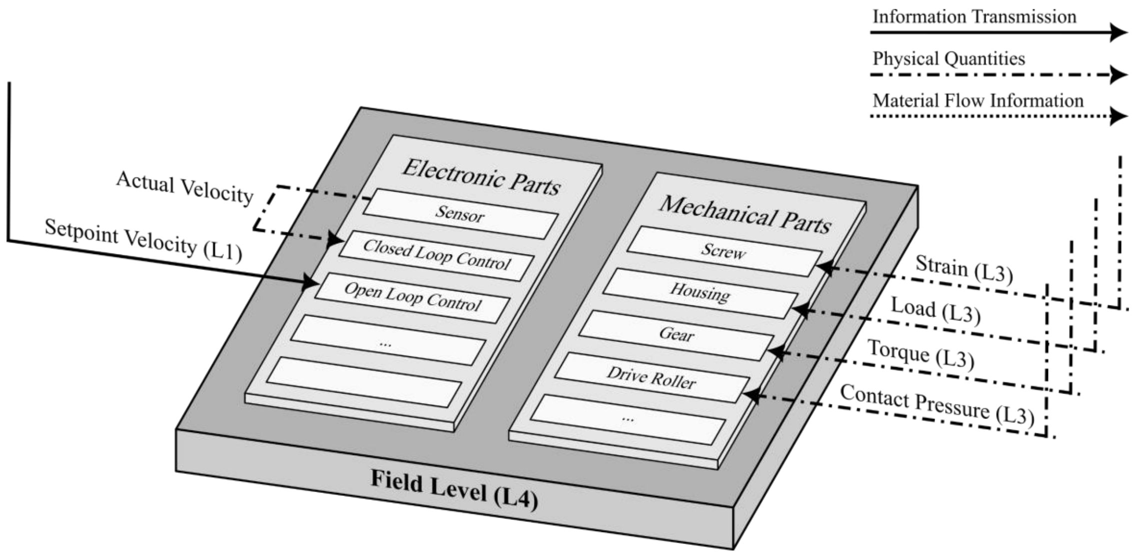

Fig. 6. Field Level (L4)

3. Results and Discussion

This section fulfills the allocation of potential tools of Digital Engineering to the respective levels of the classification model. A delineation is made for the "Design and Simulation" domain (see Table 1), as it corresponds to the expertise of the authors.

To provide an overview, existing works in these levels are exemplarily cited, while also highlighting gaps and opportunities. Furthermore, upcoming developments that the authors are engaged with are presented, offering additional perspectives for the research field. The section concludes with an overview in the form of a table (see Table 2), which illustrates the allocation of Digital Engineering tools to achieve the goals of sustainability across the entire product lifecycle. This representation facilitates a coherent depiction of the linkage between tools and sustainability goals.

3.1 Tools at the Strategic Level

At the strategic level, the primary focus lies within the realm of Computer-Aided Design (CAD), with an emphasis on Knowledge-Based Engineering (KBE)[4]. This level primarly revolves around the development of sorting system layouts.

For instance, [25] engages in the generation of systems using continuous conveyors while considering numerous technical constraints through a KBE approach. However, the utilization of information from the generated networks is not envisaged in this context. Another stride in this direction was taken by the company Interoll, wherein a KBE solution with a strong geometric orientation was published. This execution is realized within an AutoCAD plug-in and focuses on layout visualization [26] [27].

The aforementioned works heavily emphasize the CAD aspect, omitting the connection to intralogistics. A significant advancement in this domain was achieved by [23], who developed a KBE methodology enabling the integration of both design data and logistical network information into the planning process. This offers the potential to carry out detailed machine configuration based on existing three-dimensional designs, facilitating the integration of existing knowledge into planning processes. Simultaneously, it enables the derivation and retention of the logistical network information from the planned machines.

3.2 Tools at the Material Flow Level

At this level, two distinct types of tools are exemplified. Firstly, process simulation is examined in greater detail, followed by the presentation of the utilization of CAE methods including FEA, MBS, and DEM within this framework.

3.2.1 Material flow analysis using process simulation

Various approaches have already been demonstrated in the context of material flow simulation for hubs. [28] utilizing different simulation options to aid in the optimization

[4] According to [23], it is demonstrated that there are various definitions of KBE. In this paper, the definition from [24] is employed, which defines KBE as the combination of the Computer-Aided Design Process (CAD) with knowledge derived from rules, formulas, and databases.

of high-performance sorting systems. Special attention was given to the incorporation of potential failures of conveyor belts. [29] conducted simulation-based investigations to determine the throughput of various intricate sorter layouts. Another application possibility is demonstrated in the work of [30]. In that study, the discrete event simulation software AutoMod is employed to test various assignment configurations of sorting destinations to unloading stations.

It becomes evident that the use of material flow simulations as decision support for planning and operations in hubs is already firmly established. However, with the continuous development of Digital Engineering tools, additional opportunities arise that can be harnessed at this level. Therefore, actual research by the authors focuses on highlighting the potential of integrating Artificial Intelligence (AI) into material flow simulations. Special emphasis is placed on self-learning systems, as well as on conducting data analyses.

Another form of the potential of material flow analysis is presented in the dissertation project introduced in [31]. In this work, parameterizable material flow models of parcel distribution centers interpreted by multi-parameter analysis provide data to determine how sustainable single distribution process steps can be designed in future distribution centers. Moreover, these models offer an insightful evaluation of the sustainability practices within presently centers [32].

3.2.2 Analysis of the motion behavior of shipments using CAE

In addition to the layout considerations and strategy analysis, the motion behavior of shipments during the sorting process plays a significant role. Particularly, the steps of singulating and buffering, during which shipments appear in groups, are examined using Computer-Aided Engineering (CAE) to optimize these processes through software assistance. Previous investigations predominantly focused on processing cartons. In this context, both [8] and [9] employed the Discrete Element Method (DEM) to simulate singulation (i.e. the transformation of a batch of shipments into an ordered, one-dimensional sequence) and handling processes of this category of shipments. Earlier, experiments were also conducted using Multibody Simulations (MBS), where, at that time, the quantity of shipments calculated in the simulation was too low to achieve meaningful insights [33].

Although the aforementioned investigations presented promising approaches, they are limited to a shipment spectrum consisting solely of cartons. To simulate the more practical spectrum as presented in [4], further research in this domain is required. There are already initiatives for modelling individual flexible shipments. [34] also utilized Multibody Simulations (MBS), while [35] is currently exploring the combination of the Finite Element Analysis (FEA) and MBS, known as Multi Body Flexible Dynamics (MBFD), to address this gap.

3.3 Tools at the Plant Level

In this section, the focus is on simulation-based mechanical design and verification of sorting systems and their components. Currently, technical simulation models for intralogistics applications in the industry are not yet established. Only a few approaches such as [36], where Multibody Simulations were used to analyze the effects of preload force on chain force, are evident. [37] also addressed the vibration simulation of round steel electric chain hoists using system simulation. Additionally, [38] supported the design of a chain undercarriage using Multibody Simulation. These examples are not directly applied to sorting systems, but the structures of the models and simulations can be utilized to create cross-references to them.

In contrast, simulation-based approaches are long-standing and integral to other industries, such as the automotive sector. These industries benefit from tailored simulation programs offering standardized modules for various problems. However, intralogistics presents a comparatively niche context, necessitating the laborious development of customized models [12].

Contributing to this research gap is the dissertation project introduced in [39]. It addresses the challenge of complexity management of continuous conveyors with closed discrete traction elements, focusing on energy optimization of drive units. The core objective is to develop a comprehensive system model enabling precise calculation of the force on the traction element and therefore required drive power. Through the investigation and comparison of various methods, including analytical calculations, Multibody Simulations, and system simulations, efficient approaches for determining loads in such systems are enabled. Initial steps for finding a suited simulation model are now presented. Modern software solutions and simulation programs are readily accessible with intuitive usability today. While these aspects facilitate rapid result generation, they often lack immediate added value [40]. For this reason, a systematic approach (see Fig. 7) was developed for selecting the most suitable modelling approach for the conveyor systems which includes the sorting system.

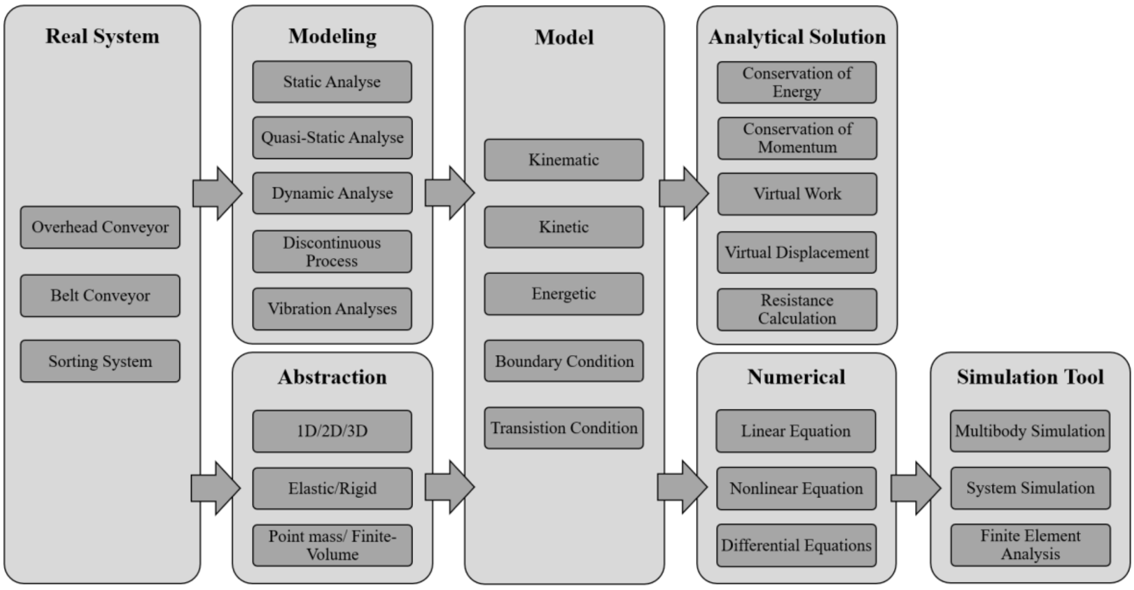

Fig. 7. Morphology for system modelling [39]

This categorization model aims to find the most suitable Digital Engineering tool for purposeful modeling, considering specific requirements and constraints. Once the necessary simulation domain is determined, the focus shifts towards constructing corresponding models, which serves as an initial step in realizing a digital twin. A methodical approach is pursued in this process, ensuring the structuring and parameterization of models in accordance with specific technical requirements. This process marks the initiation of the connection between real systems and their virtual representations, enabling comprehensive analysis, evaluation, and optimization. The resulting digital twin allows, for instance, testing various load scenarios during design and adjusting the drive design accordingly. It also facilitates real-time adjustment of drive control during operation, ensuring the drives operate at their optimal operational point, thereby enhancing the efficiency and sustainability of the system.

3.4 Tools at the Field Level

In the field level, which involves individual components (often standardized parts) commonly applied across the mechanical engineering domain, detailed considerations are omitted. Designing components using Digital Engineering tools has long been the state of the art. Approaches closely resemble those shown in level 3.

However, for such designs, knowledge of the applied loads is necessary, which in turn proves to be highly complex. Especially in sudden situations like load changes, emergency stops, or component failure, determining reaction forces for calculations is challenging. This gap can be addressed through results from simulations at other levels. The results from one level serve as the simulation basis for the other level.

An example of this could arise, for example, at the strategic level, where an increased throughput and consequently higher conveyor velocity are required. The repercussions on the material flow can be illustrated at the material flow level. Consequently, from this level, the load on the conveyer of the sorting system can be transmitted to the plant level, where the load on the drive directly influences the reaction force on the gears at the field level. This enables a holistic examination of the influences among the various levels.

Particularly useful in this context is the field of CO-Simulation, where different simulation domains can be coupled. Which also, is one of the core research areas at the Institute of Logistics Engineering at the University of Technology in Graz.

3.5 Allocation of Digital Engineering tools for achieving Sustainability Goals throughout the Product Lifecycle

In this section, the assignment of the aforementioned Digital Engineering tools to fulfil sustainability goals across the entire product lifecycle is addressed. There is again a focus on the "Design and Simulation" domain. The examination of sustainability throughout the product lifecycle is carried out separately in each of the four levels. The dimension of the lifecycle, where defined by a summary of [41], which leads into three different phases: design and development, operation and optimization and decommissioning. Optimization is understood in such a way that it is carried out on the operational running system based on the knowledge gained during operation. The goals of sustainability were defined as ecological, economic and social [42].

Furthermore, the table includes a division into "state of the art" and "development phase". The table is synthesised by the observations made in the preceding section, where the current state of the industry and research was highlighted.

The utilization of CAD and KBE methods is primarily concentrated at the strategic level, where models are chiefly employed for layout planning purposes. The material flow level is notably influenced by DES, which serves as a tool for estimating throughput and assessing feasibility. In the material flow level, FEA and MBS is applied to examine the motion behavior of individual shipments. The plant level is characterized by the dominance of MBS and FEA, wherein multibody simulations are utilized to replicate the dynamic behavior of the facility. In this context, there exist ample opportunities, particularly in the realm of CO-Simulation, for managing complex systems through the combination of different simulation domains. FEA is further employed for evaluating component strength under varying loads. Analogous methodologies are observed at the field level, where similar principles are employed for individual components.The economic aspect is inherent in the process, whether it involves conducting relevant planning during the design and development phase or making adjustments to existing facilities in the realm of operations and optimization. These adaptations can serve not only economic purposes but also environmental ones. Importantly, a combination of both objectives is achievable.

Table 2 Allocation of Digital Engineering tools

● State of the art ○ Development Phase			**Life Cycle**		
			Design and Development	Operation and Optimization	Decommissioning
Strategic Level	**Sustainability**	Ecologic			
		Economic	CAD / KBE ○	CAD / KBE ○	CAD ○
		Social			
			Design and Development	Operation and Optimization	Decommissioning
Material Flow Level	**Sustainability**	Ecologic	FEA ○, MBS ○, DEM ●, DES ●	DES ●	
		Economic	FEA ○, MBS ○, DEM ●, DES ●	DES ●	
		Social		DES ●	
			Design and Development	Operation and Optimization	Decommissioning
Plant Level	**Sustainability**	Ecologic	FEA ○, MBS ○, DEM ○, SS ○, CO-Sim. ○	FEA ○, MBS ○, SS ○, MBS/FEA-CO-Sim. ○, MBS/SS-CO-Sim. ○, FEA/SS-CO-Sim. ○	
		Economic	FEA ○, MBS ○, DEM ○, SS ○, CO-Sim. ○	FEA ○, MBS ○, SS ○, MBS/FEA-CO-Sim. ○, MBS/SS-CO-Sim. ○, FEA/SS-CO-Sim. ○	
		Social			
			Design and Development	Operation and Optimization	Decommissioning
Field Level	**Sustainability**	Ecologic	FEA ●, MBS ●, SS ●, MBS/FEA-CO-Sim. ○, MBS/SS-CO-Sim. ○, FEA/SS-CO-Sim. ○	FEA ●, MBS ●, SS ●, MBS/FEA-CO-Sim. ○, MBS/SS-CO-Sim. ○, FEA/SS-CO-Sim. ○	
		Economic	FEA ●, MBS ●, SS ●, MBS/FEA-CO-Sim. ○, MBS/SS-CO-Sim. ○, FEA/SS-CO-Sim. ○	FEA ●, MBS ●, SS ●, MBS/FEA-CO-Sim. ○, MBS/SS-CO-Sim. ○, FEA/SS-CO-Sim. ○	
		Social			

Another aspect that has been noted during the allocation process is that the utilization of Digital Engineering tools in the "decommissioning" domain has not yet been implemented. This reveals a significant gap that requires further investigation.

Furthermore, it should be noted that in the social domain, no connection points are currently identified. Progress in this area is also essential. For instance, simulations can be employed to design ergonomic workspaces or test the impact of vibrations on employees, highlighting the need for further developments in this field.

Additionally, it's worth noting that certain tools are few featured in the table that were not discussed in section 3. This discrepancy arises from the fact that these tools represent research findings which, due to confidentiality constraints, could not be disclosed.

4. Conclusions

This publication aimed to demonstrate the potential of utilizing Digital Engineering tools in the design and optimization of mechanical components and processes within hubs of the CEP industry. The initial step involved introducing a classification model that structures the various processes and components within a hub into four hierarchical levels. In addition to examining each level individually, special attention was placed on the exchange of information between these levels. Subsequently, examples were presented to illustrate how this information can be leveraged for the application of Digital Engineering tools. Finally, an overview in the form of a table was created, illustrating the phases of the product lifecycle where these tools can be employed and how they align with sustainability goals.

The benefit of the introduced classification model and the subsequent analysis of Digital Engineering tools is manifested in different ways. The systematic categorization into levels for distinct domains allows the allocation of Digital Engineering tools appropriately. Following the information flow, it becomes possible to select the tools that meet the requirements. The representation of information flow between the levels also highlights potential connections between different domains, enabling a holistic view of the hub.

As a result, when implementing changes to achieve sustainability goals, a comprehensive assessment of their impact on other levels becomes possible. For instance, the impact of a strategy change defined at the first level can be captured at the material flow level, which in turn has direct implications for the plant level. This effect extends to the field level, where the impacts can be examined down to individual components, as outlined in the example in section 3.4.

The overview shown in section 3.5 provides an opportunity to identify suitable Digital Engineering tools in hubs that contribute to achieving sustainability objectives. Simultaneously, it identifies gaps where further investigations and developments of Digital Engineering tools are necessary, for example in the phase of decommissioning.

The conceived classification model as well as the allocation of Digital Engineering tools in this work predominantly focuses on the fields of design and simulation.

Hence, future considerations could explore other disciplines within the domain of Digital Engineering. Additionally, expanding the current model is still possible; for instance, system boundaries could include the inbound and outbound transport of shipments. Generalizing the approach to logistic centers in general is also conceivable.

In summary, the study shows that the utilization of Digital Engineering tools for the design and optimization of hubs is already used in practice. However, there remains further potential for research and development. The research works and dissertations from the authors contribute to unlocking this potential and advancing this field of research. Further investigations in this domain are planned as soon as additional results become available. This will involve expanding upon the demonstrated model with new ideas and providing exemplary insights into the simulations.

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