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REDUCING TRANSIENT BEHAVIOR IN SIMULATION-BASED DIGITAL TWINS: A NOVEL INITIALIZATION APPROACH FOR ORDER PICKING SYSTEMS

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ABSTRACT

In the context of facilitating operational decision-making through simulation-based digital twins, precise and expeditious synchronization of simulation models with real-system load states is paramount. Such synchronization serves to attenuate the typical transient behavior observed in material flow simulation, confining it to a brief temporal window. This paper delineates a novel conceptual framework for initializing simulation models, illustrated through an exemplar of an order picking system integrated with SAP Extended Warehouse Management as its warehouse and operation management system. Through empirical inquiry, the ramifications of the proposed initialization framework on simulation model transient behavior are scrutinized. Notably, the reference simulation model commences in a state of 'empty' load. The findings of this study evince that the proposed approach yields a significant improvement in transient behavior.

1 INTRODUCTION

The term 'digital twin' has gained widespread usage across diverse domains, generally denoting a virtual representation of a product, process, or system. In 2012, scientists at the National Aeronautics and Space Administration (NASA) introduced the term to describe a digital flight system that allows for analysis and prognostic capabilities. (Piascik 2012; Qi, 2018; Tao 2018).

Various published instances of digital twins encompass a wide array of use cases and technical configurations. Kritzinger et al. (2018) have categorized these diverse approaches into digital models, digital shadows, and digital twins, as illustrated in Figure 1.

Central to the notion of digital twins is the establishment of a bidirectional data interchange between the physical system and its digital counterpart (Harper 2019; Kritzinger 2018; Tao 2018; Qi 2018). Although the frequency of data exchange remains unspecified, Digital twins hold promise for seamless integration into decision support systems, facilitated by the reciprocal data exchange. By maintaining a virtual real-time depiction of the real system, digital twins enable proactive assessment of decision feasibility within the virtual environment. In addition to the simulation-based digital twins addressed in this paper, there are other approaches to evaluating alternative courses of action in decision support systems.

To mitigate the risk of erroneous decision-making and facilitate decision review, the synergistic utilization of digital twins alongside forecasting models is advocated. This approach, encapsulated within the realms of predictive or prescriptive analytics in data analytics, enables purposeful and anticipatory optimization of complex logistics and production systems during operational phases. A particularly promising avenue entails the creation of a digital twin endowed with predictive or prescriptive analytical capabilities, finding applications in diverse domains such as production control, machine parameter optimization, and workforce management (Kritzinger 2018)

Figure 1 delineates the interrelation between distinct tiers of digital models and data analytics. Furthermore, the figure provides an overview of the typical data basis used and the authority responsible for decision-making. Data harvesting entails the collection and analysis of system data devoid of explicit modeling, as embraced by the paradigms of digital models, digital shadows, and digital twins. Often, data harvesting is synergistically integrated with other methodologies.

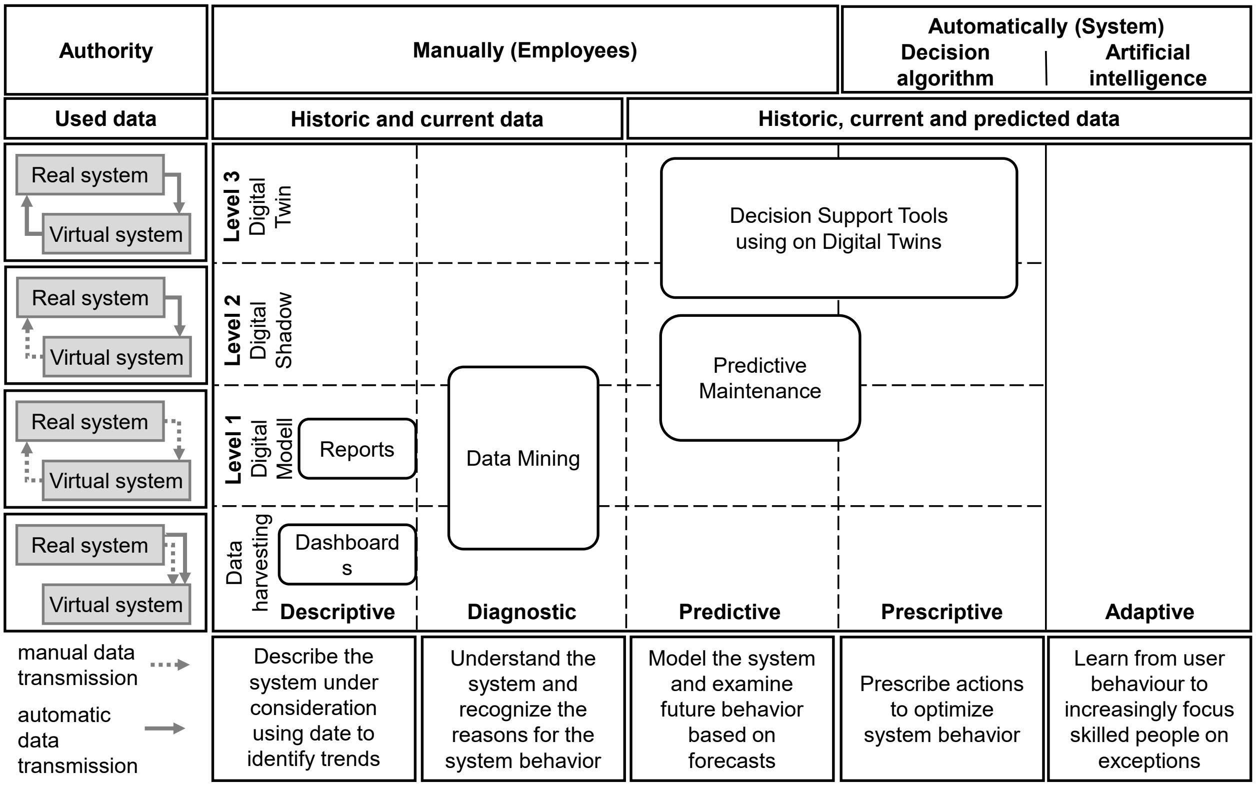

Figure 1: Different levels of digital models and areas of application (based on Kritzinger 2018; Kauke 2021).

At Level 1, digital models facilitate the generation of reports and retrospective or descriptive analyses of systems. These analyses are typically prompted at periodic intervals and cater to specific inquiries, primarily utilized in strategic planning contexts owing to limited automation in data exchange processes.

Digital shadows (level 2) automate data transmission from real to virtual systems, furnishing copious data for analytical purposes. However, compared to digital twins, digital shadows exhibit relatively subdued modeling of system behavior and interdependencies. Consequently, digital shadows excel in scrutinizing discrete facets within a system, such as individual machinery. Leveraging their extensive data repositories, digital shadows enable precise prognostics, encompassing maintenance requirements.

Conversely, digital twins (Level 3) boast comparably extensive data repositories while additionally modeling inter-system interactions, affording a holistic portrayal of system dynamics. Notably, digital twins often incorporate simulation models that autonomously process requisite data, thereby supporting the prescriptive analytics paradigm.

When employing simulation models for operational decision support, initializing the simulation model at the onset of each simulation run poses a massive challenge. It is imperative to meticulously assess the real system's current state and seamlessly transmit this information to the simulation model. Moreover, ensuring the alignment of order data utilized for simulation with the simulated system state is paramount.

This paper presents a novel approach to initializing simulation models for order picking systems, leveraging contemporary order data sourced from an SAP Extended Warehouse Management (EWM) system. The proposed methodology entails data importation, analysis, and seamless integration of system status updates from the SAP system into the simulation environment.

2 INITIALIZATION OF SIMULATION MODELLS

The initialization of simulation models encompasses the establishment of initial conditions and starting values requisite for commencing simulations. It is imperative to meticulously define the initial conditions pertaining to diverse variables and parameters within the model to ensure the production of realistic and meaningful outcomes. This entails specifying crucial attributes such as the initial positions of transportation units or other pertinent properties delineating the state of the internal transport system at the simulation's onset. The process of initialization profoundly influences the transient behavior of the model. The transient phase denotes the initial period during which the simulated system or process adapts from its initial conditions towards a stable or steady-state configuration. As elucidated by Hanisch et al. (2005), the transition time denotes the duration necessitated for a system to evolve from its initial state to a phase where its behavior exhibits greater regularity or predictability, thereby diminishing the impact of initial conditions.

Simulation constitutes a pivotal tool in material flow planning, facilitating the validation of planning outcomes prior to system implementation. Frequently, simulation runs commence with an 'empty' model, indicative of all conveyors being devoid of material and no orders being initiated. Metrics garnered during the transient phase often deviate from reality. To avert erroneous interpretations, critical system metrics should be assessed post the transient phase's culmination. Notably, the transient phase may extend over several hours of simulation time, particularly for expansive and intricate models. Simulation models integrated within the ambit of digital twins necessitate minimal transient phases. Consequently, thorough parameterization of the simulation model prior to commencing simulation runs is imperative to accurately reflect the current load status of the system.

2.1 RELATED WORK IN THE FIELD OF ORDER PICKING SYSTEMS

Order picking constitutes a critical process within intralogistics, particularly with the surge of online commerce (Günthner 2014). The efficiency of the order picking system profoundly influences the storage dynamics of a diverse array of articles and the expeditious delivery of goods, thus establishing an indispensable competitive edge, particularly for online retailers. The system operates with four principal objectives:

- High performance
- Cost efficiency
- Reduced throughput times
- Adherence to delivery deadlines

Performance, quantified in picks per hour, ensures the expeditious processing of customer orders, while cost-effectiveness remains a crucial consideration. Minimization of lead times significantly enhances overall system performance, necessitating the mitigation of buffer stocks, particularly in multi-area systems. Adherence to cut-off times is paramount for meeting delivery deadlines.

The pursuit of these objectives has been the focal point of scholarly inquiry for decades, resulting in the formulation of various approaches that, contingent upon their attributes, can exert either a positive or negative influence on the system. Numerous comprehensive literature reviews have been published over time, warranting acknowledgment (Kosten 2017; van Gils 2018). The work of van Gils et al. holds particular relevance for the development of this research endeavor.

Parameters under scrutiny are broadly categorized into strategic, tactical, and operational planning issues (van Gils 2018). Strategic parameters encompass layout design, automation levels, and handling equipment. While the digital twin does not inherently investigate variations in these parameters, it acknowledges the likelihood of an overarching system comprising diverse subsystems characterized by distinct degrees of automation, layouts, and handling equipment. Operational parameters pertain to resource allocation, including workforce size, zoning, and storage assignments, with considerations such as batching, routing, and job assignment falling within this domain.

This classification does not account for time intervals in the examination or modification of planning issues. It is reasonable to anticipate a significant increase in the frequency of these issues from strategic to operational levels. Consequently, the digital twin is designed to consider parameters at intervals ranging from daily to hourly or shorter, rendering tactical and operational parameters inherently relevant.

Periodic reassessment of specific actions is essential to ensure alignment with the defined objectives of the picking system. The scope for action encompasses three primary aspects, with the optimization of picking tour sizes emerging as a pivotal lever. Picking tours, whether singular or comprising multiple orders (multi-order-picking), necessitate optimization to meet lead time and efficiency benchmarks.

Dynamic human resource planning systems facilitate the flexible allocation of available personnel across various sections of the picking system, thereby enhancing workforce utilization in response to daily fluctuations in orders. Synchronization of anticipated partial order arrivals through time-differentiated release of picking orders can curtail buffer area requirements and bolster system reliability. The current approach to determining release times and worker allocation is based on experience, which may not always result in good decisions. Conversely, a digital twin possesses the capability to curate a tailored suite of measures from the available options through monitoring, forecasting, and simulation, optimizing outcomes to meet specific requirements.

2.2 RELATED WORK IN THE FIELD OF INITALIZATION OF MODELLS

This section examines papers that have addressed the topic of initializing simulation models, either in a narrow or broad context.

Hanisch et al. (2005) describe two approaches for initializing online simulation, which are comparable to the simulation-based digital twin mentioned earlier. The first approach involves running a simulation model (parent model) synchronously with the real system. This model can be replicated to conduct a predictive simulation more quickly, allowing for the forecasting of future states. The second approach involves creating a model as needed and initializing it with current measured values. This approach is similar to the one presented in this article. However, the authors did not provide a description of the data analysis or the exact initialization process in their article.

Le and Fang's (2024) literature review offers a comprehensive overview of the current research on digital twins for logistics and supply chains. However, the review lacks detailed consideration of the topic of initialization, with most sources only briefly mentioning its necessity.

The work of Ashrafian and Pedersens (2023) focused on the development of a digital twin for an order picking system. The article explains the data used for the simulation, but does not cover the interpretation of the real-world data or the procedure for initializing the model.

Rabe and Dross (2015) describe the architecture of a decision support system for logistics systems and the use of a reinforcement model. They demonstrate how process and warehouse data can be used for training and validation. However, they do not provide a detailed procedure explanation.

Nicoletti and Appolloni (2024) present a framework for digital twins as a service for 5PL logistics providers. The framework should include functions for data preparation and analysis, with simulation being an essential component. However, the authors do not provide a concrete procedure for model synchronization.

Simulation-based digital twins are utilized to optimize and control production systems. For example, Rachner et al. (2023) proposed an approach for flexible production systems in which workstations are connected via AGV. The authors emphasize the significance of linking real and virtual systems in terms of data technology, but do not provide a detailed description.

Models for testing are also used for virtual commissioning. Albrecht et al. (2024) presented an approach for automatic model generation and initialization. However, the focus of this work is on coupling with control instances for signal exchange. This area of application presents other challenges and cannot be compared with the initialization of material flow models for an internal transport system.

Bergmann et al. (2011) conducted a systematic investigation of the data required for initialization in production systems, how to transfer these data to the simulation model in a standardized way, and the potential problems that need to be solved to adequately initialize the model elements. The authors proposed a solution based on the CMSD standard, which can be extended to logistics systems. However, the required data analysis is not presented in detail.

In summary, transferring the real system state to the digital model is necessary to use digital twins. However, many publications do not provide detailed information on data preparation and model initialization. From the author's perspective, this is an essential aspect that significantly affects the quality of the results, particularly when investigating over a short-term time horizon.

2.3 RESEARCH METHOLOGY

This paper elucidates the initialization process of a simulation model within the framework of a case study. The methodology entails the automated extraction and analysis of data sourced from an SAP EWM system. Furthermore, the narrative outlines encountered challenges during the analytical phase. Additionally, the paper delineates discrepancies in order processing times resulting from non-synchronization between the simulation model and the prevailing system status, as observed within a simulation study. The primary objectives of this article are to address the following research inquiries:

- How can the current system status be extracted from SAP EWM data?
- How can the analyzed system state be seamlessly transferred to the simulation model?
- What are the ramifications of model initialization on simulation outcomes?

3 USE CASE

This paper illustrates the concept of initialization within the framework of a 'distribution center' (DC) use case. The DC comprises several storage zones and a sizable order picking area. Numerous inbound goods areas receive incoming shipments, while multiple outbound areas dispatch goods. Spanning across an expanse of 20,000 m², the DC has the capacity to accommodate up to 60 industrial trucks and facilitate concurrent order picking tasks by 25 workers. The order picking process is based on the person-to-goods principle. Items are provided on pallets in racks, which are located on the lower level. According to VDI 3590 (1994), this is a static and decentralized provision. The worker selects the required quantity from the pallet and places the picking units on the pallet, which is subsequently delivered to the customer. Figure 2 presents a segment of the simulation model.

This section elucidates the material and information flow within the context of order picking. Stock Keeping Units (SKUs) are initially stored on pallets within a physical warehouse, serving as the source handling unit in SAP EWM. A warehouse operator retrieves these goods and arranges them onto a pallet designated as the destination handling unit. Upon completion of the order picking process, the assembled pallet undergoes wrapping in foil before being dispatched to the shipping area. Figure 3 provides a graphical representation of this process, accompanied by detailed step-by-step information.

The initiation of the process commences with the release of the pallet for picking, prompting the creation of a warehouse order (WO-100) for SKU retrieval. Simultaneously, warehouse tasks (WT-1, -2, -3, -4) are generated for each SKU, specifying the quantities to be extracted from the source handling units. The storage locations for picking (source storage bin) are organized into types (e.g., source storage type 7200) within the EWM. Additionally, a warehouse task (WT-5) is generated to designate the final placement of the pallet. Warehouse pickers access these tasks via their terminals and proceed to the designated provision locations with picking carts. Upon confirmation of task completion, the operator records the removal of items from the source handling unit and posts them to the destination handling unit in SAP EWM. Subsequently, the operator transports the completed pallet to the designated drop-off location, confirming task WT-5. The designated drop-off location has already been allocated to a different storage type (destination storage type 7300). Upon confirmation of all warehouse tasks for the warehouse order (WO-100), signifying successful completion of all positions, a new warehouse order (WO-110) is generated. In the presented use case requiring pallet wrapping, a corresponding warehouse task (WT-6) is created. Following acknowledgment by the operator responsible for the wrapping machine, the warehouse order is confirmed. This initiates the creation of another warehouse order (WO-120) managing pallet transportation from the picking area to the shipping area, comprising two warehouse tasks (WT-7, -8). Upon completion of these tasks, the handling unit is transferred from the source storage bin to the destination resource, ensuring accurate tracking of pallet movements.

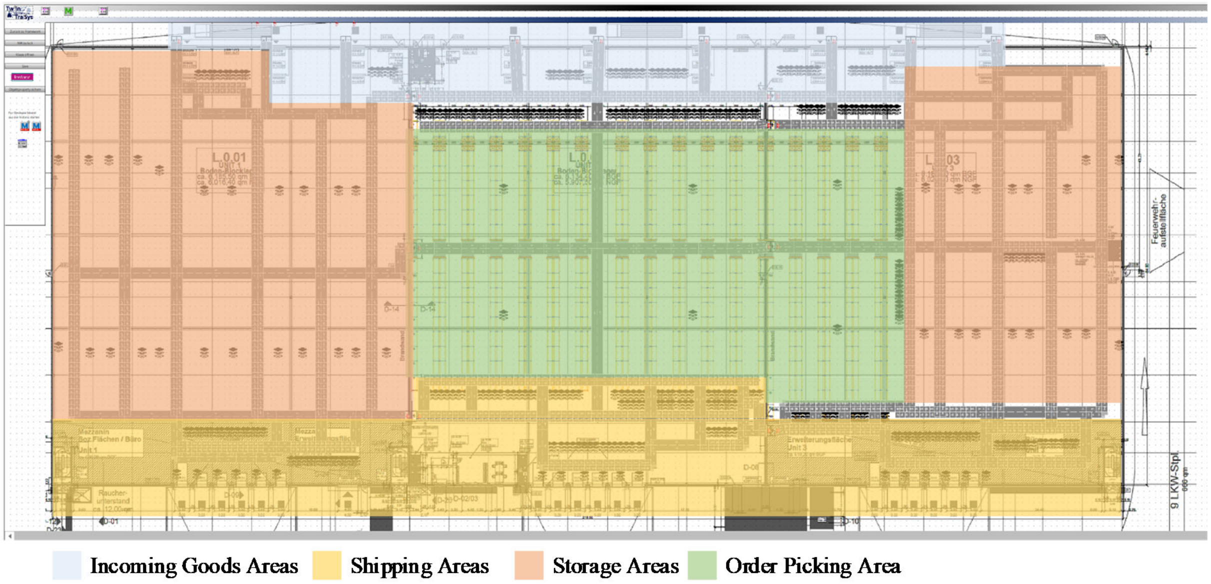

Figure 2: Simulation model of the DC using Plant Simulation with marked areas.

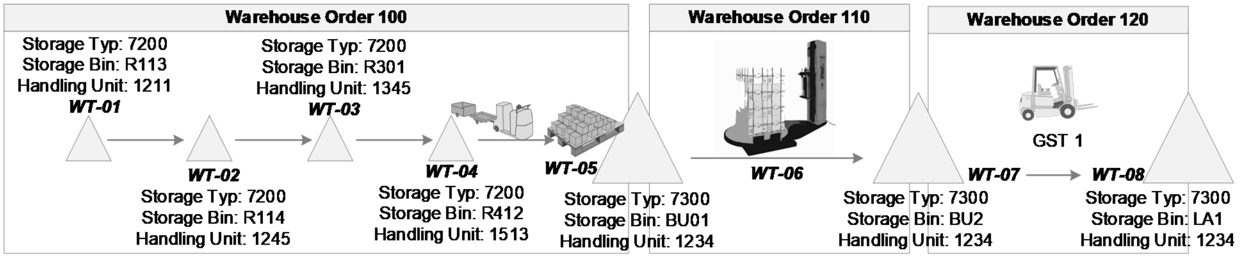

Figure 3: Illustration of the process and selected information.

Terminal displays guide forklift drivers in pallet transportation tasks, providing pertinent pickup and drop-off location information. Confirmation of task completion by the operator triggers the display of the subsequent drop-off location.

Additional warehouse orders and tasks are generated if further handling stages are necessary, mirroring the process outlined for WT-120. A comprehensive summary of pertinent information pertaining to individual warehouse orders and tasks is provided in the tables depicted in Figure 4.

The above example shows that the warehouse order and the warehouse task can be used to determine where a handling unit (e.g., a pallet) is located in the warehouse at a given time. It is not possible to determine the exact location of pallets that are currently on a forklift truck, i.e., in transit.

There are warehouse orders and tasks for all relevant processes in the DC, such as incoming goods, replenishment, stock transfers, etc. By analyzing these data, a comprehensive representation of the current task processing in the DC can be produced and transferred to the simulation.

#	WH Order (WO)	Created		Source Storage			Destination Storage			Confirmed	
		On	At	Typ	Bin	HU	Typ	Bin	HU	On	At
1	100	2.2.24	14:00	7200			7300	BU01	1234	2.2.24	14:20

#	Warehouse		Created		Source Storage		Source		Destination Storage		Destination		Confirmed	
	Order (WO)	Task (WT)	On	At	Typ	Bin	HU	Ressource	Typ	Bin	HU	Ressource	On	At
1	100	01	2.2.24	14:00	7200	R113	1211				1234	KO1	2.2.24	14:10
2	100	02	2.2.24	14:00	7200	R114	1245				1234	KO1	2.2.24	14:12
3	100	03	2.2.24	14:00	7200	R301	1345				1234	KO1	2.2.24	14:15
4	100	04	2.2.24	14:00	7200	R412	1513				1234	KO1	2.2.24	14:18
5	100	05	2.2.24	14:18			1234	KO1	7300	BU01	1234		2.2.24	14:20

#	WH Order (WO)	Created		Source Storage			Destination Storage			Confirmed	
		On	At	Typ	Bin	HU	Typ	Bin	HU	On	At
1	110	2.2.24	14:20	7300	BU01		7300	BU02	1234	2.2.24	14:25

#	Warehouse		Created		Source Storage		Source		Destination Storage		Destination		Confirmed	
	Order (WO)	Task (WT)	On	At	Typ	Bin	HU	Ressource	Typ	Bin	HU	Ressource	On	At
1	110	06	2.2.24	14:20	7200	BU01	1234		7300	BU02	1234		2.2.24	14:25

#	WH Order (WO)	Created		Source Storage			Destination Storage			Confirmed	
		On	At	Typ	Bin	HU	Typ	Bin	HU	On	At
1	120	2.2.24	14:25	7300	BU2	1234	7300	LA1	1234	2.2.24	15:01

#	Warehouse		Created		Source Storage		Source		Destination Storage		Destination		Confirmed	
	Order (WO)	Task (WT)	On	At	Typ	Bin	HU	Ressource	Typ	Bin	HU	Ressource	On	At
1	120	07	2.2.24	14:25	7300	BU2	1234				1234	GST1	2.2.24	15:00
2	120	08	2.2.24	14:25				GST1	7300	LA1	1234		2.2.24	15:12

Figure 4: Presentation of selected information on the individual warehouse tasks and orders.

With regard to the use case, it can be concluded that the material flows in the warehouse are described by warehouse orders. The progress of the orders can be identified by the status of the warehouse tasks. The example includes a warehouse task for each picking position and an additional task for dropping off the pallets. There are two tasks for each transport step. The first task represents the pick-up of a transport unit by a transport resource. The placement of the transport unit is documented by the second task. For transfer to other applications, the existing data structure must be analyzed and transferred to the initialization concept described below.

4 CONCEPT FOR INITIALIZATION

This section introduces the concept of initializing a simulation model employed to explore potential operational decisions within an order picking system situated in a DC. Given the typically abbreviated simulation period, often confined to the ensuing eight hours, minimizing the transient phase of the simulation model becomes imperative. Hence, it becomes necessary to “fill” the simulation model at the outset of the simulation run, addressing key questions such as:

- Which pallets are in the functional area (e.g., buffer locations) and which picking or transport steps still need to be completed?
- Which warehouse orders have been released?
- What resources are currently being used and where are they located in the DC?

The subsequent delineation outlines the process of "populating" the model before initiating a simulation run. Initial steps entail the extraction of pertinent data from SAP EWM and their transfer to an external database. This data transfer can be executed through methods such as CSV file exports or leveraging a

REST API in conjunction with the SAP Business Technology Platform (as discussed in Galka et al., 2023). Subsequently, the data undergo a comprehensive analysis, a procedural overview of which is provided in Figure 5 and further elucidated below.

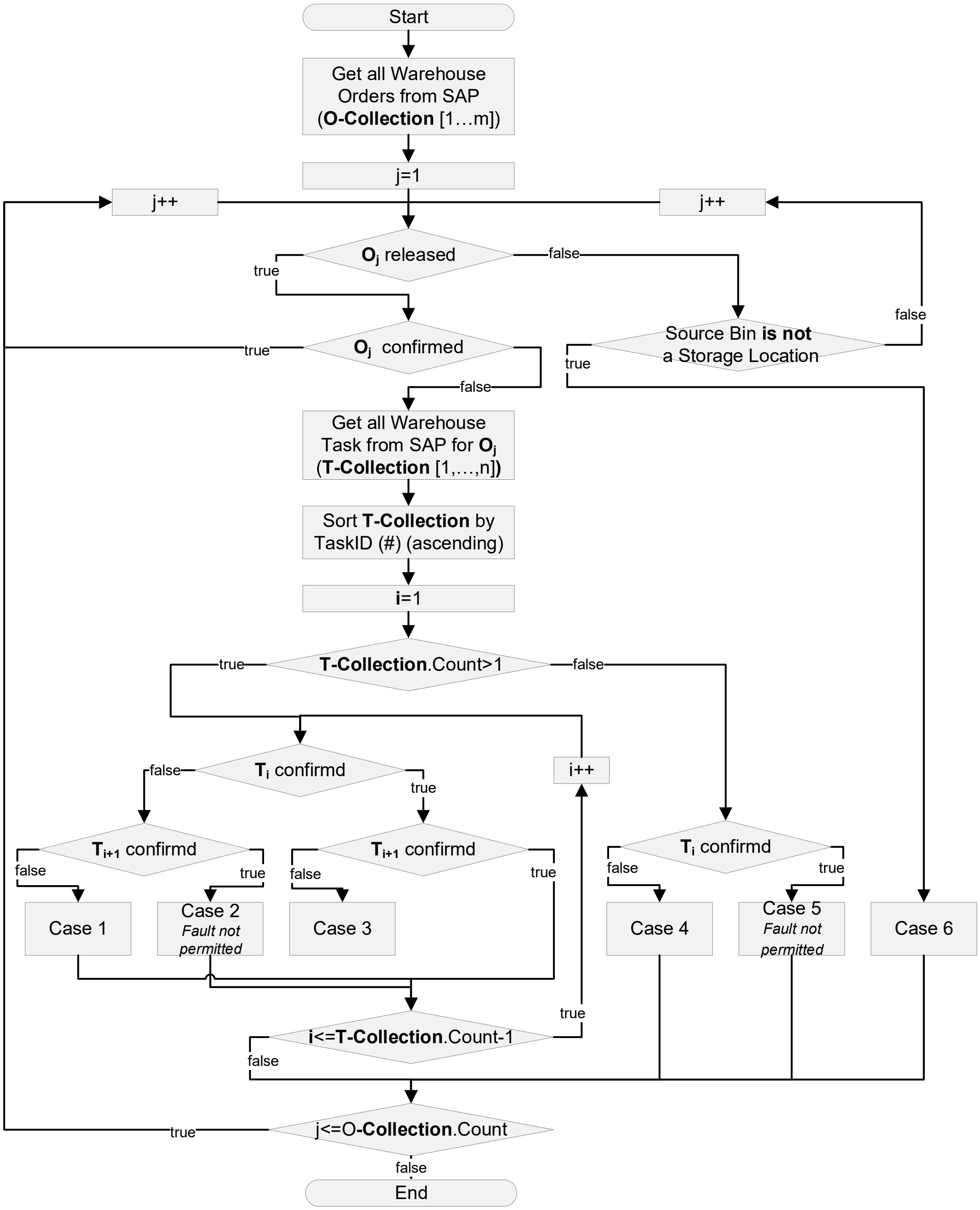

Figure 5: Presentation of selected information on the individual warehouse tasks and orders.

In addition to the warehouse order data, whose analysis is described below, further information is available for the model initializations. The number and type of vehicles can be imported from master data in SAP (cf. Galka 2023). Each vehicle has a unique identification number in SAP, which is saved when the warehouse task is confirmed. It is assumed that every vehicle used has confirmed at least one task in the analysis period. In the event that this assumption is invalid, it is presumed that the vehicle is not currently in use and that it is not created in the simulation. For simulation spanning longer periods, personnel deployment plans and shift models can also be imported. These are typically only available in limited form in the SAP system and must be imported from other data sources.

4.1 Analysis of Warehouse Orders

For each warehouse order, the algorithm verifies its release status and whether it has been fully processed, indicated by confirmation. Fully processed orders, where subsequent orders have been generated or the process has concluded, are excluded from initialization and simulation. Orders not yet released undergo further scrutiny to determine their starting position within the warehouse. If the starting position corresponds to a standard storage location, e.g., on a rack, the order is treated conventionally in subsequent simulation. However, if the source bin is a functional area, such as a buffer location, special consideration is warranted during model initialization. Here, the pallet is generated within the appropriate functional area in the simulation model, and the order is added to the list of pending warehouse orders (**case 6** in Fig. 5). As these orders have not been released, no associated warehouse tasks are present in the analyzed dataset; these tasks are created dynamically during the simulation.

4.2 Analysis of Warehouse Tasks

Regarding warehouse orders that have been released but remain unconfirmed, a meticulous analysis of the associated warehouse tasks is imperative to accurately convey the status of order processing to the simulation model. This entails scrutinizing the warehouse tasks linked to the respective order. Warehouse tasks are generated in SAP EWM with ascending document numbers (#) and executed sequentially in accordance with their assigned order. While each warehouse order comprises at least one task, it may also encompass multiple tasks. The subsequent section provides a comprehensive delineation of each potential scenario.

Case 1: All warehouse tasks associated with a transfer step or picking process remain unconfirmed until the commencement of the respective process. At present, the SKUs are situated within the 'source storage bins'. These orders are allocated to the table of released orders within the simulation framework. In cases where a warehouse task already possesses an assigned resource, the corresponding order is linked to said resource. Alternatively, if the resource is yet to be instantiated within the model, it is generated at the designated picking initiation point (base). Order processing initiates from this base location. It is noteworthy that resources may already be present within the model if they are currently engaged in executing another order.

Case 2: In adherence to official protocols, it is imperative that a warehouse task with a higher document number be confirmed only after confirmation of preceding tasks for the same warehouse order. However, deviations from this standard may occur, where a warehouse task with a higher document number has been confirmed while a preceding task remains unconfirmed. Such discrepancies typically arise due to manual intervention by authorized users. Instances may also arise when warehouse pick-up tasks remain unconfirmed while drop-off tasks have been confirmed, indicating potential manual alterations. To ensure the integrity of the simulation process, warehouse orders with inconsistent task sequences are systematically excluded and disregarded during initialization and subsequent simulation runs.

Case 3: In this case, the picking process has already been started by a resource. However, the pallet has not yet been completely picked or placed on the transfer area. Therefore, it can be assumed that the pallet is currently on its way to its destination. The data cannot be used to determine the exact location of the equipment containing the pallet. In this case, the picking vehicle is generated in the simulation model on the aisle in front of the last confirmed picking position. There, the vehicle can start its movement to the next pick position or transfer area. All subsequent actions of the vehicle are contingent upon the events depicted in the simulation model.

The program checks if the resource has already been created in the simulation model as part of another warehouse task. This may be the case if several pallets are transported simultaneously by a single resource. If the resource has already been added, another resource with the same name cannot be created in the simulation model.

Case 4: For some processes (e.g., wrapping pallets with foil), a warehouse order is created with only one warehouse task. If the warehouse order has already been released and not yet confirmed, the handling unit is located at the source storage location. In the simulation model, the handling unit is created on the corresponding area and the warehouse task is added to the queue of open tasks.

Case 5: In this case, the warehouse order should already have been confirmed. This can only happen if the posting workflow has not been completed at the time of the data transfer. This is usually prevented by locking logic in the database.

The initialization of the simulation model can be completed when all warehouse orders and tasks have been analyzed.

5 STUDY OF TRANSIENT BEHAVIOUR

To demonstrate the influence of the described initialization concept on the transient behavior of a simulation model, a simulation study was carried out using artificially generated data. Unfortunately, real data from the use case cannot be published. In addition, the feasibility of the concept was evaluated using real data as part of a research project.

The simulation study focused solely on the picking process within the DC, excluding incoming goods processes, replenishment processes, and truck loading. Over a 12-hour simulation period, 500 orders (pallets) were to be picked, each containing at least three order lines and up to twelve order lines per pallet. One position can hold a maximum of 20 picking units, which are typically cartons. The picking system was operated by eight operators. The process starts with picking up an empty pallet and ends with transferring the picked pallet to the pallet wrapper.

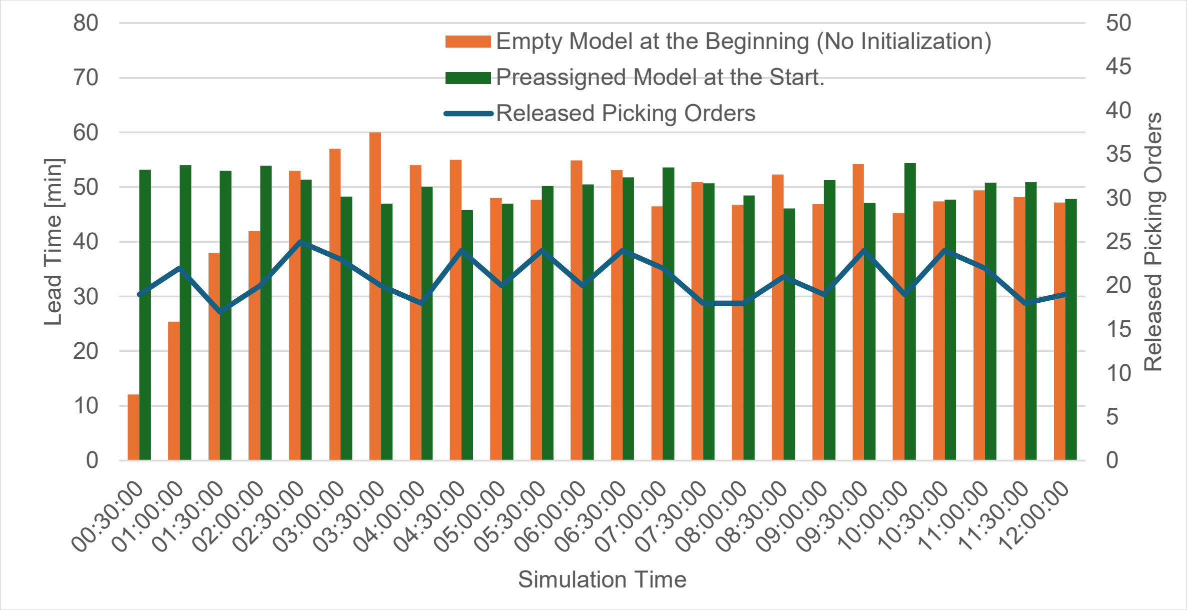

Figure 6: Results of the study: Lead time limit without initialization (red) and with initialization (green), number of released picking orders (blue line).

The study compares the proposed initialization concept with the classical approach in material flow simulation, where the model is empty at the beginning of the run. The study selected the lead time of a warehouse order as the relevant KPI. This metric describes the time between the release of the warehouse order and the confirmation of the last warehouse task. Figure 6 shows the average order lead time as a function of the simulation time. For example, orders that were confirmed within 30 to 45 minutes of the start of the simulation are grouped together and the average is calculated.

The results of the simulation study show that the described initialization concept can shorten the transient behavior of the simulation model. This results in the simulation model representing the real system more quickly when preloaded with tasks at the start of the simulation.

6 CONCLUSIONS

This paper presents an approach for initializing a simulation model for an order picking system based on transaction data from a SAP EWM system. The approach is case-specific and can be applied to similar use cases with comparable input data. The initialization and pre-assignment of simulation models is particularly important if the simulation model is to provide short-term decision support for operational decisions. In contrast to support strategic decisions, simulation for this purpose often has longer simulation periods, allowing for a longer transient time of the simulation model. It is important to take this into account when analyzing the result parameters.

The described procedure is not suitable for the permanent synchronization of simulation models. Its purpose is to significantly shorten the transient phase, thereby ensuring that the model behavior corresponds to the real system as quickly as possible. For a new analysis, the model is initialized anew and current data are imported from the SAP EWM. The time required to exchange and analyze the data depends on the amount of data. For the use case, the time required was less than one minute. The function was implemented directly in Plant Simulation for testing purposes. In order to enhance the runtime and streamline the analysis, the function was then implemented in the backend of the communication interface between SAP and Plant Simulation.

As part of a research project, which investigates simulation-based digital twins to support operational decisions, it was observed that the synchronization between the real system and the digital simulation model places new requirements on the initialization of simulation models. In this context, it is necessary to develop generally applicable approaches for the initialization of simulation-based digital twins.

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