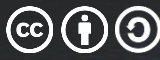
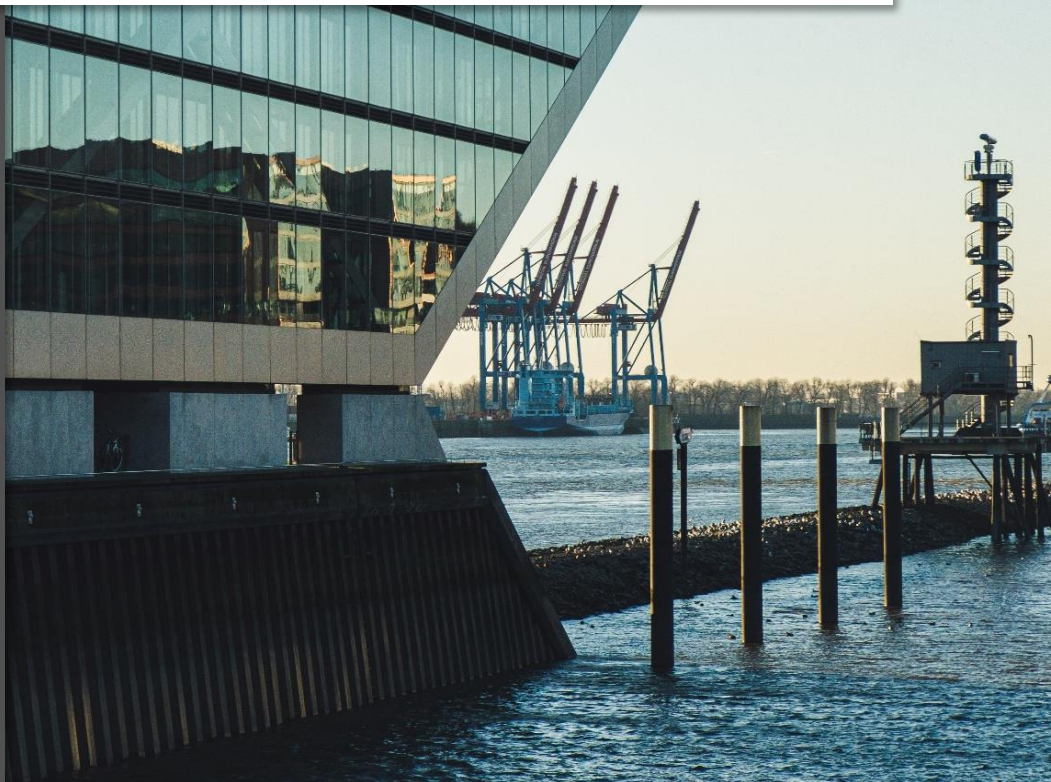


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Disruptions and exception handling in Food Supply Chains

HICL



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Disruptions and exception handling in Food Supply Chains

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The COVID-19 pandemic and resulting non-pharmaceutical interventions aspiring to reduce the spread of the virus, e.g., full or partial lockdowns, as well as social distancing measures, lead to increasing at-home consumption and panic buying. The resulting demand peaks for non-cooled perishable items hit the distribution systems of traditional brick-and-mortar retailers and have led to various out-of-stock situations on the shelves of "Europe's retailers. If the impact of demand peaks during the COVID-19 pandemic on grocery retail warehouses are unaware, this can result in out-of-stock situations in the supermarkets. In this paper, we use a process-based discrete-event simulation model to develop and apply a simulation approach to shed light on the underlying mechanisms of grocery retail warehouses in order to predict the future behavior of the examined system and prepare for such external demand shocks. Our results show that both investigated scenarios of volume peaks have a great impact on waiting times for truck drivers and the time-dependent utilization level of the warehouse dispatch area. We then derived optimal shift distributions by developing a supply chain resilience strategy varying the output quantities for order picking. Moreover, by that, we could reduce the utilization level in the warehouse dispatch area by nearly 20 percent. Our model can inform managers about the consequences of demand peaks on grocery retail warehouses. Furthermore, our methodology can be transferred to one-time disruptions, as well as to multi-wave disruptions besides COVID-19.

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1 Introduction

The COVID-19 pandemic has been causing a huge slowdown in many industries. Grocery retail is one of the few industries where sales were at a record high during, for example, lockdown situations, which has led to various out-of-stock situations. While cooled perishable items were the main growth driver for the traditional brick-and-mortar retailers in previous years, non-cooled perishable items led to demand peaks during the COVID-19 pandemic (Hobbs, 2020). The massive increase in demand hit the distribution systems of grocery retailers and led to empty shelves in supermarkets. The COVID-19 pandemic, as a new type of disruption, has been the first long-term supply chain crisis for the last decades and causes a lot of uncertainty in relation to demand, supply, and planning within the supply chain of brick-and-mortar grocery retailing. Therefore, this paper develops and applies a discrete-event simulation model to shed light on the underlying mechanisms of grocery retail warehouses in order to predict the future behavior of the examined system and prepare for such external demand shocks as a part of supply chain resilience (Ivanov, 2021c).

Reviewing existing research approaches examining the impact of the COVID-19 pandemic on logistics and SCM, we find research approaches that control the impact of COVID-19 on food supply chains, e.g., Barman, Das and De, 2021. Succeeding the consequences of COVID-19 on the food supply chain, the research community put focus on reacting and adapting the supply chain to the pandemic conditions (El Baz and Ruel, 2021; Ivanov, 2021d). While there are investigations about the entire supply chain within the distribution system, little is known about the impact of supply chain disruptions due to COVID-19 on the operational level of warehouse logistics.

Motivated by this research gap, the paper investigates the impact of time-dependent and varying output quantities of order picking and loading times on the utilization level of the warehouse dispatch area. Therefore, we examine the order volume of cooled perishable items as well as non-cooled perishable items.

We identify three research questions (RQ) for our study: (RQ₁) Which impact do demand peaks of non-cooled perishable items have on the warehouse dispatch area? and (RQ₂) Which impact do demand peaks of cooled perishable items have on the warehouse

dispatch area? In answering these RQs, we build on and extend the existing knowledge by constructing and using a discrete-event simulation model to investigate strategies for supply chains in the context of the COVID-19 pandemic within (RQ₃) How and to which extend are order picking volume variations a suitable tool to control utilization rates of dispatching areas?

This paper is structured as follows: the literature framework section highlights the relationship between pandemic caused disruptions and research in full range food retailing warehouses. Then, the third section describes the methodology adopted for the empirical research. The simulation study demonstrates and describes the model, assumptions, and experimental results. Our results, summarized in the findings, show that both investigated scenarios of volume peaks have a great impact on waiting times for truck drivers and the time-depending utilization level of the warehouse dispatch area. Finally, conclusions and an outlook on future research directions are presented.

2 Literature framework

2.1 Supply chain disruptions

Supply chain disruption management has become a significant interest of management science research (Hendricks and Singhal, 2005; Kleindorfer and Saad, 2005; Ivanov, et al., 2017; Chen, Wang and Zhong, 2021). Disruptions can occur in any part of the supply chain, including the upstream supply side, the intermediate manufacture processes, and the downstream demand side (Chen, Wang and Zhong, 2021). A local disruption at a supplier affects the entire supply chain as a ripple effect (Ivanov, Sokolov and Dolgui, 2014). The disruption-caused ripple effect could either result at the supply side and propagate along the logistics direction or originate at the demand side and spread negatively upstream, which would affect more companies in the supply chain (Ivanov and Sokolov, 2019). Li et al. investigated forward and backward disruption propagations within an agent-based model to describe the supply chain disruption propagation behavior (Li, et al., 2021).

2.2 COVID-19 as a supply chain disruption

COVID-19 affects the supply chain in two different perspectives: supply and demand. The greatest challenge in the supply chain during a pandemic is to get resources from suppliers and to guarantee the progression of movement from producers to customers (Alonso, et al., 2007). COVID-19 is characterized as a long-term supply chain crisis with uncertainty about the current situation and future developments. Furthermore, the supply chain faces a lot of problems, such as supply disruption or demand change (Ocampo, et al., 2016). Moreover, Ivanov defines COVID-19 as a super disruption which is characterized in Table 1:

Table 1: Characteristics of the super disruption COVID-19 (Ivanov, 2021b)

super disruption (supply chain crisis)	
impact	long-lasting impact with barely predictable scaling
scope	simultaneous disruptions in supply, demand, and logistics
recovery	is performed in the presence of the disruption and its unpredictable scaling
timing	simultaneous and/ or sequential openings and closures of suppliers and facilities

The paper on hand demonstrates that COVID-19 as a super disruption has a great impact on the order volume and resulting demand peaks. Furthermore, one can see that the volume is very difficult to predict. This has led to bottlenecks within the material flow of the warehouse dispatch area. The research community examines the impact of COVID-19 disruptions on the supply chain. As a new type of supply chain disruption Ivanov demonstrates the usage of simulation-based methodology to examine and predict the impacts of epidemic outbreaks (Ivanov, 2021a). Therefore, the research points out an analysis for observing and predicting both short-term and long-term impacts of epidemic outbreaks on the supply chain. The major finding of the different simulation experiments is that the timing closing and opening of different facilities at different echelons in a

supply chain is one of the most important factors predicting the impact of COVID-19 on that supply chain's performance (Ivanov, 2021a). Up-and downstream disruption durations are also very important for the performance of the supply chain (Ivanov, 2020). Further, Ivanov demonstrates the susceptibility of supply chains with postponed demand and shutdown capacity during pandemic conditions within a discrete-event simulation (Ivanov, 2021a, p.1-5). Therefore, he considers the after-shock risks according to different demands and capacity management during the pandemic (Ivanov, 2021a). Barman et al. (2021) investigate the impact of lockdown on the food supply chain summarizing recommendations on how to control and deduce the impact of COVID-19.

Besides demonstrating the impact of pandemic disruptions, the research community focuses on supply chain recovery and resilience. The recovery begins during the pandemic and is characterized by deep uncertainty (Ivanov, 2021a). Chen et al. develop a supply chain disruption recovery strategy considering product change under COVID-19 (Chen, Wang and Zhong, 2021). Moreover, Ivanov develops two strategies to avoid disruption tails within the supply chain. Therefore, a possible recovery strategy is demand smoothing over time in the post-disruption period. Additionally, a moderate capacity ramp-up prior to expected peaks of postponed demand is an effective leveraging approach for disruption tail control (Ivanov, 2021a). Besides the definition of recovery, there are numerous definitions of resilience in research. Resilience refers to the capacity of a dynamic system to adapt successfully to disruptions that threaten the viability, function, or development of the system (Masten, 2014).

2.3 Warehouse disruptions

Warehouses play a vital role for retail supply chains (Richards, 2018) and are responsible for receiving and storing items, as well as picking and shipping customer orders (Bartholdi and Hackman). Hence, disruptions can have various impacts on different warehouse operations. Our literature framework includes research about warehouse disruptions in general, as well as in a specific part of the supply chain in retail logistics. The more detailed investigation refers to typical warehouse processes of retail logistics storing, picking, packing, and shipping (Mohsen, 2002). Rana et al. examine the impact of demand disruptions on two warehouse perishable inventory systems during the COVID-

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19 pandemic. First, the authors investigate the enforcement and ease of lockdown caused by COVID 19 when the owned warehouse is being vacated. Second, they examined the experiment using lockdown enforcement during the inventory dispatch from the owned warehouse and relieved as the items are taken from the rented warehouse (Rana, et al., 2021). Klumpp and Loske (2021) investigate the impact of information technology disruptions on retail logistics efficiency. Here, the authors apply the network data envelopment analysis to measure the impact of IT disruptions on the efficiency of operational processes in retail logistics using and comparing the efficiency of order picking and truck loading data (Klumpp and Loske, 2021). The literature review points on a research gap regarding supply chain disruptions in operational warehouse processes. There is a lot of existing research across the entire supply chain. The research community investigates the impact of supply chain disruptions of suppliers for example delay in delivery due to pandemic restrictions within the supply chain, but there is little known about intralogistic warehouse processes.

3 Methodology

The case study is developed in a German full-range food retailing warehouse, which is responsible for the complete and on-time delivery of roughly 400 supermarket stores. Considering the dynamics of demand-caused disruptions, we simulate the time-dependent utilization level of the warehouse dispatch area for volume peaks. The quantitative simulation approach of this paper is based on the dataset of order picking and truck loading. Our empirical dataset utilized in the simulation model consists of N=13,488 transport units (roll cages) in the timeframe of 16.10.2020 – 23.10.2020. The non-random quasi-experimental study uses primary data of the companies Data Warehouse which has been validated by observation. More precisely, we used the barcode scan of every roll cage picked in the warehouse and transported to the dispatch area. Furthermore, the empirical data contains the time-dependent barcode scans to document the loading process performed by truck drivers for all transport units in the warehouse dispatch area. Therefore, the simulation model calculates the time-dependent utilization in the warehouse dispatch area and demonstrates demand-caused

disruptions due to volume peaks. After simulating the different experiments based on RQ_1 high volume of non-cooled perishable items and RQ_2 consequences of the high volume of perishable items to the warehouse dispatch area of non-cooled perishable items, we analyze the dependence between the utilization rate and the disruptions in the warehouse dispatch area as a result. The utilization rate is defined by provided transport units in the loading lines of the warehouse dispatch area compared to the total capacity of the loading lines within the warehouse dispatch area. Finally, we simulate the consequences to the warehouse dispatch area by varying the output quantities for order picking within RQ_3 .

Aspiring to answer the formulated research questions, we use a discrete-event simulation model within the simulation tool AnyLogic. AnyLogic is a multimethod simulation modeling tool to create, for instance, a 2D or 3D model (Tutorials AnyLogic Help, 2021). Discrete-event modeling is one of 3 types of modeling in addition to agent-based modeling and system dynamics. The characteristic of discrete-event modeling is that the modeler considers the system being modeled as a process (Borshchev, 2013). Therefore, we use predetermined process blocks made available in the simulation tool. We create a process flow adapted to the warehouse processes of the grocery retail warehouse. Different from agent-based simulation, the processes in the case study are well-known. There is a clear structure to be found which is to be modeled.

4 Simulation model

4.1 Problem context

The simulation approach considers the processes of order picking and truck loading within the warehouse dispatch area of non-cooled perishable items to investigate the impact of high volume of non-cooled perishable items and high volume of perishable items. The COVID-19 pandemic and daily fluctuating volumes make the utilization rate of the warehouse dispatch area and the impacts on delivery times of customers difficult to predict. Furthermore, seasonal peaks like Easter or Christmas enlarge the impact of high volume on the utilization rate. Demand peaks cause disruptions in the warehouse

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dispatch area, the interface between order picking and truck loading. Figure 1 demonstrates the individual situation within the investigated grocery retail warehouse:

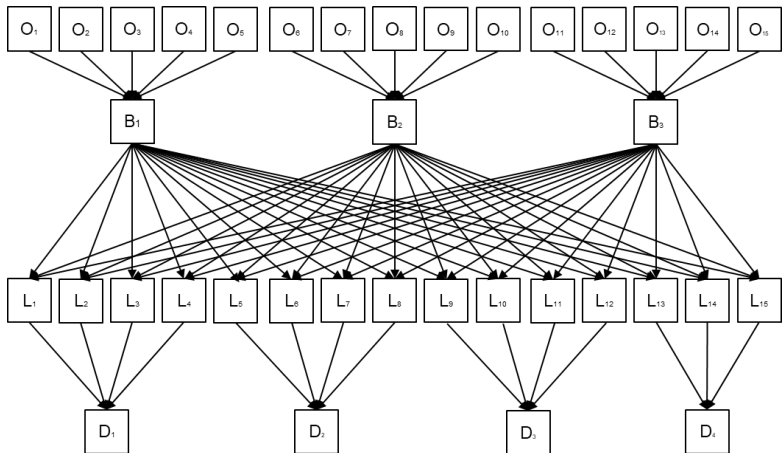


Figure 1: Material flow of the grocery retail warehouse (Gudehus, 2012)

O_n demonstrates the order picking zones separated in range-specific areas. After order picking, the transport units are placed in the buffer zones (B_n). At this time, the barcode of every transport unit is created. Furthermore, the transport units are placed in the loading lines (L_n) of the warehouse dispatch area. Each L_n has a capacity of 41 transport units (roll cages). The warehouse dispatch area consists of 39 loading docks and 2 to 5 loading lines per dock, depending on the respective area. The transport units of a customer placed in a loading line are loaded by truck drivers at the loading docks (D_n) according to the delivery time window. Resulting demand peaks due to COVID-19 and seasonal peaks cause disruptions within the individual loading lines when volume exceeds the capacity of 41 transport units. The simulation model demonstrates the mentioned time-dependent demand-caused disruptions during the COVID-19 pandemic and displays the utilization rate. Volume peaks do not affect the structure of the investigated warehouse processes. It means that processes are not scalable, and there is a rigid structure of grocery retail warehouse processes during

demand peaks. Figure 2 demonstrates the material flow of the grocery retail warehouse within the created 2D model with the help of the AnyLogic simulation tool.

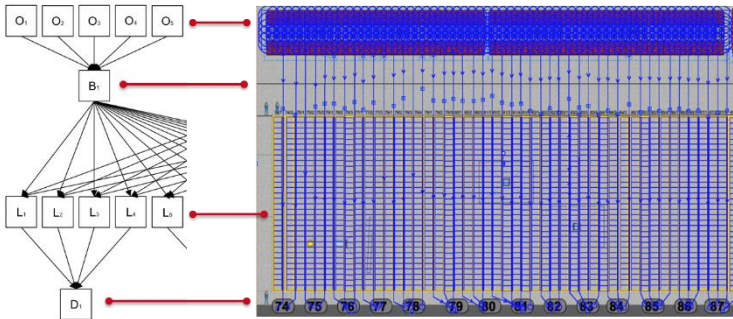


Figure 2: Simulation model from order picking to truck loading, created in AnyLogic 8.7.2

4.2 Model assumptions

We developed a discrete-event simulation model using the software AnyLogic. Because of model restrictions, the simulation focuses on 1 of 3 parts of the warehouse dispatch area. Furthermore, the simulation experiments have been limited to selected days due to the effort involved in the simulation model. Consequently, the model covers 14 loading docks, including 45 loading lines. We assume that the supply chain structure does not change during the pandemic period. Furthermore, to implement the data into the simulation model, we assume that a transport unit constitutes a roll cage. The simulation model is based on the time-dependent process, creating the barcode for each transport unit after order picking up to this time loading the transport units of the customer by truck drivers. The transformation of the processes within the warehouse dispatch area into the discrete-event simulation is shown in Figure 3.

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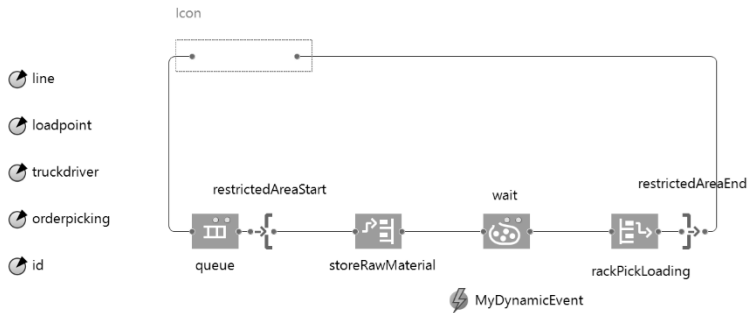


Figure 3: Process-flow from order picking to truck loading, created in AnyLogic 8.7.2

4.3 Parameters

The end of each picking process is documented with a timestamp for printing a barcode label containing all relevant information of a batch with all SKUs stacked on one roll cage (1). The sum of all batches assigned to one store, and, therefore, the total number of transport units per store, quantifies the total size of each order (2). Finally, the information flow at the end of the order picking process contains the loading line for the entire order (3). Relevant for the truck loading process is the information about the delivery day (4), which is also printed on the barcode label. As the order picking time depends on the respective time window of the store, we also use this information in our simulation approach (5). Last, to evaluate the length of stay for roll cages on the dispatch area, we quantify the material outflow through a time stamp documenting the loading time (6). To simulate the time-dependent utilization level of the warehouse dispatch area, we need the following data.

Table 2: Simulation-relevant Data

Order picking	Truck loading
(1) Time of barcode generation	Delivery day (4)
(2) Transport units of customers	Delivery time window (5)
(3) Individual loading line	Loading time of barcode (6)

The data listed in Table 2 is part of different systems integrated and transformed into the Data Warehouse of the investigated grocery retail warehouse. The data warehouse export of Monday to Friday is evaluated for creating the simulation model. In combination with the process-based discrete-event simulation model shown in Figure 2, the data constitute the basis for the experimental research of volume peaks.

4.4 Validation of the simulation model

We validate our model in three different ways. We (1) validate the data from the companies Data Warehouse by observation within the warehouse dispatch area. Therefore, we observe the material flow on site and verify the collected data for the time of the barcode generation, placed in the correct loading line in the warehouse dispatch area, and the number of transport units as well as the loading time. Then (2) we validate the simulation model and its assumptions to the warehouse dispatch area, which we have observed in the examined company. We visually checked the dynamics of material flows through the simulation model. Finally (3), we validate the implemented data which we used for the discrete-event simulation in AnyLogic and the simulation experiments. The validated simulation model with real-context data in the period between Monday to Friday represents the basis for the non-random quasi-experimental study. The difference between implemented data and original data is the standardization of the transport units in the simulation model. The real-context data consists of different transport units of different sizes. The implementation of the data into the AnyLogic database requires the

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standardization of the transport units to 1 (roll cage). To enable the accuracy of the simulation model, we consider the overall size of transport units for each customer.

Figure 4 demonstrates the utilization level of the warehouse dispatch area between the specified date.

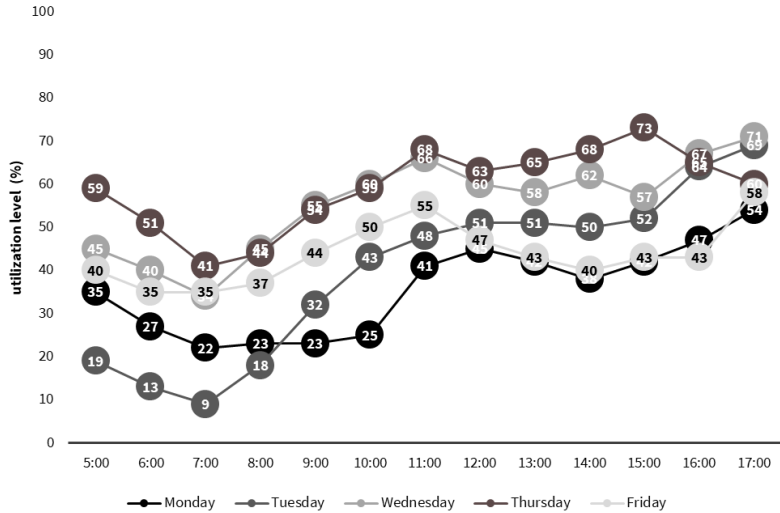


Figure 4: Utilization level of the warehouse dispatch area during COVID-19

The simulation between Monday and Friday demonstrates the percentage utilization level in a normal week during the COVID-19 pandemic. On Thursday, there is the most utilization during the investigated week. At 15:00, one can determine the highest occupancy. In the investigated warehouse, a disruption defines one or more overloaded loading lines due to a high volume of order picking and less truck loading of transport units. If the supply of order picking volume exceeds the capacity of a loading line of 41 transport units, one can notice a traffic jam at the buffer zone. A utilization level of more than 65 percent in total leads to multi-wave disruptions. The simulation run shows that the traffic jam at the buffer zone exceeds the capacity of the loading lines. In

consequence, the level of material flow in the warehouse dispatch area is only possible to a limited extent. This scenario affects the loading times of the truck drivers and delivery time windows that cannot be met.

5 Simulation Experiments

5.1 Seasonal Peaks during COVID-19

The non-random quasi-experimental study of high volume due to seasonal peaks during COVID-19 demonstrates the influence on the utilization level in the investigated dispatch area of non-cooled perishable items. Therefore, we used the percentage increase in volume at easter of the previous year to demonstrate the seasonal volume during the COVID-19 pandemic. We were able to determine an increasing volume of 10 percent on Monday, 25 percent on Tuesday, and 15 percent on Wednesday in the easter week of 2019. Furthermore, the volume was increased by the stated percentage within implemented data of our simulation model. By that, we simulate and predict the increase in volume during COVID-19 and additionally seasonal peaks on the warehouse dispatch area. The impact of demand peaks of non-cooled perishable items on the warehouse dispatch area is demonstrated in Figure 5.

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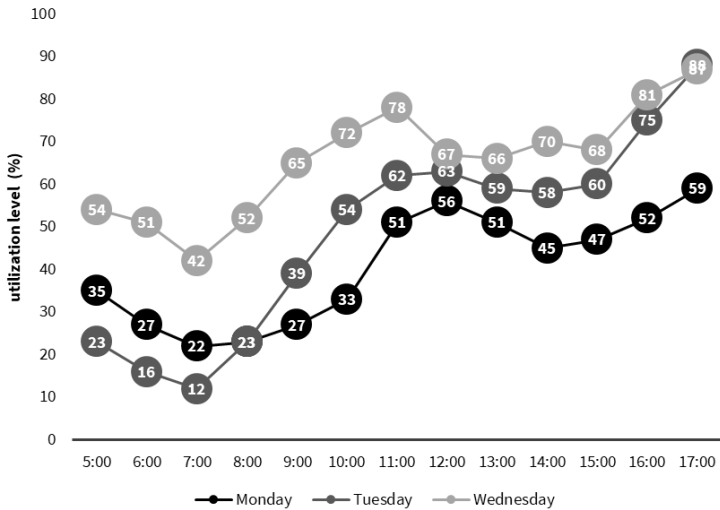


Figure 5: Impact of seasonal peaks on the utilization level

Figure 5 illustrates the experimental results for demand peaks and depicts that the utilization level increases due to seasonal volume. Moreover, the increasing utilization level on 21.10.2020 leads to disruptions in the warehouse dispatch area due to an increase of up to 16 percent.

5.2 Demand peaks of cooled perishable items during COVID-19

The non-random quasi-experimental study of high cooled perishable items volume during COVID-19 demonstrates the influence on the utilization level in the investigated dispatch area of non-cooled perishable items. High volume of cooled perishable items leads to delayed return times and, as a result, delayed loading times of non-cooled perishable items. Moreover, the transport units remain longer in the loading line contemporaneously the supply by order picking increases because of unchanged and

unscalable order picking. Consequently, disruptions occur due to capacity overrun within the loading lines. Therefore, the simulation model demonstrates the utilization level delaying truck loading $t+2h$.

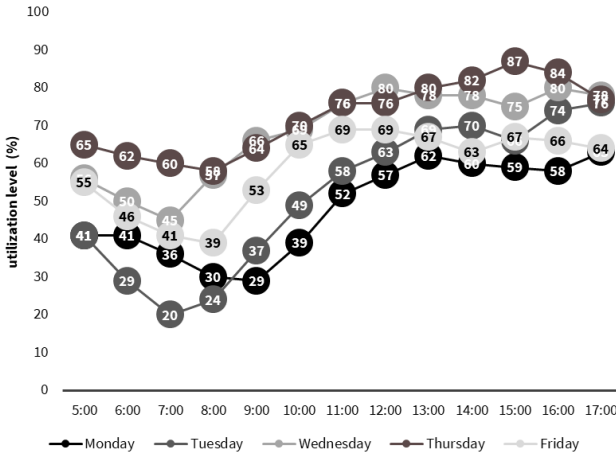


Figure 6: Impact of cooled perishable items on the utilization level

Figure 6 illustrates the experimental impact of demand peaks of cooled perishable items to the warehouse dispatch area of non-cooled perishable items. The delay in truck loading leads to continuously higher utilization. There is no relief due to delayed loading times which leads to disruptions between order picking and truck loading. The transport units remain at the buffer zone creating disruption tails in the process flow.

5.3 Supply Chain Resilience Strategy

Contrary to the simulation experiments for demand peaks, we investigate a strategy for supply chain resilience when volume increases during COVID-19 pandemic and seasonal peaks. We derived optimal shift distributions by developing a strategy varying the output quantities for order picking.

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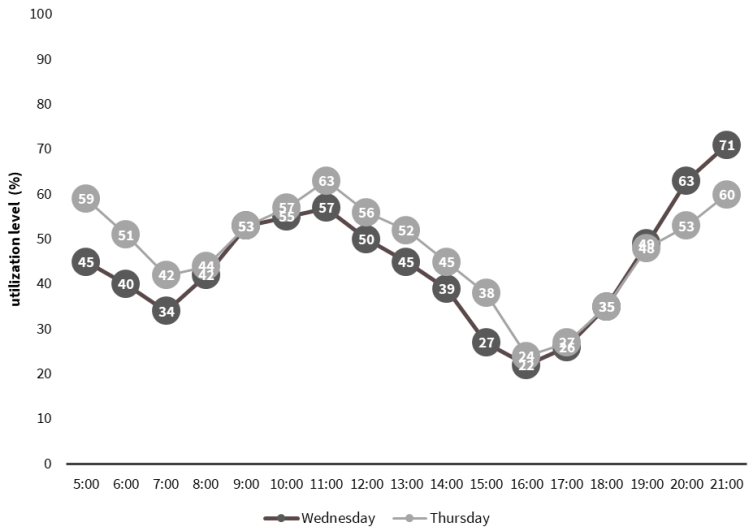


Figure 7: SC resilience strategy for demand peaks

Therefore, we investigate the supply chain resilience strategy on Wednesday and Thursday, the days with the most observed utilization level during the investigated week. We reduce the order picking volume per hour by implementing two shifts and distribute the volume over a period of 14 hours instead of 7.5 working hours. In the non-quasi experimental study, the first layer works from 7.00 to 15.30 and the second layer from 12.30 to 21.00. Figure 6 demonstrates the reduced utilization level due to lower order picking volume per hour. We can perceive a positive effect on the warehouse dispatch area by reducing the utilization level to daily peaks at 15 am by nearly 20 percent at both investigated delivery days. Furthermore, future disruptions during the material flow can be prevented by implementing two shifts and reduce the order picking volume per hour.

6 Findings

The model examined three different simulation experiments demonstrating the impact on the utilization level of the warehouse dispatch area. Aspiring to answer the formulated research question "Which impact have demand peaks of non-cooled perishable items on the warehouse dispatch area?" a simulation experiment based on real-context data was conducted. Therefore, we added the percentage increase in volume during easter to the data collected between Monday to Friday. To provide deeper insights, we demonstrate the impact of demand peaks of non-cooled perishable items in Figure 6. We investigate high order picking volume due to demand peaks in the warehouse dispatch area. Moreover, the simulation model has shown that the time-dependent utilization level increases up to 15 percent. Consequently, the simulation run demonstrates disruptions in the material flow. If the utilization is over 60-70 percent, depending on the situation within the warehouse dispatch area, no material flow can be guaranteed. Furthermore, the simulation model illustrates disruptions of multiple loading lines due to high utilization in the warehouse dispatch area.

The second research question has investigated the scenario of a high volume of cooled perishable items. Therefore, we aspire to answer the formulated research question "Which impact have demand peaks of cooled perishable items on the warehouse dispatch area?". Therefore, we examine the impact of later truck loading times $t+2h$ on the utilization level of the warehouse dispatch area. We observed a continuously high utilization rate within the simulation experiment. This can be explained by the strong inflow from order picking and the delayed outflow from truck loading. Consequently, the warehouse dispatch area shows disruptions during the material flow. The loading line capacity has been used up, but the order picking inflow remains unchanged. As a result, transport units remain at the buffer zone and cause disruptions. For that reason, a truck driver may not find customers' transport units in the loading lines, which results in long loading times and delayed delivery.

We then developed a supply chain resilience strategy to counteract the high volume during the COVID-19 pandemic and demand peaks. Therefore, we investigate the research question How and to which extend are order picking volume variations a

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suitable tool to control utilization rates of dispatching areas?". Subsequently, we are varying the output quantities of order picking by expanding the order picking volume on two shifts. By that, we could reduce the utilization level of the warehouse dispatch area, especially at time-dependent demand peaks. In addition, the disruptions in the material flow could be significantly reduced.

7 Discussion

The discrete-event-simulation model developed and applied in this paper demonstrates the impact of COVID-19 and resulting demand peaks on the utilization level of the warehouse dispatch area. Although the type of disruption may be different, e.g., increasing customer demand during Eastern or the COVID-19 pandemic, the stressor affecting the logistics system is the same. We operationalize this stressor by increasing order picking and transport volume modeled as an independent variable. At the same time, the utilization level of the warehouse dispatch area is the dependent variable.

The simulation model of the normal week based on data from a real application scenario showed the volatility within the different days during the COVID-19 pandemic. In addition, the time-dependent utilization level during a day is also shaped by fluctuations. The volatility makes it difficult to forecast the utilization level. Comparing the delivery day Monday to Friday, differences of up to 20 percent can be recognized. This is due to different factors like order volume, output quantities for order picking, and truck loading times. The problem of the warehouse dispatch area is the scalability and the inability to adapt the processes to volume peaks. This underlines the fragility of the examined logistics system, whose overall efficiency is highly affected by the stressor. Furthermore, the simulation experiments demonstrate that already a capacity of 60-70 percent leads to multi-wave disruptions within the material flow. In this regard, the capacity and utilization level of the individual loading lines must be considered in particular. Moreover, the disruptions lead to longer truck loading times and, additionally, to delayed delivery. Also, the transport units cannot be found in the individual loading line, so customers do not receive all of the ordered goods.

In summary, it is possible to forecast the utilization level of the warehouse dispatch area as the dependent variable by modifying the transport volume as an independent variable (stressor affecting the logistics system). Instead of forecasting absolute measures for the utilization level, our approach spawns insights about the relative impact of stressors causing an acceleration. Taleb (2014) illustrates this aspect of fragility with the following example of a traffic system. The driving time from the city center of New York to the airport increases by ten minutes when additional 10,000 cars enter the traffic system. Furthermore, another 10,000 cars increase the driving time by 30 minutes. Thus, we investigate an acceleration effect caused by the stressor (number of cars, independent variable) affecting the efficiency of the system negatively (increase in driving time, dependent variable). The absolute driving time remains unknown.

Our discrete-event simulation model does exactly the same: expressing the impact of stressors on the systems' efficiency in a relative rather than an absolute measure. We find that the acceleration effect caused by highly increased transport volume disrupted the underlying and highly fragile logistics system. Based on these results, we then derived optimal shift distributions by varying the output quantities for order picking. These shifts may be one possibility to reach a more robust system.

8 Conclusion

The paper has shown a way forward in analyzing the impact of COVID-19 and the resulting demand peaks to grocery retail warehouses. This was done by investigating order picking and truck loading through a discrete-event simulation in German food retail logistics based on order picking volume and truck loading times in the timeframe of Monday to Friday. The contribution of this paper consists of (1) the calculation of the utilization level within the warehouse dispatch area during the COVID-19 pandemic, (2) the impact of seasonal demand peaks, and (3) the high volume of cooled-perishable items on the warehouse dispatch area. Furthermore (4), we developed a strategy varying the output quantities for order picking to reduce disruptions within the process flow. The material flow is exposed to challenges due to the increased volume during the pandemic. Seasonal demand peaks or a high volume of cooled perishable items cause disruptions

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within the material flow. A highly volatile order volume due to seasonal peaks in demand and short-term, weather-dependent increases in demand are contrasted with rigid network capacity. The simulation study sheds light on the processes of the warehouse dispatch area and calculates its utilization level. Our Model can inform managers about the consequences of demand peaks on grocery retail warehouses. Furthermore, our methodology can be transferred to one-time disruptions, as well as to multi-wave disruptions besides COVID-19.

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