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WAREHOUSE OPERATIONS SIMULATION FOR SAFETY IMPROVEMENT

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Abstract: *Warehouse operations often include hazards due to relatively fast moving equipment. While there are multiple approaches to minimize hazards and increase safety in such environments, an alternative is to consider scheduling operations to further avoid potential threats. Spatial planning usually involves providing enough space for warehouse items, while transport routes and safety buffers can be neglected. This can lead to congestion effects within the warehouse which does not only decrease efficiency but can also increase accident occurrence. With performance usually being the highest priority, the operation organization is usually targeted to meet this priority and putting safety second. In this paper we cover an approach to organize the warehouse operation in order to increase efficiency by reducing congestion effects and thus increasing both safety and efficiency.*

Key words: *warehouse operation, forklift, discrete-event simulation, operation scheduling*

1. INTRODUCTION

Within the dynamic expanse of industrial environments, where the seamless and secure movement of materials constitutes a bedrock of operational efficiency, emerges the imperative presence of forklifts as indispensable workhorses. These mechanical entities navigate intricate tasks and expedite the unobstructed circulation of goods. However, commensurate with their pivotal roles, there arises an exigent demand for the augmentation of safety measures and strategic enhancements to forestall collisions and optimize overall performance. The compendium of scholarly papers at hand presents an exhaustive exploration of innovative paradigms and advanced technologies that coalesce to reinforce forklift safety while concurrently propelling operational efficiency to uncharted summits.

Spanning across diverse domains encompassing virtual reality, traffic engineering, automation, and the cutting-edge realm of ultra-wideband (UWB) technology, these scholarly

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articles collectively illuminate pathways that endeavour to revolutionize the intricate realm of forklift operations. Each paper contributes a distinct facet to this multifaceted discourse, amalgamating into a mosaic of insights that collectively redefine the paradigm of forklift operations within the broader landscape of industrial endeavours.

Through immersive simulations, the initial paper delves into the nuanced arena of virtual reality, dissecting the situational awareness of forklift operators. It probes the depth of their perception vis-à-vis their surroundings and potential collision hazards. This vantage point augments the development of targeted training regimens and accident prevention strategies that are informed by a nuanced comprehension of operator cognition (Choia, et al., 2020).

The subsequent paper engenders a holistic perspective by amalgamating the domains of forklift safety, traffic engineering, and intelligent transport systems (ITS). Pioneering this holistic approach through an incisive case study, the paper explores the synergy inherent in harmonizing these facets. Such an amalgamation engenders improved traffic flow, augmented communication systems, and ultimately the cultivation of safer forklift operations (Horberrya, et al., 2004).

Embedded within this discourse, a comprehensive guidebook occupies a pivotal role, illuminating the arena of industrial traffic management and forklift safety. As a pragmatic resource, it proffers a roadmap for the delineation of optimal layout designs, implementation of traffic regulations, and formulation of communication protocols. This holistic guide holds the potential to evolve into an industry standard, reshaping safety practices across industrial complexes and akin settings (Larsson, et al., 2003).

Moving into the domain of automation, the fourth paper ushers in a paradigm of automatic analysis of resource flows. Tracking the intricate trajectories of materials and forklifts within warehouse environments, this approach discerns zones prone to collisions. Empowered by data-driven insights, researchers and practitioners alike can instate preemptive strategies that mitigate risks, thereby shielding personnel and material assets from harm's way (Cantini, 2020).

Lastly, the fifth paper unveils the potential catalyzed by ultra-wideband (UWB) technology. The integration of UWB within forklift operations ushers in a new era of precision. Facilitating accurate positioning, collision evasion, and real-time tracking, this technology metamorphoses forklifts into astute tools that navigate with unparalleled precision, mitigating the prospects of accidents and magnifying operational finesse (Sun & Ma, 2017).Collectively, this assortment of scholarly contributions weaves a rich tapestry of ideas and innovations poised to advance forklift safety and efficiency. From harnessing the immersive capacities of virtual reality to reimagining traffic management through intelligent transport systems, each paper affords a distinct prism through which the intricate challenges of industrial landscapes are perceived. The embrace of innovation and interdisciplinary synergy emerges as a common underpinning, unveiling a realm of enhanced safety, augmented productivity, and accomplishments in the realm of forklift operations.

Simulating logistic operations is a widely used approach for many performance analyses including warehouse operations (Pawlewski, 2015). This paper uses the simulation approach to asses the safety aspect of forklift operations based on the planned organization and material flow.

2. WAREHOUSE SIMULATION

The presented paper covers a simulation of a potential warehouse organization. The warehouse is intended for supplying manufacturing of chemical products. As such the function of the warehouse is to store inbound materials from which the production lines are supplied. The materials are stored in EUR pallets in block storage. The entrance point of the warehouse consists of a ramp for trucks from which the pallets are unloaded with forklifts and moved to storage locations within the warehouse. Due to the space constraints the pallets can occupy either a single slot or they can be stacked one on another, with a maximum of two pallets occupying being at the same slot. Overall, the pallets are doubly occupying a slot at approximately 50 %. With storage of inbound pallets presents the first process part, the second part consists of supplying the pallets to production lines. All movements of pallets are performed by forklifts. This scenario includes two priorities, which are supplying production lines on schedule and unloading cargo from the trucks to free the loading ramps.

2.1. Warehouse modelling

A virtual model of the warehouse was constructed in Flexsim (Flexsim Software Procucts, 2023) based on the planned warehouse layout. The 3D model includes the position of walls, objects such as elevator or conveyers and passages. A key part of the 3D model (Figure 1) includes the position of floor storages intended for pallet storage. The aim is to provide enough storage for a daily turnover of pallets, which covers around 400 pallets. The presented case differently sized storage locations to accommodate for the passages and maximized storage capacity.

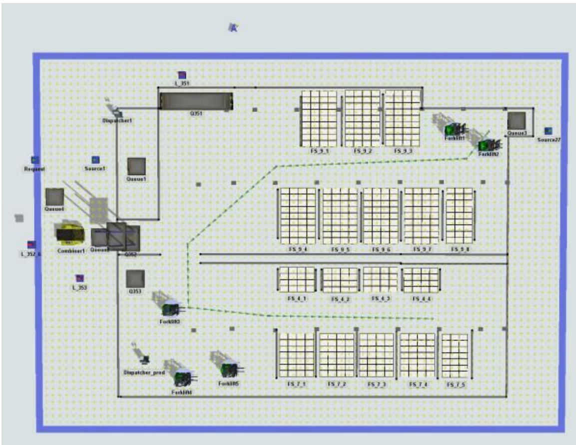

Figure 1. 3D model of the warehouse
Source: Authors

The 3D model includes any obstacles that cannot be passed by forklifts. The software allows for exact positioning of objects with set coordinates and dimensions. Moving the transport objects (forklifts) is done by the A* algorithm (Candra A, 2021), which finds the optimal path between the origin and destination location. For this purpose, the warehouse area is divided into nodes between which the transport objects can move. As the mathematically optimal path may lead to infeasible routes additional restrictions are included in the travel model, with the main one to avoid the forklifts to travel across the storage locations, which should only be entered from their direct front access. Another addition is the preferred path (marked green), which the forklifts will mostly follow except when their target object is close enough.

Another consideration during travelling is object collision. The software allows collision avoidance by constructing a circular buffer around the forklifts. In case of two forklifts coming to close one will stop, while the other will continue its travel until the proximity alert is finished. Proximity count and duration is a metric that can be used to assess the safety of forklifts during their operations with fewer proximity alerts and lesser proximity durations meaning higher safety.

2.2. Material flow

As stated previously, the main activities of the warehouse operations include unloading the cargo from the trucks, storing them at the floor storage locations and eventually supplying the materials to the production lines. In order to simulate the material flow it is necessary to consider: Pallet slots; Forklift specifications; Shift information; Inbound material flow; Production line requirement and Relocation requirements.

Table 1. Storage locations (*Source: Authors)*

Storage locations	Slots	Capacity
7	4x9	54
4	4x4	24
4	4x7	42
1	3x9	40
1	3x7	31

The storage locations (Table 1) show the available slots and approximate storage capacities given that it is possible to store two material pallets stacked one on the other at the same slot in half of the cases. The initial content of the warehouse is 400 pallets, which is the daily turnover.

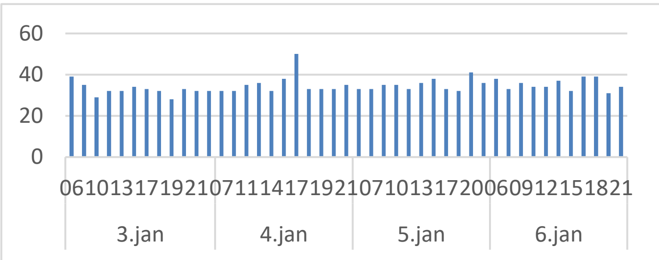

Figure 2. Inbound material quantities over time
Source: Authors

Expected inbound material pallets can be seen in Figure 2. The inbound arrivals are distributed over two shifts in which the forklifts unload the trucks and store them at available slots.

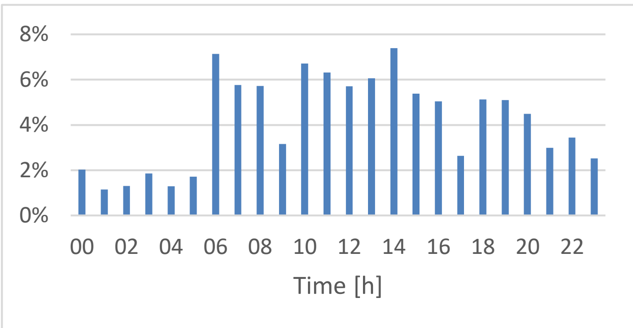

Figure 3. Distribution of production line requirements
Source: Authors

Along with storing materials in the warehouse the main priority is to provide a timely supply of the materials for the production lines. Figure 3 shows the distribution of pallet requirements for the production with visible spikes at the shift start and a low during the last shift.

2.3. Relocations

One of the main causes of congestions in the warehouse is the need for pallet relocations. The high variability of the production line requirements does not allow for an orderly storage of materials, which are consequently stored at a random slot with a few exceptions where materials of the same type are stored on adjacent slots. In the studied case such occurrences present less than 10% of required production orders and do not alleviate the problem. As the warehouse is mostly occupied at around 80% of capacity, supplying the production lines requires the time for finding the correct pallet, and in case of the pallet being stashed behind other, those need to be cleared in order to pick the ordered one. Depending on the depth of the ordered pallet this can lead to long delays, where pallets are intermittently stored in front of the storage locations or in case of many required relocations also in the transport route. While such relocation process takes place, other forklifts need to wait until the path is cleared again, and approaching such an event can increase accident occurrence.

Table 2. Probability of relocation needs (*Source: Authors*)

Relocations	4x4	4x7	4x9	Delay [min]
0	38%	24%	16%	0,00
1	23%	14%	10%	1,33
2	28%	16%	14%	2,67
3	6%	13%	11%	4,00
4	5%	13%	9%	5,33
5		8%	11%	6,67
6		6%	10%	8,00
7		3%	5%	9,33
8		1%	3%	10,67
9		1%	4%	12,00
10			4%	13,33
11			1%	14,67
12			1%	16,00

As shown in Table 2 the probability of relocation depends mainly on the depth of the storage location. The estimated delays cover the time of finding the picked pallet, removing all pallets stored in front of the required one, and storing all of the removed pallets back to the storage location. These times are considered for the average filled capacity of 80%. Each required relocation increases the probability of a safety issue.

3. SIMULATION RESULTS

Along with observing the schedules of production lines and truck arrivals, a key question is how many forklifts are required to fulfil all orders. We present two alternatives with the first having 4 forklifts in the first two shifts and 2 forklifts in the 3rd shift, the activities cover breaktimes. This solution is unfeasible as the available forklifts are not able to fulfil the requests for the production lines (Figure 4). Additionally, in this case the forklifts have practically no free time except for the breaks and are constantly on the either loading, unloading or moving, which occupies the workers to the maximum.

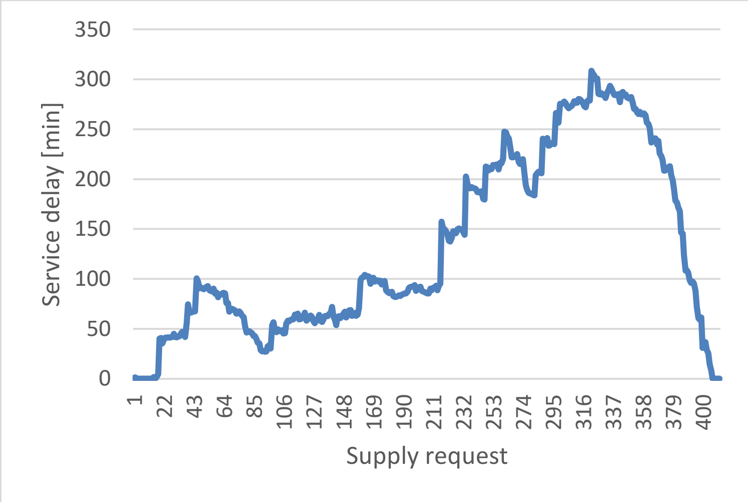

Figure 4. Delays for production lines in 1st scenario
Source: Authors

An alternative solution using 5 forklifts in the first two shifts and 3 forklifts in the 3rd shift can be seen in Figure 5.

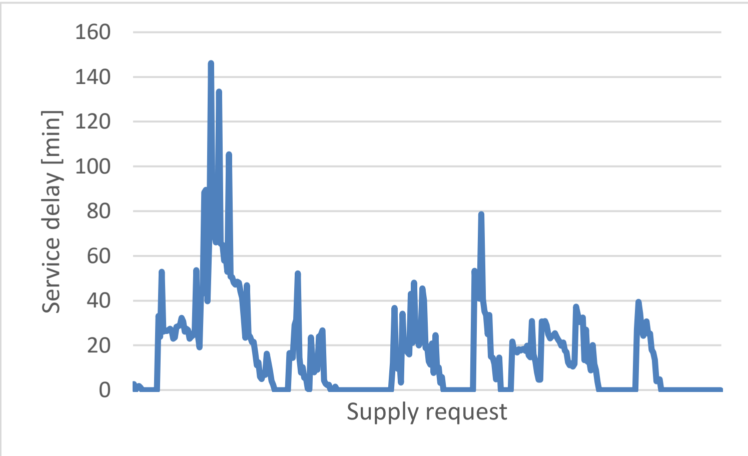

Figure 5. Delays for production lines in 2nd scenario
Source: Authors

This solution alleviates the forklifts throughout the day, while having spikes with delays they are still handled by the end of the work day. From the production point of view any delays are unwanted, meaning that both solutions are not feasible for fluent operations and alternative solutions may need to be explored

4. CONCLUSION

The presented simulation explores the option to analyse warehouse operation through simulation. From a production point of view both proposed solutions do not meet the requirements. Increasing the number of forklifts per shift does improve the warehouse performance, however it needs to be considered that this increases the number of near encounters between the forklifts and consequently the probability of accidents. The solution to improve the situation both the performance as well as safety issue is by improving the overall organisation, meaning that the research should focus on effects of decreasing the supply in the warehouse and reorganize the inbound material frequency. Another option to increase safety is to designate forklifts to operate only in specific zones to avoid route mixing. The simulation approach provides an opportunity to analyse storage strategies and provide options to plan and improve organizational decisions.

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