FORKLIFT OPERATIONS IN THE WAREHOUSE – DESIGN AND ANALYSIS WITH GRAPHICAL MODELLING AND SIMULATIONS

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The paper examines the material handling activities and travel routes of forklifts in the warehouse. The method consists of model development, which includes a forklift traveling through the various sectors of the warehouse while carrying cargo, and simulation of this travel. The goal is to examine the number of pallets transferred and obtain results that demonstrate the effectiveness of forklift activity. The main features that will be researched include travel distances and pathways, as well as the impact of the speed of the forklift. The forklift operations are designed and analyzed utilizing modular modeling and discrete event simulations with Arena simulation software. The designed model will include pallet picking in aisles, typical forklift travel routes within the warehouse, unloading in the outbound buffer zone, then pickup from the buffer zone, travel to the truck and load the pallets on the truck as a final activity. The model will have two forklifts that work at the same time. The results will be presented in graphical and tabular formats, representing the forklifts' performance in the instance of pallet handling.

Keywords: Warehouse, Forklift, Pallets, Travel Routes, Modular Modeling, Simulations, Performance Analysis

1. Introduction

Forklifts are the primary material handling machines used in warehouses, where they primarily handle packed items and pallets. They conduct a variety of tasks, such as loading and unloading materials from aisles and racks, transporting them in various warehouse sectors, and loading or unloading from the trucks.

Many companies that deal with materials handling use forklifts for work operations. They look for the best forklift performance and detect challenges that may arise in their regular tasks. It is critical to investigate the impact of travel distances between locations and forklift speed on the number of pallets transferred. And, based on the findings, what can be done to increase the number of pallets placed on the truck as a last activity, as well as how to reduce the number of pallets that stay unhandled, stranded between warehouse regions, but

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must be processed within a certain timeframe. This is a complex warehouse management process that needs accurate planning and performance analysis, proper infrastructure design, forklift route design, and work time planning.

Development of the warehouse model, forklift activities and running of simulations is accomplished using Arena Simulation software [1]. The model created in this software is a schematic depiction of forklift activities. Development of the work model is done by placing modules that define the objects and activities and are interconnected with connector lines, which represent the travel of forklifts, transfer of materials, and their motion direction (Fig.2). This form of model development is also known as data flow programming [2], [3].

For the implementation of the task, we used the example of a company in Kosovo that has a warehouse that mostly stores packaged products and pallets. Their warehouse is large, and they typically use two forklifts for everyday operations.

In Fig.1 is given the warehouse layout taken for study, which comprises of main infrastructure parts and sectors, to mention few:

- *Inbound area*, where materials enter the warehouse; *Aisles and racks* – multilayer racks, where materials and pallets are temporary stored; *Routes of forklifts* – travel paths of forklift(s) in the warehouse; *Buffer zone* or *Outbound area* – materials and pallets are placed temporary in the basement out of aisles and for further transfer to the trucks; *Outbound docks* – parking lots of trucks, positioned for loading or unloading pallets from their trailers, by forklifts.

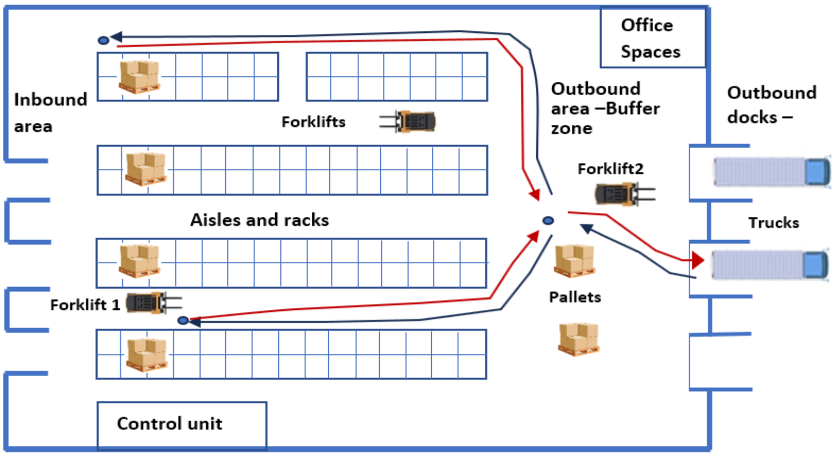

Fig.1. Graphical representation of the warehouse layout taken for study

Simulations of forklifts routing should be properly planned and tested to represent the exact behavior of the forklift motion [4]. The results will provide insight into the performance issues that require correction, the possibility of optimization of forklift activities and truck loading with pallets.

2. Literature Review

Literature review contains publications and contributions of authors in the topic of forklift activities, warehouse management, route optimization, and modelling and simulation with various software and different methods.

2.1. Authors' contribution using Arena software

Ch.-Y. Liong et al. [5] in their paper worked on finding a strategy for the residence times of lorries in the warehouse of the detergent factory and the ways to optimize it. They did these using simulations with Arena software of the unloading and loading system, where forklifts are also present. They analyzed the waiting times of lorries and queues at the various processes. *I. Doçi et al.* [6] have developed a model of materials handling line of the production company in Arena software. There are forklifts and conveyors that transfer boxes through the line and present results of their usage. They investigated the bottlenecks in the line that created queues and slowed down the transfer of boxes.

Awang N. et al. [7] used the Arena simulation software to investigate the effectiveness of forklift-based part distribution. They suggested modifications of the manufacturing setup to increase efficiency. *S. Abedinzadeh et al.* [8] developed a model and simulated a warehouse of an automotive company using Arena software and analyzed the waiting times. They presented strategies to reduce the average waiting time and improve the performance of the warehouse.

2.2. Authors' contribution using other software and methods

Burinskiene, A. [9] in her paper worked on empirical study to create simulation model and tested different scenarios, to find possible improvements of the forklift operations. She examined the new routing method and suggested programming algorithm for forklift route optimization. *S. Vonolfen et al.* [10] in their paper implemented a simulation study to show how the integrated optimization of warehouse picking and forklift routing leads to more efficient material handling in an industrial company. Optimization models are coupled by means of simulation and are optimized using metaheuristic algorithms. *Burinskiene, A.* [11] in her paper presented the potential for travel distance savings where she created a simulation model. The analysis showed that the travel distance of forklifts can be reduced by 27-37 % when RF-based process is implemented. She suggested ways to optimize travelling by implementing a multiple-tasks approach in WMS. The results show that, when multiple-tasks approach is used, the travel distance of forklifts can be also reduced by 9 %. *N. Sooksaksun et al.* [12] investigated the impact of warehouse layout configuration (items location) on order picker travel distances in a narrow aisle warehousing system. They used Monte Carlo simulation to compare travel distances for several layout configurations, as well as two routing policies: traversal and return.

J. Piskáček [13] in his thesis conducts research in the Forklift Scheduling Problem. He proposes two algorithms, one is based on a constructive heuristic approach, and another is based on column generation method and an Integer Linear Programming model. *S. M. M. Rahman* [14] presented the methodology to minimize the total travel distance of the forklift. He developed a heuristic algorithm by combining two methodologies of heuristics and machine learning for the incapacitated and capacitated problems. The developed algorithm can find practical solutions that could potentially be implemented into actual warehouses to reduce overall warehouse costs and order picking time. *M. Jiaju* [15] in his thesis proposes a model of the forklift fleet management system, with warehouse design and warehouse management system. It can perform vehicle routing and joint optimization of storage location assignment. Then, he designed a new warehouse operation strategy without changing its current layout and aims to minimize the traveling distance of the forklifts. *A J. Saderova* et al. [16] in their paper observed and measured the forklift's work cycle, which unloaded pallets from the trucks and obtained data from the analysis implemented in the simulation model. They used EXTENDSIM8 software to create a simulation model.

Most of the papers mentioned above include model development of the warehouse and simulate forklift activities for the analysis. The authors were able to demonstrate the importance of planning and analysis for various forklift actions by using modeling and simulations. They used specialized software, developed various algorithms, and worked on programming to obtain data.

2.3. The contribution of the paper compared to the cited literature

While there has been previous research on this subject, this work makes an essential contribution. To name a few, the model developed is quite comprehensive, with 15 modules of various types representing the specific forklift tasks. It includes two forklifts that work simultaneously in the warehouse, on 2 separate routes, incoming and outgoing. The model calculates the number of final pallets loaded on the truck as the primary performance parameter, based on time (hours) limits, travel distances and travel speeds. It calculates the pallets stuck in queues, and their position, which creates bottlenecks in the process. The study is carried out using a hybrid model of travel-distance and travel-time analysis, which yields accurate and numerous findings. Furthermore, the model developed allows the optimization of forklift activities, work with several forklifts at once, and further development of the model with different types and layouts of warehouses.

3. The Warehouse Model and Forklift routings

In Fig. 2 is the Model of the warehouse and forklift travel routes developed with the software. It represents the logic and the process of forklift activities. It has four major parts, which are represented as modules, symbols, and routes, interconnected with entity transfer lines [17]. For our case, the material carried is the entity that is transferred through the warehouse, which is the *pallet* [4].

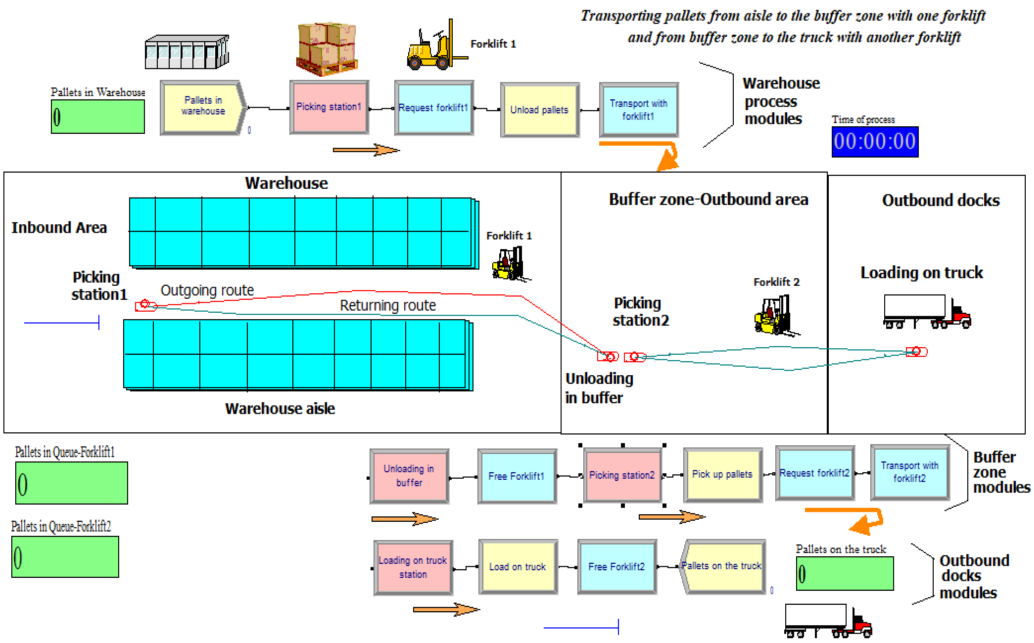

Fig.2. Model of the Warehouse and Forklift(s) travel routes

There are two forklifts defined in the model that work simultaneously. First, *Forklift1* picks up pallets in the *Picking station1* located in the warehouse aisles, and transports them to the *Buffer zone*, where it unloads them. Then, the second *Forklift2* picks up the pallets in the *Buffer zone* (*Picking station2*) and transports them to the *Outbound docks*, where it loads them on the truck. We will explain the model parts in further detail.

3.1. Warehouse process modules – are the first part of the model and the process (at the top in Fig.2). It contains the *Inbound area* where pallets arrive and the forklift activities between the warehouse aisles and Buffer zone. In Fig. 3 is a detailed description of modules.

Pallets in Warehouse – It is the first module, type *Create Module*, where is defined the name of the entity, in this case *Pallet*, and the number of incoming pallets from the *Inbound Area*. Each pallet enters the warehouse aisles constantly, every 3 minutes, and the maximum arrivals are Infinite. This means that the limiting parameter is the time of one working shift (8 hours).

300 pallets are the maximum amount that the warehouse may accept in an 8-hour work shift. We will analyze this to find if the limit is kept or surpassed.

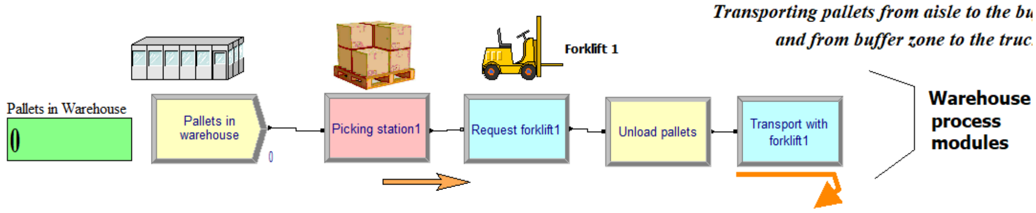

Fig.3. Warehouse process modules, the first part of the model and the process

Picking station1 - Is the type of *Station* module. It defines a physical location; in this case, it is the picking point of the pallets in the warehouse aisles by the first forklift named *Forklift1*. *Request forklift1* – Is a type of *Request* module that assigns a transporter unit, in this case the *Forklift1* to an entity (pallet) and moves the *Forklift1* to the pallet's next station. It is also used for the calculation of queues. *Unload pallets* – Is a type of *Delay* module, which is used to represent the time the forklift unloads the pallets from the aisle. The time of delay is represented with the uniform function UNIF(2,4) minutes. This means the time of pallet unloading is appropriated in between 2 and 4 minutes. *Transport with forklift1* - Is a type of *Transport* module that transfers the entity (pallet) to a destination station together with the *Forklift1*. After the time delay required for the transport, the entity reappears in the model at the Station module [1]. This module specifies that *Forklift1* will move the pallets to the next station, *Unloading in buffer*, in the warehouse's Buffer zone.

3.2. Buffer zone modules – are the second part of the model and the process and represent the outbound area of the warehouse. It is the place where the pallets come with *Forklift1* from Warehouse aisles and unload to the *Buffer zone*. Then, they are loaded on the *Buffer zone* and transported to the *Docking station* of the trucks with *Forklift2*. It contains two stations (red colored modules) (Fig.4).

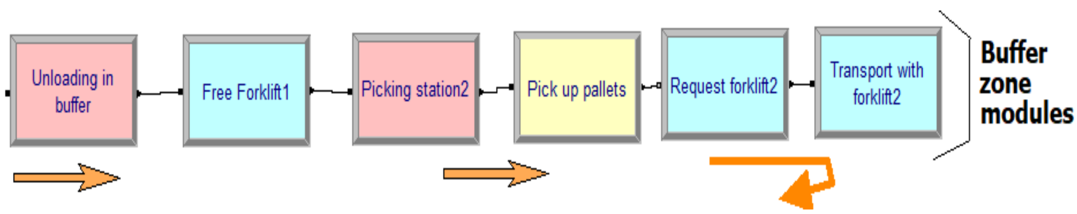

Fig.4. Buffer zone modules, the second main part of the model and the process

Unloading in buffer – Is the type of *Station* module. It defines a physical location [1], [2]. It is the unloading point of pallets by the first forklift *Forklift1* in the Buffer zone. *Free Forklif1* – Is the type of *Free module*, which releases allocated *Forklift1*, that has previously unloaded the pallets in the *Unloading in buffer* station. *Picking station2* – Is the type of *Station* module. It defines a physical location; in this case, it is the picking point of the pallets in the Buffer *zone* by the second forklift named *Forklift2*. *Pick up pallets* - It is a type of *Delay* module, which is used to define the time *Forklift2* needs to pick up pallets in the *Picking station2*. The time of delay is represented with the uniform function UNIF(1,2) minutes, meaning that the time of one pallet picking is appropriated in between 1 and 2 minutes. *Request forklift2* – It is a type of *Request* module, that assigns a transporter unit, in this case the *Forklift2* to an entity (pallet) and moves the *Forklift2* to the pallet's next station. It is also used for the calculation of queues in this area. *Transport with forklift2* - It is a type of *Transport* module, that transfers the pallets to a destination station together with the *Forklift2*. It specifies that *Forklift2* will move the pallets to the next station *Loading on truck*, in the *Outbound docks*.

3.3. Outbound dock modules - are the third part of the model, and represent the Outbound docks where trucks are parked, waiting to be loaded. Pallets are coming from the buffer zone with *Forklift2,* and then loaded on truck. (Fig.5).

Loading on truck station – Is the type of *Station* module. It defines a physical location; in this case it is the point close to the cargo bed of the truck where *Forklift2* stops and starts to load the pallets.

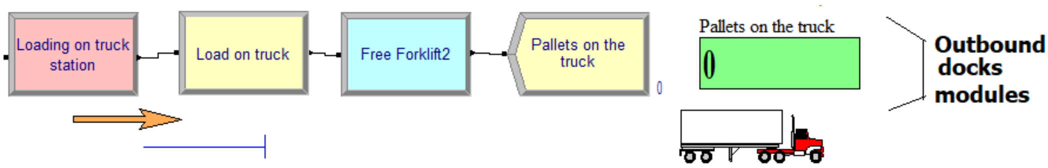

Fig.5. Outbound docks modules, the third main part of the model and the process

Load on truck- Is a type of *Delay* module, which is used to represent the time the Forklift2 loads pallets in the truck. The time of delay is represented with the uniform function UNIF(2,3) minutes, meaning that the time of one pallet loading is appropriated in between 2 and 3 minutes. This longer delay includes the time to load more than one truck, and there is time required for the trucks to be positioned in the outbound docks. *Free Forklift2* – Is the type of *Free module*, which releases most recently allocated *Forklift2*, that has previously picked the pallets in the *Loading on truck station*. *Pallets on the truck* – is the last module of the model, type *Dispose* and the ending point of the process, in this case the number of pallets loaded on the truck.

3.4. Graphical representation of warehouse areas and forklift routes

There are no modules in this part of the model, but it graphically depicts the warehouse's key parts (Fig.6). Here are defined the Outgoing routes (in red) and incoming routes (in blue) of both forklifts, where forklifts travel back and forth during the simulations. The *Forklift1* travels between two stations: *Picking station1* and *Picking station2*, and has *Outgoing Route* and *Incoming Route*. *Forklift2* travels between the *Picking station2* and *Loading on truck*, and has *Outgoing Route* and *Incoming Route* too. Both Forklifts work simultaneously. After the *Forklift1* sends first pallets in the *Picking station2*, the *Forklift2* starts the work to pick up pallets to load them on the truck.

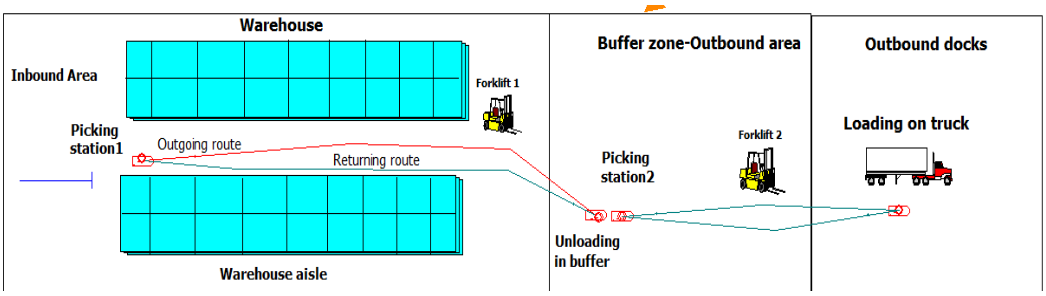

Fig.6. Graphical representation of warehouse areas, forklifts routes and stations

4. Simulation of the model

The simulation of the model in this study is a hybrid of two types of simulations: A travel-distance simulation while it examines performance based on forklift distances and a travel-time simulation while it examines performance based on forklift speeds. This will yield broader findings and more accurate results of performance and functionality.

The simulation scenario is as follows (Fig.2 & Fig.6): The simulation starts from the left upper part of the model, in the first module named *Pallets in Warehouse,* where the pallets enter the process. It continues in the right direction of the Warehouse process modules, in which the *Forklift1* will transfer pallets. Then to the *Buffer zone* modules, in the right direction. In the module *Picking station2* the *Forklift2* will enter in work and pickup pallets unloaded by *Forklift1*. Then, the *Forklift2* will send the pallets to load on the truck, in the station module *Loading on the truck,* which is the start the *Outbound docks* modules. The activity of the *Forklift2* is further described with the module *Load on truck,* and *Free Forklift2,* to release it from pallets. The simulation ends with Dispose module named *Pallets on the truck* where the loaded pallets on the truck are counted. The results will be displayed in the green boxes. There is also a time box that displays the process in hours, minutes, and seconds (Fig.2). The simulation will end when the timer reaches 5 days, 8 hours per day.

4.1. Calculating the warm-up period

For the proper analysis, we will define the warm-up period of the simulation. It is the time necessary for the model to reach steady-state and, therefore, mimic the actual system [1], [2]. Arena Software enables us to define warm-up in the setup of the simulation.

The software module that is a part of Arena software called *Output analyzer*, will give us the form of WIP (*Work In Progress*) function and warm-up period (Fig.7). The red curve gives the form of WIP function. In the *x* axes is the warm-up time. It can be noticed that the warm-up time starts from 0 to around 10 hours, and after that continues in a smoothed steady-state form (flat red line). Therefore, we can conclude that the warm-up time is 10 hours, and this will be implemented in further simulations. While warm-up period is 10 hours or 1 day and two hours in an 8-hour shift, the simulation will not give real results if we run it for one day. Therefore, the simulation will last five days, and then we will calculate the results for one working day, an 8-hour shift, in a day with steady-state mode. In a 5-day simulation, there are 1.5 days warm-up period (10 hours), and 3.5 days of steady-state simulation. We will acquire results in one day (8-hours) of the 3.5 days of steady-state simulation, which will give us required results. The simulation starts in a warm-up period and lasts until it reaches 10 hours. Then the process is reset and starts from the start. In the meantime, there are some pallets remaining in the queues, which we will discuss in the next chapter.

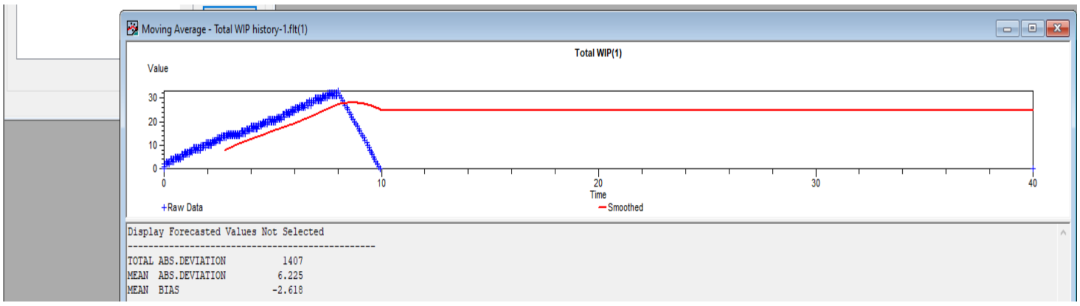

Fig.7. WIP average shown in red curve. Warm-up time lasts from 0 to 10 hours (*x axes)* and then continues in the steady state form

5. Analysis and results

Most important result to acquire and analyze is the number of pallets transferred and loaded on the truck. Then we will compare it with the number entering the Warehouse. An important indicator is the number of pallets stuck in queues in different areas, unable to be loaded on the truck. Parameters on the modules in this Chapter are of type constant input and uniform delays. It is a form of deterministic analysis.

Travel distances include distances that *Forklift1* has to travel, starting from the warehouse aisles (*Picking station1*) to the Buffer zone (*Unloading in buffer*). The closest distance (gap) between these two stations is 35 meters, and the longest distance is 100 m. *Forklift1* will travel double of this distance, the outgoing route with pallets and return route free of load. Five values of distances in both ways will be examined: 70, 100, 130, 160, 200 m. The speed of *Forklift1* will be constant, 10 km/h. *Forklift2* has a shorter distance of 12 m to travel (24 m in both ways), between the stations *Picking station2* and *Loading on truck*. The *Forklift2* rarely makes longer distances, while they do not change significantly in most warehouse layouts.

- Forklifts speed is the variable that can have impact in the results. Typical speed of the forklift in the warehouse is 8 – 15 km/h [9], [18]. Four values of speeds will be examined: 8, 10, 12, 15 km/h, only for *Forklift1*. The speed of *Forklift2* will be assumed constant, 8 km/h, while it travels short distance, 24 m, and cannot reach high speeds.

5.1. Performance of the Forklifts based on the travel distance.

In Table.1 are given results based on 5 values of travel distance by *Forklift1*. Results are for the number of pallets. *Forklift1* travel speed is 10 km/h. *Forklift2* travel speed is 8 km/h. Data are for steady-state working days, 8-hour shift/day.

Table.1. Performance based on travel distance of the *Forklift1* and *Forklift2*

1	Travel distance of Forklift1 (m)	70	100	130	160	200
2	Travel distance of Forklift2 (m)	24				
3	No. of Pallets in the warehouse aisles (3.5 days in steady-state mode)	601	601	601	601	601
4	No. of Pallets in the warehouse aisles (1 day in steady-state mode)	171	171	171	171	171
5	No. of Pallets in queues in the Picking station1 (Forklift1) (1 day in steady-state mode)	87/3.5 = 24	123/3.5= 35	156/3.5 = 44	185/3.5 = 52	220/3.5 = 62
6	No. of pallets in queues in the Buffer zone	0	0	0	0	0
7	No. of Pallets loaded on the Truck (3.5 days in steady-state mode) (Forklift2)	533	507	482	460	435
8	No. of Pallets loaded on the Truck (1 day in steady-state mode) (Forklift2)	152	144	137	131	124
9	Travel distance difference of Forklift1 (m)	0	30	60	90	130
10	Difference (with first distance 70 m) of loaded pallets on the Truck	0	8	15	21	28
11	Dropout of pallets on the Truck in %	0	5.5%	10.9%	16%	22.6%
12	Time required to load all the pallets in the truck	9.6 h	10 h	10.55 h	11.1 h	11.65 h
13	Number of trucks required (26 pallets per truck)	5.84 (6)	5.53 (6)	5.27 (6)	5.03 (≈5)	4.76 (5)

From the data in Table.1, the number of pallets at the start of the process for one day in steady-state mode is 171 (Row.4). The process will not exceed the capacity of 300 pallets per day. Most important result is the *Number of Pallets loaded on the Truck* by the *Forklift2* (Row.8). With the increase of travel distance of the *Forklift1,* from 70 m to the highest 200 m, the number of pallets loaded on the Truck drops significantly, 28 pallets less (Row.10), or 22.6% (Row.11).

Next results from Table.1 is the *Number of Pallets in queues in the Picking station1 (Forklift1)* (Row.5). The number of pallets in queues in this station does not reset at the end of the warm-up period. There are still pallets in queues waiting to be transferred, which is 24 for the lowest distance of 70 m, up to 62 for the 200 m distance. This is an increase for 38 pallets remaining in queues for the longest distance of 200 m, or an increase of 158.8 % compared to the lowest distance of 70 m, which is a negative outcome. A positive result is that by the end of the process there are no pallets remaining in the queues in the Buffer zone.

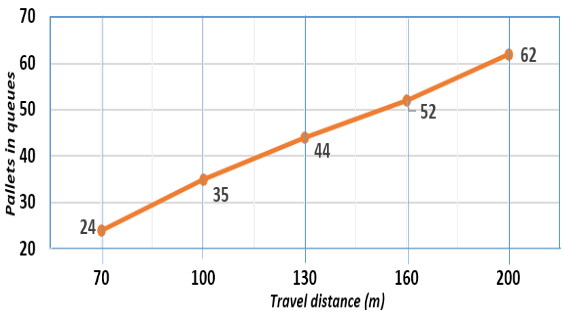

Fig.8. Number of pallets in queues in the *Picking station1* based on *Forklift1* travel distance

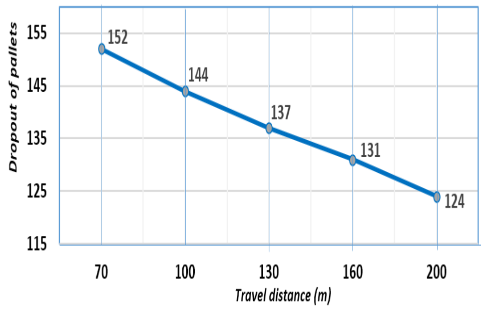

Fig.9. Dropout of loaded pallets on the truck based on *Forklift1* travel distance

Conclusion is that with the increase of forklift travel distances there are less pallets at the end of the process, and there are more pallets in queues (Fig.8 & Fig.9). These are negative results for the overall outcome of both forklifts' performance and warehouse activity in general.

Based on Table.1, Row 12, for each travel distance evaluated, the time required is higher than the 8-hour shift. This is a significant conclusion. The company that uses the warehouse should either expand the operating hours of both forklifts or purchase another forklift to deal with pallets in the warehouse aisles.

According to the literature [19], in one truck trailer fits around 26 pallets. In Row 13 are given the values for the number of trucks required to load the pallets. The last truck is not fully loaded in four cases. The company managing the loading will have to decide whether to dispatch the last truck not fully loaded, or to wait for more pallets to fill it in, which will increase the number of working hours.

5.2. Performance of Forklifts based on the travel speed.

In Table.2 are given results based on four values of travel speed by *Forklift1*. *Forklift1* reference travel distance is taken 130 m, as a medium travel distance. *Forklift2* travel distance is constant 24 m, and the speed is 8 km/h, same as in previous example.

Based on the data from Table.2, the most important result is the *number of Pallets loaded on the Truck (Forklift2)* (Row.8). With the increase of travel speed of the *Forklift1,* from 8 km/h to the highest 15 km/h, the number of pallets loaded on the Truck by *Forklift2* increased by 13%, or 17 pallets more (Row 9 & Row 10). The number of stuck pallets in the queue in *Picking station1* is 53 pallets for the lowest speed, 8 km/h, and drops to 31 pallets for the highest speed, 15 km/h. This is a drop for 22 pallets in queues, which is a positive outcome.

Table.2. Performance based on travel speeds of the *Forklift1* and *Forklift2,* for one day in steady state mode

1	Forklift1 speed (km/h)	8	10	12	15
2	Forklift2 speed (km/h	8			
3	Travel distance of Forklift1 (m)	130			
4	Travel distance of Forklift2 (m)	24			
5	No. of Pallets in the warehouse aisles	171	171	171	171
6	No. of Pallets in queues in the Picking station1 (Forklift1)	53	44	37	31
7	No. of pallets in queues in the Buffer zone	0	0	0	0
8	No. of Pallets loaded on the Truck (Forklift2)	131	137	142	148
9	Difference (with first speed 10 km/h) of pallets on the Truck	0	6	11	17
10	Increase of loaded pallets on the Truck in %	0	4.6%	8.4%	13%
11	Time required to load all the pallets on the truck	11.1 h	10.55 h	10.15 h	9.8 h

We can conclude that higher forklift speed delivers more pallets at the end, and there are less pallets in queues. However, there are also unsatisfying results. The increase in travel speed from 8 km/h to 15 km/h is 87.5%, but the increase of loaded pallets on the truck is only 13% (Table.2, Row 10). This concludes that the increase in speed did not yield a big increase of pallets on the truck. This is due to the pallets in queues and delays for loading and unloading.

Based on Table.2, Row 11, for each of the travel speeds evaluated, the time required is higher than the 8-hour shift to load all the incoming pallets coming from the warehouse aisles to the truck. This is another significant conclusion. The company should either expand the operating hours of both forklifts or purchase an additional forklift to deal with pallets in the warehouse aisles.

6. Stochastic analysis of pallets distribution

For comparison purposes from the previous analysis, we will implement stochastic analysis for the existing model. The analysis will be based on the random income, pickup and transfer of pallets using the *Normal distribution* method. This type of distribution is probabilistic distribution widely present in the theory of stochastic processes [20]. Replication parameters of simulation are the same as in previous Chapter 5. The incoming pallets in the process and their transfer will vary in a random manner based on the normal distribution function *NORM(Mean, StdDev)*. The software Arena simulation is well suited for stochastic analysis regarding the probability distributions of the time between events [1]. We will rewrite the parameters in some modules. The first module to have parameters of Normal distribution is the first module *Pallets in Warehouse.* The Normal distribution function is NORM(3, 0.5), with a mean of 3 minutes and a standard deviation of 0.5 minute (in Chapter 5 is constant every 3 minutes).

Next modules to have probability distribution are of *Delay Type* and they are *Unload Pallets, Pick up pallets* and *Load on truck.* These modules represent the time the forklifts carry their main activities. The Delay Type Module named *Unload Pallets* will have a normal distribution function NORM(3, 1), with a mean of 3 minutes and a standard deviation of 1 minute (in Chapter 5 is UNIF(2, 4)). The NORM function will be selected close to the delivery with deterministic analysis implemented in Chapter 5, for comparison purposes.

For the module *Pick up pallets,* the function will be NORM(1.5, 0.5) (*in Chapter 5 is UNIF(1 , 2)*). For the module *Load on truck* the function will be NORM(2.5, 0.5) (in Chapter 5 is UNIF(2, 3)*)*. In Table.3 are the results of stochastic analysis, based on the travel distances of forklifts.

Based on the results in Table.3, the number of pallets at the start of the process, in the warehouse isles, for one day in steady-state mode varies between 172 and 173. (Row.4). Also, we can conclude that the process will not exceed the capacity of 300 pallets per day. For this analysis, with the increase of forklift travel distances there are less pallets loaded, and there are more pallets in queues.

Table.3. Performance based on travel distance of the *Forklift1* and *Forklift2* in stochastic analysis. *Forklift1* speed is 10 (km/h), *Forklift2* speed is 8 (km/h).

1	Travel distance of Forklift1 (m)	70	100	130	160	200
2	Travel distance of Forklift2 (m)	24				
3	No. of Pallets in the warehouse aisles (3.5 days in steady-state mode)	605	604	606	606	603
4	No. of Pallets in the warehouse aisles (1 day in steady-state mode)	172	172	173	173	172
5	Pallets in queues in the Picking station1 (Forklift1) (1 day in steady-state mode)	109/3.5 = 31	115/3.5=32	169/3.5 = 48	194/3.5 = 55	224/3.5 = 64

6	No. of Pallets loaded on the Truck (3.5 days in steady-state mode) (Forklift2)	528	513	485	463	432
7	No. of Pallets loaded on the Truck (1 day in steady-state mode) (Forklift2)	150	146	138	132	123
8	Travel distance difference of Forklift1 (m)	0	30	60	90	130
9	Difference (with first distance 70 m) of loaded pallets on the Truck	0	4	12	18	27
10	Dropout of loaded pallets on the Truck in %	0	2.7%	8.6%	13.6%	22%
11	Number of trucks required (26 pallets per truck)	5.76 (6)	5.61 (6)	5.3 (6)	5.07 (≈5)	4.73 (5)

7. Comparison of the analysis and results

In Table 4. are the data for both analyses, Constant/uniform (Deterministic) from Chapter 5 and Stochastic from Chapter 6, for the main indicators. The comparison data are for the travel distances of forklifts.

Table.4. Comparison of the performance based on travel distance of the *Forklift1* and *Forklift2*

1	Travel distance of *Forklift2* (m)	24									
2	Travel distance of *Forklift1* (m)	70		100		130		160		200	
3	Type of ANALYSIS	*Const./Uniform*	*Stochastic*	*Const./Uniform*	*Stochastic*	*Const./Uniform*	*Stochastic*	*Const./Uniform*	*Stochastic*	*Const./Uniform*	*Stochastic*
4	No. of Pallets in the warehouse aisles (1 day in steady-state mode)	171	172	171	172	171	173	171	173	171	172
5	No. of Pallets in queues in the Picking station1 (Forklift1)	24	31	35	32	44	48	52	55	62	64
6	No. of Pallets loaded on the Truck (Forklift2)	152	150	144	146	137	138	131	132	124	123
7	Difference (with first distance 70 m) of loaded pallets on the Truck	0		8	4	15	12	21	18	28	27
8	Dropout of loaded pallets on the Truck in %	0		5.5 %	2.7 %	10.9 %	8.6 %	16 %	13.6 %	22.6 %	22%
9	Number of trucks required (26 pallets/ truck)	5.84 (6)	5.76 (6)	5.53 (6)	5.61 (6)	5.27 (6)	5.3 (6)	5.03 (≈5)	5.07 (≈5)	4.76 (5)	4.73 (5)

Based on the results from Table.4, we can conclude that results vary slightly. The income of pallets for constant/uniform analysis is constant 171, and for stochastic analysis varies between 172 and 173 (Row 4). This is a minor difference. Notable differences in the values are for the *Difference of loaded* *pallets on the Truck* for the distance 100 m (8 compared to 4) (Row 7), and *Dropout of loaded pallets in %* (5.5% compared to 2.7%) (Row 8). The number of loaded trucks is similar for each analysis. The end result is that the last truck remains unloaded in four cases of distance travelled, for both analyses.

8. Conclusions

In this study, we presented a model and simulations of forklift activities in a warehouse using Arena software. The objective was to develop an adequate model that represents the warehouse areas, forklift travel routes and implement simulations to analyze the performance. This was achieved while the results gave the performance of two forklifts and yielded numerous conclusions. Two types of analysis were performed: Deterministic analysis and stochastic analysis. Comparison of the results of two types of analysis are given in table 4. The results did not differ significantly.

With the development of this type of model it is possible to design the warehouses, define the entity to be transferred, which in this case were pallets, plan the number of forklifts and design the travel routes of forklifts. Simulations can be applied in a precise time frame. The results were obtained over an 8-hour work shift. The main outcome was the number of pallets transferred from the warehouse aisles to the truck. This is most important in the performance of warehouses that deal with pallets. Because two forklifts are working at the same time, the analysis becomes more complex. The analysis was both time-distance and time-velocity based. It is feasible to acquire better outcomes by implementing this form of hybrid analysis.

The investigation focused on two primary input parameters: forklift travel distance and forklift travel speed and results were discussed. Another significant result to note is: if we investigate the performance for the minimum travel distance of 70 m, and maximum speed of 15 km/h for the *Forklift1*, the time required to load all the pallets in the trucks is around 9.25 hours. This is still not enough to finish the work in 8-hour shift. In this instance, the company needs to extend the operating hours of both forklifts or purchase another forklift. If there are more than 171 or 172 pallets in the aisles that need to be transferred to the truck(s), these changes become mandatory. Little alternatives could improve the performance in the existing warehouse.

With the methodology presented in this study, it is possible to analyze the time required to process all the required pallets, and to determine the number of forklifts needed in the warehouse. This model can be further developed by adding more forklifts in the process and more stations, which would increase the complexity of the model. It would be very useful for the companies that plan to extend the warehouse capacity and infrastructure.

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