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Simulation of Finished Goods Warehouse – Towards a Detailed Factory Simulation

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Abstract

Customers of the packaging material industry are demanding shorter and more customized orders for each year. In many cases, the production has adapted to the new market demands. However, some finished goods warehouses are still adapted to the larger order sizes following a build-to-stock policy. In finished goods warehouses a shorter order sizes create problems, such as an increased amount of handling due to mixed orders. This paper presents a simulation model of a finished goods warehouse at a packaging material factory in Arganda, Spain. The model is used to perform different experiments that analyze potential improvements of the layout and the warehousing activities. The main advantage of using a simulation is that experiments with different scenarios of the layout and warehousing activities can be performed without affecting the performance of daily operations. Five scenarios were carried out to understand the potential behavior and performance of the warehouse. Two scenarios resulted in performance improvements as well as the reduction of the total cost. The overall best scenario included an additional loading dock for shipments. With this scenario, more goods can be loaded at the same time, resulting in lower inventory levels. Lower inventory levels in turn reduce the mixing of orders in the storage zones. Mixing of orders is directly correlated with double handling. Therefore, double handling is also reduced. For Tetra Pak, the investigation has contributed to an improved understanding of how customized orders affect the warehouse. This simulation model of the finished goods warehouse is also a step towards a detailed factory simulation where the relevant parts of the factory are simulated. The factory model will be a major asset for efficient planning of shorter production orders.

Keywords

Discrete-event simulation, Logistics, Packaging, Production, Scenarios, Warehouse

1. Introduction

It would be an understatement to say that many companies are finding that the needs and demands from the market are increasing. Decreased lead time and increased service level are some of the demands placed on suppliers that have resulted in smaller and customized orders. To meet these market needs there is a growing trend in industry to transform production strategies from build-to-stock to build-to-order (Holweg and Pil, 2001). The packaging material industry is definitely no exception to this trend and many companies have changed their marketing orientation and production strategy to build-to-order. As a result, the production process of these companies suffers from shorter production orders with the direct effect of increased setup time. This in turn has had a major impact on the storage of finished goods inventory, which often is designed for long production orders with dedicated storage. Bartholdi and Hackman (2011) stress that smaller order size makes it difficult to keep a dedicated storage for each production order, and the utilization of space is low.

This paper presents a simulation model of the finished goods warehouse (FGW) at a packaging material factory in Arganda, Spain. The model is used to perform different experiments that analyze potential improvements of the layout and the warehousing activities. The study focuses on the FGW and only on warehouse activities concerning the physical flow of storage keeping units (SKUs). The FGW is located in the distribution of a factory chain, see Figure 1. The factory in Arganda is suffering from shorter production orders and has transformed its production into complete build-to-order strategy. The FGW has not yet been adapted to the market needs of shorter production orders and the layout is still dimensioned for a build-to-stock strategy. Thus, the warehouse performance needs to be explored.

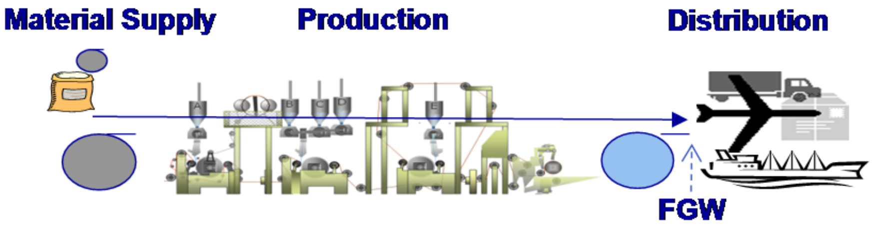

Figure 1: FGW’s position in the Arganda factory chain

The paper is organized as follows. The next section provides a brief description of the methodology. Section 3 presents the frame of reference. Section 4 describes the simulation model followed by Section 5 where the scenarios are presented. In Section 6, the results from the experiments with the scenarios are provided. A concluding discussion and direction for further research is presented in the last section.

2. Methodology

A discrete-event simulation model was developed in this investigation. Simulation is a problem-solving method that is very useful when the systems become so complex that common sense and simple calculations are not enough (Banks, 2000,). The purpose of a simulation model is to provide the observer with information about the behavior and performance of the real system (Banks et al., 1996; Cassandras and Lafortune, 2008; Law and Kelton, 2000). By using simulation, it is possible to answer different types of questions like “What if?” and “Is it possible?” (Banks, 2000; Banks et al., 1996). The main advantage for using simulation in this study is that experiments with different scenarios of the layout and material handling activities could be performed without affecting the performance of the real FGW.

Tetra Pak is currently using software called *FlexSim*. It is a discrete-event simulation program based on C++ program language that observes the behavior and dynamics of the system, and creates statistics that can easily be evaluated. *FlexSim* has a very strong graphical advantage due to 3D illustrations of the modeled system. Another reason for using *FlexSim* in this study was to be able to adapt to the earlier simulation models that were generated in this software for other parts of the Tetra Pak factory.

2.1. Simulation Process

The simulation study is based on the Banks (2000) model. There are numerous steps in this model with various feedback loops. The fundamental steps of collecting data, verifying and validating the simulation model, and experimental design are briefly described.

Data Collection

Data was collected in numerous ways. An in-depth understanding of the system was established by identifying all the needs and constraints that are placed on the FGW. First, all relevant stakeholders were identified. Thorough interviews were carried out with them to identify their needs and views on the system constraints. Once these are identified, they can be translated into system requirements (Alexander and Beus-Dukic, 2009). The system requirements placed on the FGW were then translated into model requirements, according to which the simulation model was designed. Detailed observations of the all the activities were made. Finally, detailed historical data regarding shipments for 100 days were collected as well as the data generated for the arrivals of goods to the FGW.

Verification & Validation

All the identified requirements and the model behaviors were verified by the stakeholders. The verification was performed through a step-by-step walkthrough where a list of needs was compared to the model requirements. Each requirement was shown in the model to the stakeholder. The stakeholders were then able to see if there were any steps missing, any steps in the wrong order or any misunderstandings regarding the requirements (Alexander and Beus-Dukic, 2009).

Experimental Design

Five scenarios were created to find an improved layout or material handling process. The scenarios were created to improve the key performance parameters identified in the FGW: inventory level, number of relocations, stay time in the floor storage zones, throughput and traveling distance for the forklifts. Each scenario was evaluated with respect to both the performance parameters and the total impact on the life-cycle cost of the packaging material.

3. Frame of Reference

This section discusses warehousing and storage activities, performance and cost. The dimensioning of the floor storage bin size is also explained. The section ends with the framework for calculating and evaluating the performance for an FGW.

3.1. Warehousing and Storage Activities

The key activities in warehousing are: Receiving, Put-away, Storage, Picking, and Packing/Shipping (Coyle et al., 2003; Frazelle, 2002). Receiving is the first activity when goods arrive. Put-away is when the goods are placed where they are supposed to be stored. When a demand for certain goods arises, there are three main departure activities. First, the ordered goods are picked from the storage. Then they are packed and finally shipped, according to the customer's demand. In addition to these activities, the placing policy is of importance in the warehouse (Mulcahy, 1994). The main placing policies in a warehouse are dedicated storage and shared storage. Dedicated storage is when each set of goods has its own unique location that cannot be occupied by other kinds of goods. Shared storage is when all the goods share the storage space and there is no specific storage location or bin. Smaller orders make it difficult to keep a dedicated storage for each production order, and the utilization of space is low (Bartholdi and Hackman, 2011). This leads to the use of shared storage for the production orders, which maximizes space utilization (Stock and Lambert, 2001). When using a last-in-first-out (LIFO) policy in a warehouse with shared storage, double handling is a major disadvantage. Double handling is when an SKU is moved to be able to reach another SKU. Double handling is not a value-adding activity; it only adds cost.

3.2. Floor Storage Bin Size

In a floor storage system, all goods are stored on the floor. There is no equipment for storage such as racks or boxes. A bin is a single row where SKUs can be placed in a floor storage system. The depth of the bin is crucial for how many SKUs can be placed in it. The bin size in a warehouse describes how many SKUs can be stored at each level. According to Bartholdi and Hackman (2011), to minimize the total average floor space consumed by a pallet, the bin size can be approximately calculated with:

$$K = \sqrt{\frac{a*1*\sum_{i=1}^{n}\frac{q_i}{z_i}}{2*n}} \quad (1)$$

where

K= the depth of the bins

$\boldsymbol{q_i}$=order quantity

$\boldsymbol{z_i}$= stack height in number of SKUs

n= number of SKUs

a= aisle width

3.3. Warehouse Performance and Cost

The performance of a warehouse is connected to the cost for a warehouse. There are many ways to measure warehouse performance. Some warehouse performance parameters are (Coyle et al., 2003):

- Handling cost
- Holding cost
- Stay time in warehouse
- Inventory level

In a floor storage system where the placing policy is shared storage, there is a set of certain costs. The cost for relocations can be connected to the handling cost. Relocation is when one SKU is moved if it is blocking an ordered SKU. Fifty percent of the total handling cost can be associated with the picking activity (Frazelle, 2002). The relocation cost is assumed to be 25% of the handling cost because relocations only occur in the picking activity. The holding cost for a warehouse is proportional to the inventory level. The inventory level cost can be calculated by multiplying the inventory level by the holding cost for a single SKU. Fifty-five percent of the time, the forklift's picking activity is dedicated to traveling (Bartholdi and Hackman, 2011). The traveling cost in an FGW is assumed to be 27.5% of the handling cost. Average travel distance per SKU can be calculated with equation (2), and travel cost per meter can be calculated with equation (3). By using these equations, the total traveling cost can be calculated by multiplying formula (2) by (3).

$$\frac{Total\ travel\ distance}{Total\ throughput+Number\ of\ relocations} \quad (2)$$

$$\frac{Average\ Travel\ distance\ per\ SKU}{Total\ throughput*Travelling\ Cost} \quad (3)$$

4. Simulation Model

Just as the real system, the simulation model consists of an LIFO floor storage system. The floor storage is divided into zones which are divided into bins. The bins are divided into pallet positions, which are the squares in the floor storage zones. The FGW structure has 27 different floor storage zones. The light colored floor storage zones are entered from the side aisles and the dark colored floor storage zones are entered from the main aisle. Figure 2 shows an overview of the model including the Production Finishing Area Exit, and the FGW Entry and Exit.

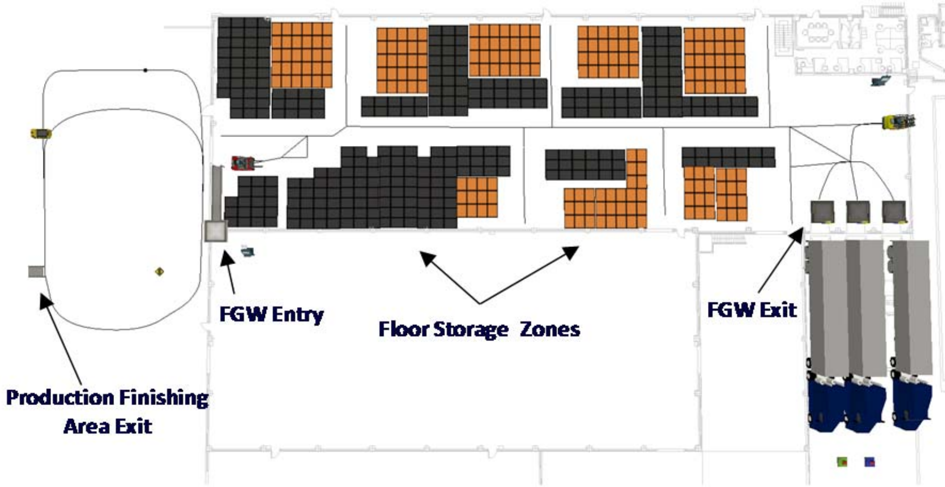

Figure 2: Overview of Simulation Model

4.1. Generating SKUs

The SKUs consist of wooden pallets with reels of packaging material. These are generated at the Finishing Area Exit, which is the last part of the production process. The production process has a make-to-order policy. This means customized production with small batches and longer lead times compared to the make-to-stock policy. Reels of packaging material are stacked on a pallet. Based on the input data, all relevant information regarding how many reels should be stacked on each pallet as well as the height of each reel is stored in labels on the SKU. A production order can contain different numbers of SKUs. The maximum diameter of the reel is set to make sure that the reels do not reach outside the frame of the pallet. The SKUs that belong to the same production order are assigned a specific color. The SKUs with the same color should be stacked together if possible. The color simplifies the identification when the animation is viewed and the stacking is controlled.

The SKU is collected by an AGV at the Finishing Area Exit. Thereafter, it is transported to the FGW Entry. The AGVs follow a path with a single capacity; the vehicles cannot pass each other. The path, pickup point at the Finishing Area Exit and the FGW Entry are illustrated in Figure 3.

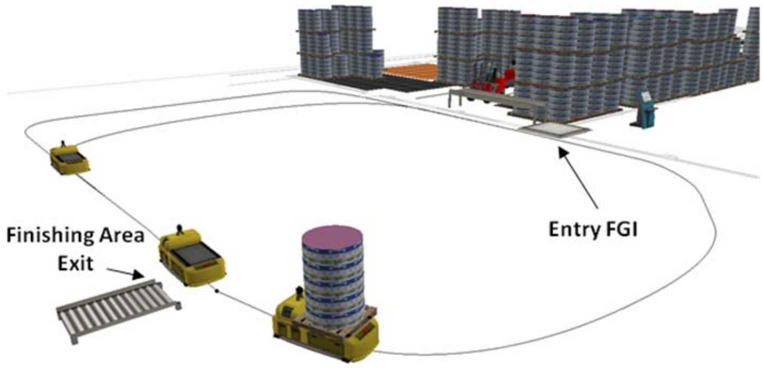

Figure 3: Transport of SKUs to the FGW

4.2. Receiving

The SKU is placed on the receiving conveyor belt by the AGV, see Figure 4. The conveyor belt has a safety delay time of approximately 30 seconds that starts directly when the SKU is put down on the conveyor belt. The conveyor belt has a length of 6 meters and a speed of 0.2 m/s. It is modeled to have no breakdowns in the simulation. After the SKU has been transported to the end of the conveyor belt, it is ready to be picked by a forklift. The forklift picks the SKU from the conveyor belt. The time for each pick from the conveyor belt, including the scanning of the barcode on the SKU, is simulated with a triangular distribution. If the FGW becomes full, the arriving SKUs will stay on the conveyor belt until there is an available pallet position. There are two forklifts working during each shift.

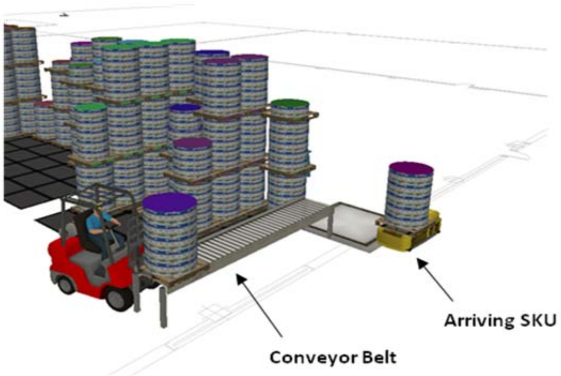

Figure 4: Receiving arriving SKUs in the FGW

4.3. Put-away

When the arriving SKU is on the conveyor belt, its storage location is set in the FGW. The order size is not taken into consideration when suggesting a bin. If there are any matching SKUs from the same production order in the FGW, the arriving SKU is placed in that bin. If possible, the arriving SKU is stacked on top of the matching SKU. However, there is a height constraint of 5.3 meters for a stack of SKUs. If the stack exceeds the height constraint, the arriving SKU is placed in the pallet position in front of the matching SKUs. If there is no pallet position in front of the matching SKUs, the SKU is placed in an empty bin or the bin with most available pallet positions. When stacking, the minimum diameter allowed for the top reel of the matching SKU is 975 mm, hence to the dimensions of the bottom structure of the wooden pallets. If the top reel diameter is any smaller than 975 mm, the stacked SKU will not be considered stable and has an increased risk of tipping over. No mixing of the production orders is allowed at the same pallet position. The unloading sequence is a mean of the time it takes for unloading at different heights. After a put-away, the forklift returns to the receiving area. The virtual put-away activity is visualized in Figure 5.

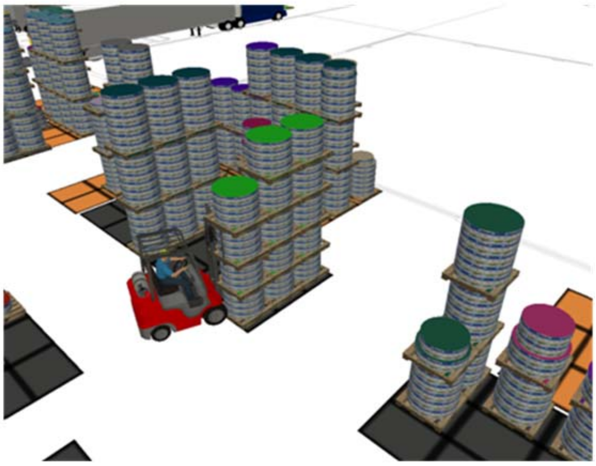

Figure 5: Put-away of SKU in a stack

4.4. Picking

When a picking list arrives, the forklift is ordered to drive to the specific floor storage zone and bin. When reaching the bin, the forklift picks up the ordered SKU. If another forklift is blocking the way by picking or put-away activities, the last arriving forklift has to wait until the first forklift is finished. This is modeled by a temporary lock set on the bin for the other forklifts. It is also possible that the ordered SKU is blocked by other SKUs, see Figure 6. If this is the case, the blocking SKUs must be relocated to another bin in the FGW.

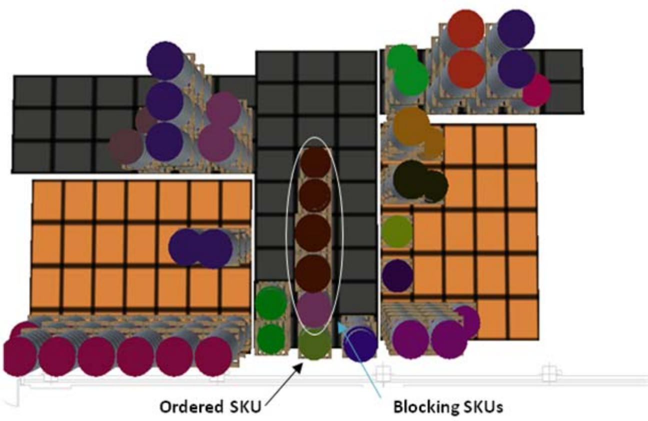

Figure 6: Blocking SKUs when picking an order

The relocation follows the same logic as when placing an arriving SKU in the FGW. In the relocation process, the height and top reel diameter constraints are taken into consideration as well. When the forklift picks up the blocking SKU for relocation, the current bin is locked so no other forklift can place other SKUs in that bin. A label is put on the floor storage zone while the forklift is relocating the SKU. The logic code for relocating is programmed to compare the suggested bin for relocating the SKU to the label on the floor storage zone. If there is no match, the SKU can be placed in the suggested bin. When all SKUs have been relocated, the ordered SKUs can be picked.

4.5. Shipping

Once an SKU is picked, it is transported by the forklift and unloaded in the loading area, see Figure 7. The SKU is placed in a FIFO queue at the correct loading dock. Between 08.00 and 20.00, a human resource represents the truck driver in the model and has a walking speed of 1.4 m/s. Once a picking list has been completed, there is a delay for the next picking order to arrive. Since the trucks are assumed to arrive independently of each other, the arrivals can be assumed to follow a Poisson process with an exponential inter-arrival time (Marklund and Laguna, 2005). This symbolizes the undocking and exit of the current truck and entering and docking of the arriving truck.

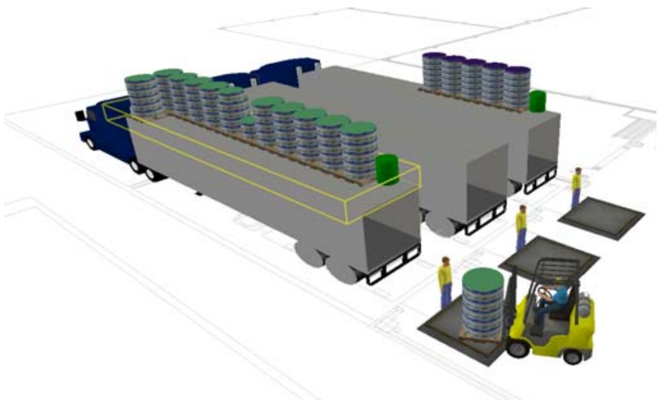

Figure 7: Loading of trailers at the loading docks

5. Experimental design and analysis

Five scenarios were created through discussion with the Arganda warehouse management team. These are compared to the performance of the Base Scenario. Moreover, a cost analysis was performed for each scenario to investigate the potential of the improvements.

5.1. Scenario A: Add one loading dock

One extra loading dock was added in this scenario. By doing so, four trailers could be loaded at the same time. It was observed in the real system and in the Base Scenario that during the peak hours in the middle of the day, a bottleneck would occur in the loading of trucks. An extra loading dock might reduce the bottleneck problem.

The performance of Scenario A is illustrated in Table 1. The model managed to pick orders much more efficiently resulting in shorter picking order queues. The majority of the performance parameters improved. The average inventory level decreased by 12%, which is a direct result of the significant decrease of average stay time in the inventory of 34%. The reason could be that more trucks can be loaded in the FGW at the same time and the picking activity can be started faster. These improvements will have a large impact on the holding cost. The number-of-relocations parameter also decreased significantly, which impacts the handling cost. This could be due to the lower inventory level. A lower inventory level results in fewer mixed orders in each bin. The average forklift-total-distance parameter increased. This is explained by the longer distance to reach the additional loading dock.

Table 1: Performance of Scenario A in mean values with a confidence interval of 95%

	Inventory level (SKU)	Number of relocations	Stay time in bins (s)	Throughput (SKU)	Forklift total distance (m)
Base Scenario	717	658	55,304	5,333	825,585
Scenario A	632	451	36,511	5,234	861,494
Difference %	-12	- 31	-34	-2	4

The total cost was reduced by approximately 43,000€, see Table 2. By implementing this scenario, the life-cycle cost of the packaging material is affected in a positive direction, which is why Scenario A is recommended for further evaluation. The annual relocation cost decreased compared to the Base Scenario due to the lower number of relocations. The annual holding cost also decreased due to the lower inventory level in Scenario A. The traveling cost increased due to the longer distance to reach the additional loading dock. No investment cost has to be made since the trailers can be loaded from the side directly from ground level instead of docking to a "real" loading dock.

Table 2: Comparison of costs for Scenario A and the Base Scenario

	Scenario A	Base Scenario	Difference
Annual relocation cost (€)	63,250	92,250	-29,000
Annual holding cost (€)	59,750	103,250	-43,500
Annual traveling cost (€)	206,324	176,461	29,863
Investment cost (€)	0	0	0
Annual total cost (€)	329,324	371,961	-42,637

5.2. Scenario B: Add one loading dock and forklift

This experiment was the same as Scenario A except that one extra forklift was added to the picking team. The additional forklift was put on the picking overlap schedule. This scenario was created to see of there could be any further improvements compared to Scenario A.

All performance parameters improved except the average forklift total distance for the picking forklifts, see Table 3. The average inventory level decreased by 13%, which is a direct result of the significant decrease of average stay time in the inventory of 37%. This could be because more trucks can be loaded in the FGW at the same time and the picking activity can be started faster. The number-of-relocations parameter also decreased significantly, due to the decreased inventory level. A decreased inventory level results in fewer mixed orders in each bin. The average forklift-total-distance parameter increased. This is explained by the longer distance to reach the additional loading dock.

Table 3: Performance of Scenario B in mean values with a confidence interval of 95%

	Inventory level (SKU)	Number of relocations	Stay time in bins (s)	Throughput (SKU)	Forklift total distance (m)
Base Scenario	717	658	55,304	5,333	825,585
Scenario B	627	414	36,968	5,224	856,771
Difference %	-13	-37	-33	-2	4

The comparison of the Base Scenario and Scenario B shows a small reduction of total cost of approximately 12,000€, see Table 4. This will affect the life-cycle cost of the packaging material in a positive direction. Therefore, Scenario B is recommended for further evaluation. The relocation costs decreased significantly, which can be explained by the lower average inventory level. By having a lower average inventory level, fewer SKUs have to be relocated due to mixed orders in the bins. The decreased average stay time in the FGW in combination with the decreased average inventory level contributes to the substantially lower holding cost compared to the Base Scenario. However, there are additional costs compared to the Base Scenario, which are the salary of a forklift driver and the rental of a forklift. The annual rental cost of a forklift has been estimated to 5,000€. As in Scenario A, there is no investment cost since the trailers can be loaded from the side at ground level. No actual platform has to be built.

Table 4: Comparison of costs for Scenario B and the Base Scenario

	Scenario B	Base Scenario	Difference
Annual relocation cost (€)	51,807	92,250	-40,443
Annual holding cost (€)	60,250	103,250	-43,000
Annual traveling cost (€)	206,163	176,461	29,702
Investment cost (€)	0	0	0
Annual forklift driver salary (€)	36,400	0	-36,400
Annual rental of forklift (€)	5,000	0	-5,000
Annual total cost (€)	359,620	371,961	-12,341

5.3. Scenario C: Most space efficient lane depth

This experiment changed the layout regarding bin size. The most space efficient bin size was calculated using Equation 1. The results indicated that it was six pallet positions' deep. Since the average order size is constantly getting smaller for each year, the bin sizes in the FGW are not up to date. This scenario was generated to reduce the mixing of orders in the different bins. The trade-off with this change is that the total SKU capacity decreased from 1,554 to 1,443. The new layout can be seen in Figure 8.

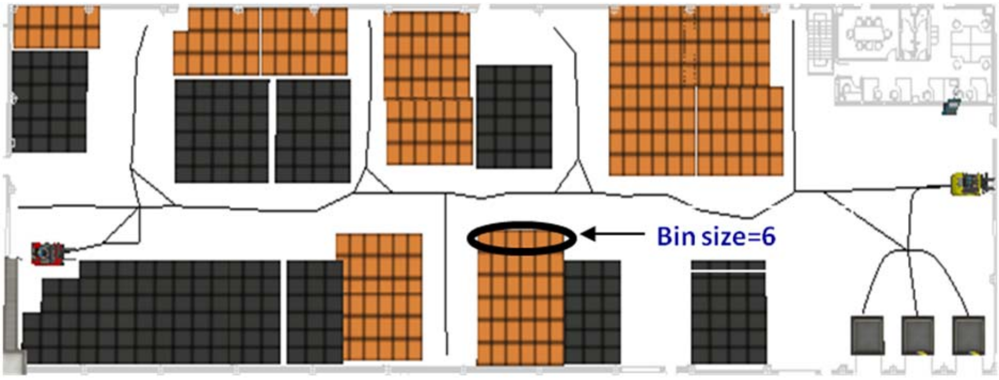

Figure 8: Layout of FGW with bin size six

The results of Scenario C were mixed. The inventory level decreased by 4% and the average stay time by 10%, see Table 5. However, the number of relocations increased substantially. This was probably due to the reduced FGW capacity. Because of this, the forklift was given fewer alternatives to store the SKUs and consequently, more relocations were necessary. Moreover, the large production orders had to be divided into several bins, which increased the risk of mixing orders. Because relocations became more common, it was obvious that the forklifts needed to drive a longer way due to the unnecessary driving to relocate blocking SKUs. It was also noticeable that the experiment started to fail when the FGW capacity reached over 800 SKUs. The relocations were too time consuming, so the FGW started to be overfull after a while.

Table 5: Performance of Scenario C in mean values with a confidence interval of 95%

	Inventory level (SKU)	Number of relocations	Stay time in bins (s)	Throughput (SKU)	Forklift total distance (m)
Base Scenario	717	658	55,304	5,333	825,585
Scenario C	*686*	771	49,572	5,375	868,766
Difference %	-4	17	-10	1	5

There was an increased total cost of approximately 14,000€, see Table 6, which will affect the life-cycle cost of the packaging material in a negative direction. Scenario C is not to be recommended for implementation. The results show that it would be more expensive to implement this layout than keeping the original layout. The increased level of relocation was too big to result in any savings. The relocation cost increased compared to the Base Scenario. The traveling cost also increased due to the longer distance the forklifts had to travel. The main improvement was the reduction of the annual holding cost because of the lower amount of time each SKU spent in the FGW. However, having the same bin size for all bins is not recommended.

Table 6: Comparison of costs for Scenario C and the Base Scenario

	Scenario C	Base Scenario	Difference
Annual relocation cost (€)	108,250	92,250	16,000
Annual holding cost (€)	88,500	103,250	-14,750
Annual traveling cost (€)	188,992	176,461	12,528
Investment cost (€)	0	0	0
Annual total cost (€)	385,742	371,961	13,781

5.4. Scenario D: High capacity layout

The layout for this scenario was changed, see Figure 9. The bins were expanded as much as possible. The SKU capacity of the FGW was increased from 1,554 to 1,668 because of the additional pallet positions. This scenario was generated because the managers of the warehouse said that one of the main issues in the FGW was the number of relocations and lack of space. This scenario was carried out to see if more pallet positions would increase the performance of the FGW.

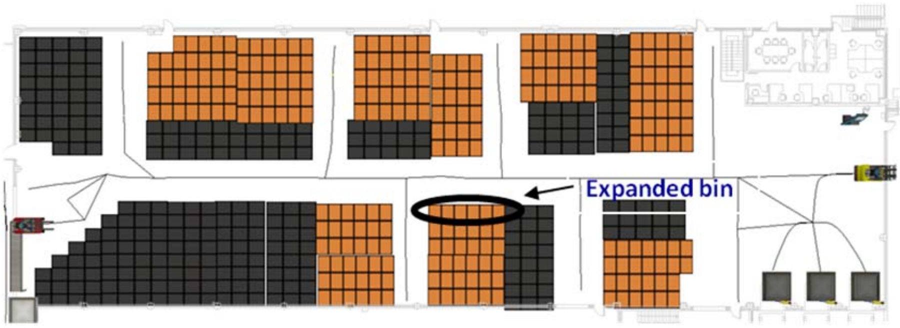

Figure 9: Layout of FGW with expanded bins

The average inventory level increased by 10%. The relocation was 99% higher than in the Base Scenario, see Table 7. In addition, when increasing the capacity in the FGW by using another layout, an increased mix of orders could be observed. This resulted in the substantial increase of relocations. That is probably the reason for the higher inventory level as well. The total travel distance was 74% higher in this scenario which affects the usage of the forklifts and will increase the annual traveling cost. It is possible that the scenario is a little less employee friendly due to smaller aisles. For this scenario, it will be harder to manage the forklift in the FGW.

Table 7: Performance of Scenario D in mean values with a confidence interval of 95%

	Inventory level (SKU)	Number of relocations	Stay time in bins (s)	Throughput (SKU)	Forklift total distance (m)
Base Scenario	717	658	55,304	5,333	825,585
Scenario D	786	1,311	56,221	5,220	1,435,681
Difference %	10	99	2	-2	74

Scenario D increases the total costs by approximately 430,000€, see Table 8. The big increase means that Scenario D is not recommended. The results of the comparison show that Scenario D is on the whole a worse alternative to the Base Scenario. The large increase in the number of relocations would have a great negative impact on the total cost. The traveling cost increased significantly. This is the main reason for a significant increase in the total cost. Thus, expanding the bin sizes is not recommended.

Table 8: Comparison of costs for Scenario D and the Base Scenario

	Scenario D	Base Scenario	Difference
Annual relocation cost (€)	184,008	92,250	91,758
Annual holding cost (€)	115,000	103,250	11,750
Annual traveling cost (€)	500,121	176,461	323,660
Investment cost (€)	0	0	0
Annual total cost (€)	799,220	37,1961	427,259

5.5. Scenario E: Vertical rack

In this scenario, there was a small change in the layout. A small pallet shelf was installed, illustrated in Figure 10. The rack only can store SKUs with a total height of less than 80 cm. The implementation of this shelf decreased the FGW capacity by 37 possible locations. The managers of the warehouse in Arganda discussed an installation of a vertical rack for smaller SKUs with only two or three reels on. The aim of Scenario E was to remove the small SKUs from the floor storage, which would give more space for the higher SKUs, and to utilize the space better in the FGW.

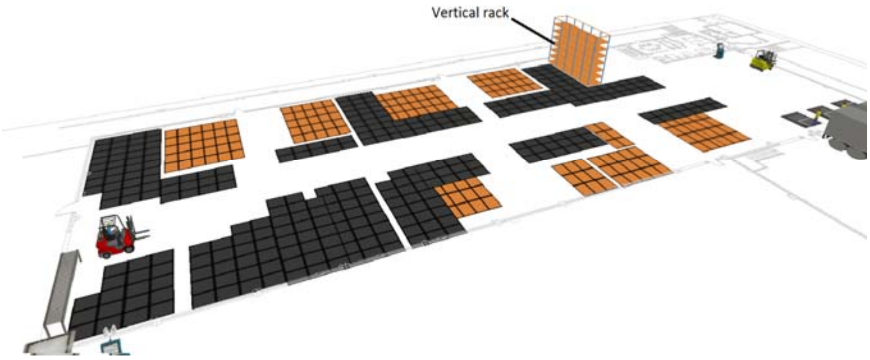

Figure 10: Layout of the FGW with a vertical rack

As order sizes decrease, the amount of incomplete full-sized SKUs increases. The observation was that the installation of a rack, which stores these small SKUs, will increase the mixing of orders in the bins. This is because the SKUs with a top reel diameter of less than 0.975 m would be stored in the rack so the space utilization in the bins would increase due to more complete stacks. This would lead to a higher number of mixed orders in each bin, resulting in a higher number of relocations.

The result of the comparison showed that Scenario E was a worse alternative than the Base Scenario. All performance parameters increased, especially the amount of relocations. The relocations increased in this experiment by 80%, see Table 9. The reason for the substantial increase in relocation could depend on the loss of pallet positions due to the installment of the rack. In addition, the forklifts needed to drive a longer way when relocating smaller SKUs. Due to this, the receiving forklifts would be able to fill up the FGW more compared to what is shipped. Removing small SKUs would mean mixing the orders more and in doing so, increase the relocations to be able to retrieve the ordered SKU. This would start a negative trend in the behavior and the inventory level would increase. It is only natural that the average stay time would increase along with the number of relocations and higher inventory levels as well, because the time is spent on relocating SKUs instead of picking them.

Table 9: Performance of Scenario E in mean values with a confidence interval of 95%

	Inventory level (SKU)	Number of relocations	Stay time in bins (s)	Throughput (SKU)	Forklift total distance (m)
Base Scenario	717	658	55,304	5,333	825,585
Scenario E	797	1184	60,578	5,310	841,905
Difference %	11	80	10	0	2

The comparison of the Base Scenario and Scenario E clearly shows that Scenario E increases the total cost by approximately 90,000€, see Table 10**.** The annual relocation cost increased dramatically compared to the Base Scenario due to the higher number of relocations. The annual holding cost also increased due to the larger average inventory level. The traveling cost increased since the orders had to be separated into small SKUs and large SKUs. Therefore, it is not recommend to only install a rack. However, combining a rack with a more dynamic layout of the bins is a recommendation for further research.

Table 10: Comparison of costs for Scenario E and the Base Scenario

	Scenario E	Base Scenario	Difference
Annual relocation cost (€)	166,250	92,250	74,000
Annual holding cost (€)	125,750	103,250	22,500
Annual traveling cost (€)	170,031	176,461	-6,430
Investment cost (€)	1,500	0	1,500
Annual total cost (€)	460,531	371,961	88,570

6. Results

When comparing all the scenarios with the Base Scenario in Figure 11, the results show that the annual total cost can potentially be reduced by approximately 43,000€ in Scenario A. However, it must be emphasized that there annual savings are tied up capital. The recourses are utilized more efficiently when implementing Scenario A. Thus, the recourses can be used in other parts of the warehouse. Comparing Scenario A and Scenario B, the only differences are an additional forklift and driver. Scenario B adds an additional cost due to rental of the forklift and salary of the driver. The overall total cost is annually 30,000€ lower for Scenario A compared to Scenario B. However, Scenario B has better performance but not to the point that it justifies the increased cost.

Implementing Scenario A does not require a large initial investment. This is because the trailer can be loaded from the side by the forklifts; there is no need for an actual dock. Instead, the trailer canopy can be removed and the forklifts will load the trucks from ground level. The truck driver can assist in correcting the position of the SKUs. This was considered when modeling this in Scenario A, see Figure 12 where the location of the additional dock is shown.

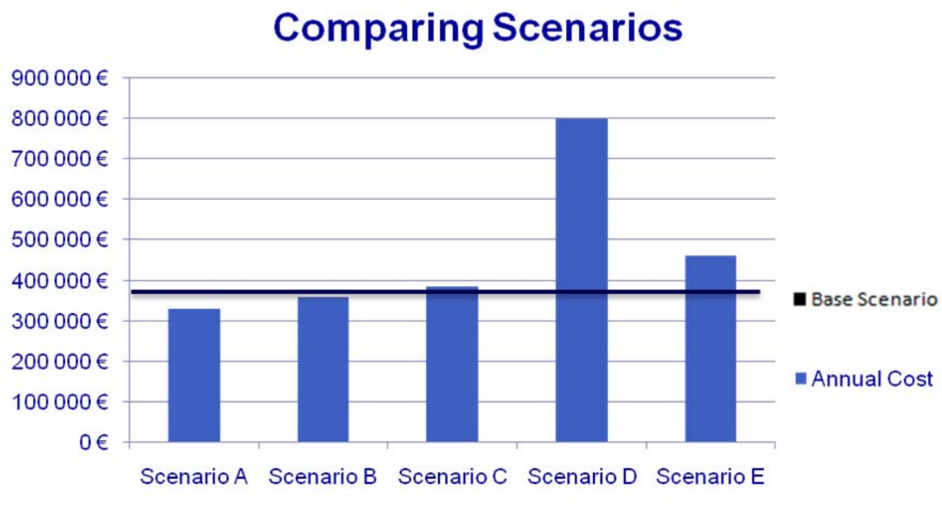

Figure 11: Cost comparison of scenarios with the Base Scenario as reference

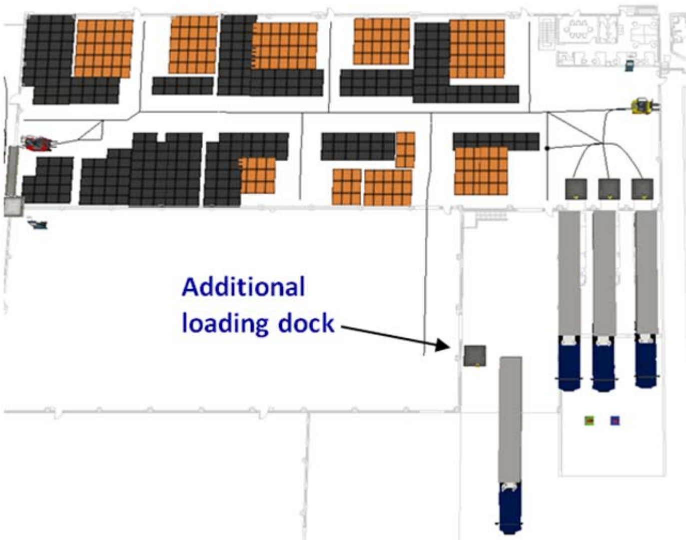

Figure 12: Layout for Scenario A with the location of an additional loading dock

7. Concluding Discussion

In this investigation, a discrete-event simulation model was developed to run experiments exploring how the FGW in Arganda can improve its performance and reduce the total cost. The findings indicate that if the FGW in Arganda implements one extra loading dock, the annual savings would be approximately 43,000€. The results will have a positive effect on the life-cycle cost of the packaging material. The savings are mainly connected to a more efficient use of the forklifts. Therefore, the savings will contribute to having forklifts available which can assist other parts of the warehouse and factory. The findings confirm what the warehouse management team have been discussing, but have not investigated in detail. There is a plastic wrapper that needs to be moved and could be the reason for why the scenario has not yet been implemented.

For Tetra Pak, the investigation has contributed to an improved understanding of how the customized orders affect the FGW. Through simulation, bottlenecks were identified and knowledge of the complex parts, the behavior and the dynamics of a FGW was obtained. The performance of the FGW was shown to be extremely sensitive to the sizes of the bins. In an ideal scenario, each production order would have a bin with a matching size. In the real system, this is not always possible due to lack of space. The goal should be to have a layout with additional small bin sizes and consider using a rack to avoid mixing of orders. This would reduce the double handling and in a wider perspective, reduce the life-cycle cost for the packaging material.

This simulation model of the FGW is also a step towards a complete factory simulation, which is a long-term strategy for Tetra Pak. The strategy involves having a factory simulation model for every packaging material factory by the end of 2017. The first goal is to have a factory simulation model of the Arganda factory by the end of 2012. To reach this goal, simulation models have to be developed for each activity of the factory. Once all models have been validated, the idea is to connect them to a complete factory simulation. By having a factory simulation, the complete flow can be analyzed. Furthermore, the production of tomorrow can be simulated to see, for example, how a rush order affects all parts of the factory and the associated costs. Thus, it will be a major asset for efficient planning of the shorter production orders. The development of simulation models of the different activities will build a library of models. These can be used as a basis for future factory simulations. The model library, in combination with the knowledge and experience gained, will reduce the development time for upcoming factory simulations. Thus, the advantages of the factory simulation will be obtained for each factory within the time limit for the long-term strategy.

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