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Planning of Warehousing Systems

HOMEWORK – PLANNING OF WAREHOUSING SYSTEMS

2025

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Contents

1. Introduction

Warehouses are typically employed for the storage and distribution of completed products. They are significant as they facilitate the expedited movement of products and diminish inventory levels for businesses.

Key warehouse management processes encompass inventory tracking, picking and packing, receiving and storing, shipping, and reporting. Effective warehouse management can enhance production techniques and expedite customer order processing.

Warehouse management entails the proficient oversight and arrangement of all operations within a warehouse to guarantee the efficient storage, movement, and monitoring of goods. It is integral to the supply chain and logistics operations of enterprises, facilitating inventory management optimization, cost reduction, and enhancement of customer satisfaction.

This project intends to find out essential data for decision making in warehouses. Such as: Average Pallet Height, Average Pallet Weight, the number of pallets needed, the average number of pallet, minimum number of pallets and the maximum number of pallets. And based on this information, selecting the best transport for transferring the goods.

2. Data analysis

The collection and analysis of data is essential for warehouse management, as the dimensioning of the warehouse and the planning of its activities are directly dependent upon the provided data. Data can be categorized into primary, consisting of facts newly gathered for the project, and secondary, comprising facts previously documented before the project. Primary data can be categorized into two distinct groups: observational data, which involves observing individuals, and questionnaire data, which involves gathering responses from individuals. Secondary data can be divided into internal data, sourced from within the organization, such as customer orders, inventory, and reports, and external data, obtained from outside the organization, such as studies conducted by trade associations.

Here the work is done with primary data of an industry. Information concerning initial stock, inbound logistics, and outbound logistics was supplied, enabling the calculation of the average, maximum, and minimum daily stock in pallets. Figure 1 illustrates the daily inventory for a the selected product 3.

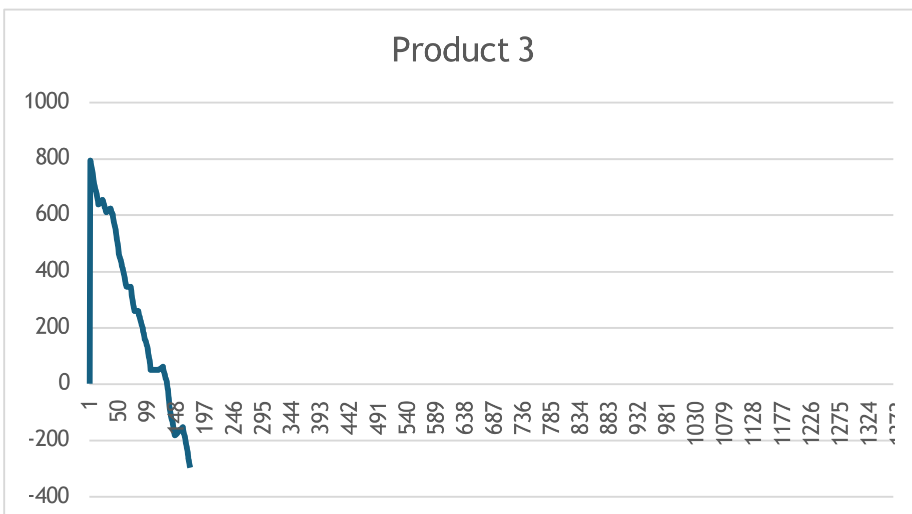

Figure 1: Daily stock – Product 3

The graph in Figure 1 indicates that the stock values are negative on certain days, which is impossible; therefore, these negative values were rectified by substituting them with zeros. The revised graph is depicted in Figure 2.

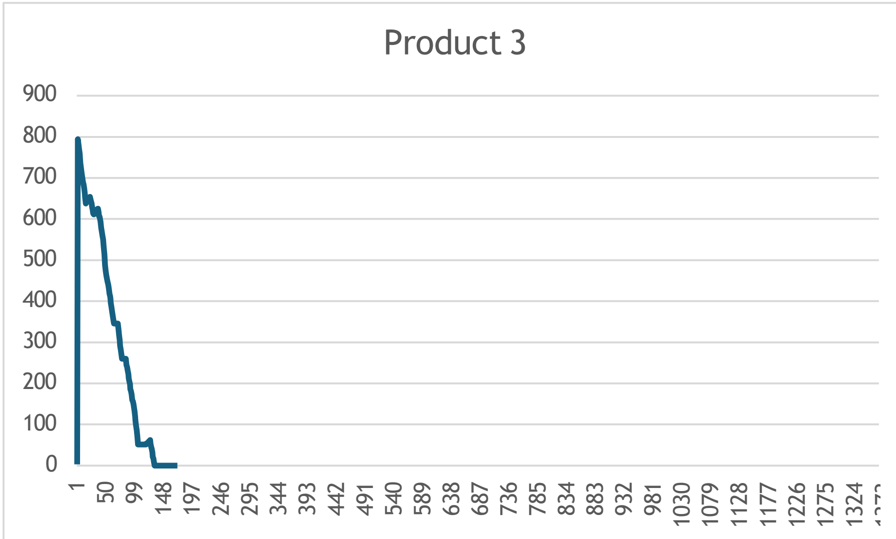

Figure 2: Corrected daily stock – Product 3

After correction of the data for each product the average, minimum and maximum values of pallets in stock were calculated, and the results can be observed in Figure 3.

SUM	
Avg. pallet	4969
Min. pallet	841
Max. pallet	1032

Table 1: Average, minimum and maximum pallets in stock

3. Lorry Selection

Identifying the right vehicle for transporting products to and from the warehouse is a crucial step. An analysis of the most suitable vehicle was conducted using data on pallet dimensions and average weight, aided by catalogues from various vehicle types. Table 2 represents all the details of the pallet and Table 3 presents a comparative table detailing all the vehicles considered, along with their capacities, mass, and volume efficiency.

Avg. homogeneous pallet height [mm]	1354
Avg. mass/ pallet [kg]	830.814815
Pallet width [mm]	1200
Pallet length [mm]	800
Pallet volume [m3]	1.29984

Table 2: Pallet Details

		Area of loading					Pallets to be placed			Pallets by size		Pallets by weight		KPI's	
		Length [mm]	Width [mm]	Height [mm]	Volume [m3]	Weight [kgs]	Length	Width	Height	No. Pallets	Weight [kgs]	No. Pallets	Weight [kgs]	Mass %	Volume %
Large Truck	A. KO Box Trailer	7350	2490	2650	48.499	18000	9	2	1	18	14954.667	21	17447.111	96.93%	56.28%
	S. C. S. universal	13620	2480	2550	86.133	29700	17	2	1	34	28247.704	35	29078.519	97.91%	52.82%
	S. KO City	11050	2490	2550	70.162	22000	13	2	1	26	21601.185	26	21601.185	98.19%	48.17%
Small Truck	Iveco 4100	4005	1800	1500	10.814	3700	5	1	1	5	4154.074	4	3323.259	89.82%	48.08%
	Iveco 3450	3395	1800	1500	9.167	3500	4	1	1	4	3323.259	4	3323.259	94.95%	56.72%
	Merc dropside L2 519	3408	2035	1500	10.403	2550	4	1	1	4	3323.259	3	2492.444	97.74%	37.48%
Lorry	Iveco 4100 H2	4680	1800	1900	16.006	3500	5	1	1	5	4154.074	4	3323.259	94.95%	32.48%
	Iveco 3450 H1	3130	1800	1545	8.705	1900	3	1	1	3	2492.444	2	1661.630	87.45%	29.87%
	Merc L2 519	3272	1790	1550	9.078	2550	4	1	1	4	3323.259	3	2492.444	97.74%	42.95%

Table 3: Lorry selection via comparison

Three vehicles from each category were selected, and their dimensions, weight, and volume are detailed in the loading area section of the table. Then in the pallets to be placed area, depending on the dimension, how many pallets could be placed in the vehicles in each dimension were calculated.

Then the total number of pallets by size that the vehicles could hold was found by multiplying the number of pallets that could be placed lengthwise, widthwise and height wise. And the weight was calculated by dividing the number of pallets by average weight.

As for how many pallets vehicles could hold, weight wise, was calculated by dividing the total capacity of vehicles by the average weight of the pallets.

And from this capacity per volume and capacity per weight, the KPI per volume and weight was calculated. The KPI by volume was calculated by dividing the total volume of the truck by the volume of a single pallet. The KPI by weight was calculated by dividing the total weight capacity of the truck by the weight of a single pallet.

Based on the analyzed KPIs, the selected vehicle is the **A. KO Box Trailer** large truck, as it has most utilization.
A loading plan for the chosen vehicle has been created.

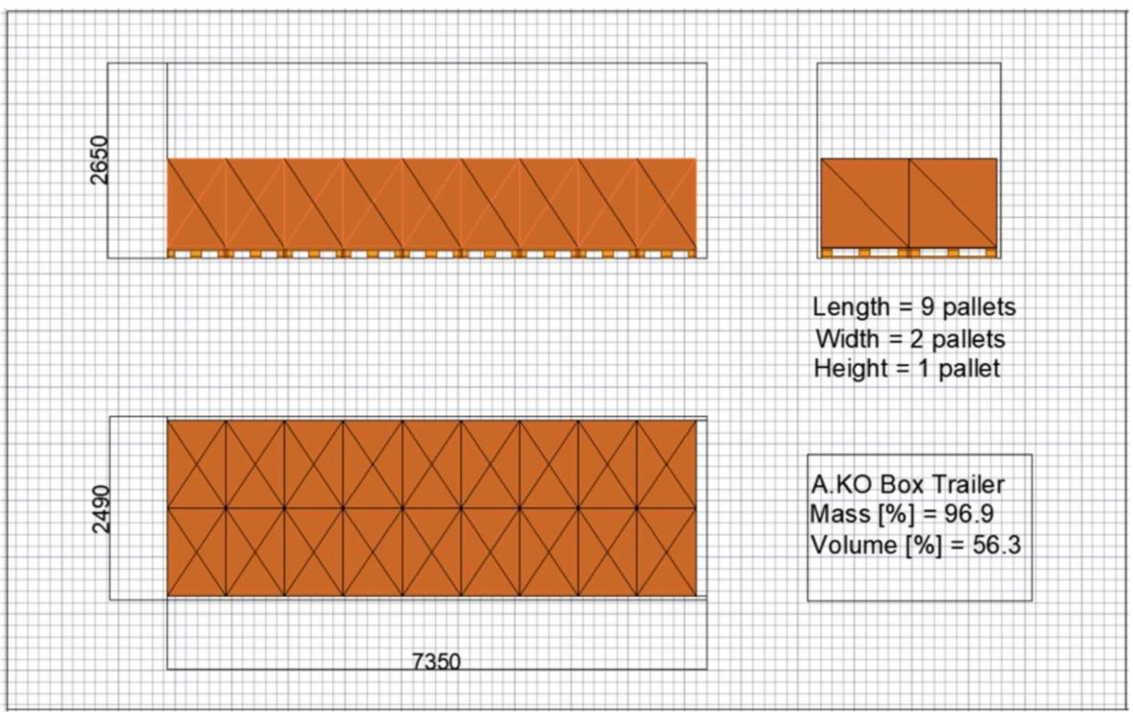

Figure 3: Loading Plan (Source: own authorship)

The main specifications for the selected loading plan are presented in Figure 3, its mass efficiency is 97% and its volume efficiency is 56%. It can be inferred from the drawing that it is possible to load 18 pallets in the vehicle selected.

4. Layout planning of warehouse

The primary objective of this project is to design a commercial warehouse utilizing the data provided. Upon calculating the daily inventory, warehouse planning can commence. This section will be divided into several steps that increase comprehension and improve the organization of information.

4.1 Selecting a forklift

By considering the average weight of a pallet, one can determine the most suitable forklift for warehouse operations. Numerous forklift variants exist, and the most appropriate model for this task is the counterbalance forklift. The optimal forklift for the analyzed data set was identified using catalogues. Figure 6 illustrates the chosen forklift.

Figure 4: Chosen forklift – EFG/ Duplex ZT (Jungheinrich)

The selected forklift is the EFG/ Duplex ZT that is supplied by Jungheinrich UK Ltd. The specification of it is given below:

- The capacity of this is 1300 kg
- The lift (h_3) is 3500mm
- The working aisle (A_{st}) is 3230mm.

4.2 Bay load and field load

The average height of a pallet can be utilized to determine the attributes of the bay and field.
The initial step involves establishing the shelf height, which requires considering a beam height of 100mm and a lift value of 150mm.

(1) $$Shelf\ \ Height\ =\ Height\ UL\ +\ Height\ beam\ +\ Lift$$
$$= 1354 + 100 + 150 = 1604mm$$

Now, the number of bays is determined, based on forklift lift (h_3) and shelf height:

(2) $$Number\ of\ bays =]\frac{Forklift\ lift\ (h_3)}{Shelf\ \ height}] =]\frac{3500}{1604}] = 2.182 = 3\ bays$$

Then bay load and field load is calculated, so the adequate rack system is selected.

(3) $$Bay\ load\ =\ 3\ pallets * \frac{830.815kg}{pallet} = 2493kg$$

(4) $$Field\ load = (3\ bay\ level - 1) * Bay\ load = 3 * 2493kg = 7479kg$$

In field load, 1 is deducted from the 3-bay level as the products positioned on the floor will not impact on the integrity of the racks. Below figure illustrates the values derived from equations 3 and 4.

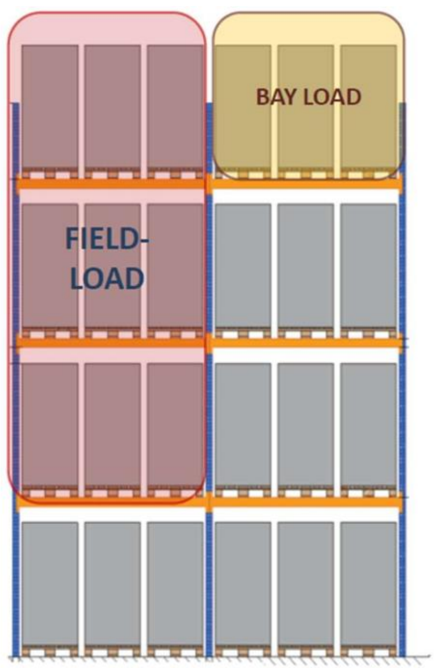

Figure 5: Visual representation of bay load and field load *(Puskás, E.)*

Based on the previously obtained values, it is possible to select a suitable rack system.

4.3 Selection of a rack system

Based on the bay load and field load and with the help of a catalogue it is possible to determine the appropriate rack system for the warehouse.

4.3.1 Beam selection

The catalogue is used to determine the beam based on the bay load. Typically, it is designed for 3 pallets per beam, as was the case for this work. The chosen beam was PT 112 LN P25. The dimension of the beam is given in the table below. The pallets are chosen to be positioned perpendicularly.

Table 4: Dimensions of the Beam

Beam Type	PT 112 LN P25
TH x TB	(112 x 50) mm
Capacity	3000 kg
Beam Length	2700mm

				90 mm		120 mm	
FB	Type PT ...	TH x TB (mm)	P 18 Q= (max. kg)	P 20 Q= (max. kg)	P 25 Q= (max. kg)	P 20.12 Q= (max. kg)	P 25.12 Q= (max. kg)
1.350 mm	PT 80 SN	80 x 50	1.300	1.300	1.300	1.300	1.300
1.800 mm	PT 82 LN	82 x 50	2.600	2.600	2.660	2.625	2.625
2.200 mm	PT 82 LN	82 x 50	2.180	2.180	2.250	2.220	2.270
2.700 mm	PT 82 LN	82 x 50	1.720	1.710	1.800	1.760	1.815
	PT 112 LN	112 x 50	3.000	3.000	3.000	3.000	3.000
	PT 127 LN	127 x 50	3.500	3.500	3.500	3.500	3.500
	PT 127 SN	127 x 50	3.920	3.950	4.030	4.000	4.175

Figure 6: Rack beam and dimensions. BITO Catalogue

4.3.2 Frame selection

The catalogue is used to determine the frame based on the field load. It also depends on the first bay height, which is calculated using Equation (1). The dimension of the chosen frame is shown on the table below.

Table 5: Dimension of the chosen frame

Type	PT 112 LN P25
FA	1725 mm
Capacity	10970 kg

4.4 Optimal aisle number

The first step in obtaining the ideal aisle number is to select the layout and rack orientation. The plan used for this project was through, with expedition and reception goods sections on either side of the warehouse, and rack orientation parallel, which means the racks are organized in the same direction as the flow from incoming and outward areas. Below figure illustrates the arrangement and rack orientation.

Figure 7: Selected layout and rack orientation *(Puskás, E.)*

Some calculations are performed to determine the final dimensions of the warehouse. At first, the number of levels in the rack (BY – Y direction) is determined.

(5) $$BY = \left]\frac{HLI\ (h_3) - DFF - 0.25m}{HB}\right] = \frac{3500mm - 0 - .25m}{1604mm} = 2.18 = 3\ bays$$

Here:

HLI= the maximum lift height of the forklift

DFF= the distance between the first storage level and the floor

HB= The height of the bay

Next, it is possible to determine the planned height of the storage area (HSA):

(6) $$HSA = DFF + BY * HB + SAF = 0 + 3 * 1604mm + 500mm = 5.312\ m$$

Here:

DFF= the distance between the first storage level and the floor

HB= height of bay

SAF= safety clearance above the storage height.

Next it is possible to determine the optimal aisle number (Na_{opt}).

$$Na_{\text{opt}} =]G * \sqrt{\frac{RC * WB}{(2 * DB + AST) * CB * BY}}]$$

(7)

$$Na_{\text{opt=}}0.577 * \sqrt{\frac{4969 * 2.8m}{(2 * 1.3m + 3.3m) * 3 * 3}} = 9.34557 = 10\ aisles$$

Here:

RC= The required storage capacity

WB= Width of bay

DB= Depth of bay

AST= Width of aisle parallel to the racks

CB= Bay capacity

BY= Number of storage bay

For the G parameter the value is predetermined by a table, considering both the orientation and layout of the warehouse.

Now the number of fields in the X direction (FX) is calculated, using the required storage capacity (RC), optimal aisle number (Na_{opt}), bay capacity (CB) and number of storage bay (BY).

(8) $$FX =]\frac{RC}{2 * Na_{\text{opt}} * CB * BY}] = \frac{4969}{2 * 10 * 3 * 3} = 27.605 = 28\ fields$$

For the calculation of the length of pallet rack row (L), FX is the number of fields and WB is the width of bay.

(9) $$L = FX * WB = 28 * 2.8m = 78.4m$$

The number of storage rack rows to be put side by side (n) is determined by the length of the proposed pallet rack row (L) and the maximum length of the rack row (L_max), which is considered to be 30 meters.

(10) $$n =]\frac{L}{L_{\max}}] = \frac{78.4m}{30m} = 3\ rows$$

The number of cross direction aisles (NCA) is calculated by subtracting 1 from the number of storage rack rows to be placed side by side (n).

(11) $NCA = n - 1 = 3 - 1 = 2\ aisles$

For the maximum number of fields in a pallet rack (FX_{imax}), the maximum length of rack row (L_{max}) and the width of bay (WB) are used.

(12) $FX_{imax} =]\frac{L_{max}}{WB}] = \frac{30m}{2.8m} = 11\ fields$

The number of fields in a pallet rack row (FX) is again calculated, now using the number of storage rack row to be placed side by side (n) and the maximum number of fields (FX_{imax}).

(13) $FX = n * FX_{imax} = 3 * 11 = 33\ fields$

For the planned length of storage space (LSA), the number of aisle (NA), depth of bay (DB) and width of the aisle parallel to the racks (AST) are used.

(14) $LSA = NA * (2 * DB + AST) = 10 * (2 * 1.3m * 3.3m) = 59m$

The planned width of storage space (WSA) is calculated using distance to the left of the storage area (DISL), distance to the right of the storage area (DISR), number of cross aisles (NCA), width of the aisle perpendicular to the racks (APE), number of fields in a pallet rack and width of bay (WB).

(15)

$$WSA = DISL + DISR + NCA * APE + FX * WB$$

$$WSA = 3m + 3m + 2 * 2.5m + 33 * 2.8m = 103.4m$$

For the planned volume of the storage area (VSA) the planned height of the storage area (HSA), planned length of storage space (LSA) and width of storage space (WSA) are used.

(16) $VSA = HSA * LSA * WSA = 5.312m * 59m * 103.4m = 61349.69m^3$

The planned storage capacity (PC) is calculated based on the number of aisles (NA), bay capacity (CB), number of fields in X direction (FX) and number of storage bays in the Y direction (BY).

(17) $PC = 2 * NA * CB * FX * BY = 2 * 10 * 3 * 33 * 3 = 5940\ pallets$

Finally, it is possible to calculate the rate of the planned storage capacity (PC) and required storage capacity (RC).

(18) $\frac{PC}{RC} = \frac{5940}{4969} = 1.20$

Based on the calculations carried out earlier, a final scaled drawing of the warehouse can now be developed. Several considerations and adjustments were made during the design process, which are outlined below:

- The pallets on the shelf are oriented perpendicularly, meaning that a 1200mm pallet is placed on a shelf that is 1100mm wide. This results in some overhang of the pallet beyond the shelf. This overhang was accounted for when determining the aisle width, with the catalog from the previous semester providing the reference for the 1100mm shelf dimension.
- The distance between the racks along the two walls of the warehouse was assumed to be 200mm, based on a catalog provided in the previous semester's assignment.
- The depth of the bay is 1300mm, but the pallet only measures 1200mm, creating an additional 100mm of space for each pallet. Consequently, the gap between two racks is calculated as 200mm (the distance between the racks) + 50mm + 50mm (to account for the pallet overhang). Therefore, a 300mm gap between frames was used.
- The APE (Average Pallet Elevation) was assumed to be 2.5m, based on information provided in the class slides.
- The optimal number of aisles was adjusted to 13, so that the number of fields in the X-axis direction would total exactly 30. This adjustment resulted in a more compact warehouse layout, which improves space utilization and ensures that the pallet racks are uniform, with each rack containing 10 fields. Below table illustrates all the input data used for the warehouse design and dimensioning process.

The table below summarized the input values (highlighted in grey) which are needed to determine further designing parameters:

Table 6:Input data for designing of warehouse

Parameter	Value
Homogeneous pallet height [mm]	1354
Mass/pallet [kg]	830.8148148
Forklift name	EFG/ Duplex ZT
Capacity/load [kg]	1300
Lift (h3) [mm]	3500
Working aisle (Ast) [mm]	3230
Height of beam [mm]	100
Lift [mm]	150
Shelf height [mm]	1604
Safety clearance [mm]	500
DFF [mm]	0
Number of bays (BY)	3
Capacity of bay [pallets]	3
Bay load [kg]	2493
Field load [kg]	7479
Height of storage area (HSA) [m]	5.312
Beam type	PT 112 LN P25
THxTB [mm]	(112 x 50) mm
Beam max. weight [kg]	3000 kg
Beam length [mm]	2700mm
Frame type	PT 112 LN P25
Layout type	Through
Rack orientation	Parallel
G parameter	0.577350269
Pallet orientation	Perpendicular
Required (ideal) storage capacity [pallets]	4969
Width of bay (WB) [m]	2.8
Depth of Bay (DB) [m]	1.3
Maximum length of rack row (L max) [m]	30
DISL [m]	3
DISR [m]	3
Width of aisle perpendicular to rack (APE) [m]	2.5
Width of aisle parallel to rack (AST) [m]	3.3
Optimal aisle number (NAopt)	10
Number of fields in X direction (FX) [fields]	28
Length of planned pallet rack row (L) [m]	78.4
Number of storage rack rows (n)	3
Number of cross direction aisles (NCA)	2
Max number of fields in pallet rack (FXimax) [fields]	11
Number of fields in a pallet rack row (FX) [fields]	33
Planned length of storage space (LSA) [m]	59
Planned width of storage space (WSA) [m]	103.4
Planned volume of the storage area (VSA) [m3]	61349.69
Planned storage capacity (PC) [pallets]	5940
Rate (planned capacity/required capacity)	1.2

The final drawing of the warehouse with all its dimensions and design is provided in a different PDF file.

5. Outside warehouse design

To ensure the efficient operation of the warehouse, it is essential to plan not only its internal layout but also its external environment. This includes considerations such as road and rail traffic, material flow, legal regulations (such as designated parking areas and green spaces), and safety requirements.
Given the known quantities of pallets for each product in both inbound and outbound processes, the required number of vehicles for each section can be determined. Figure 11 illustrates the goods flow for each group.

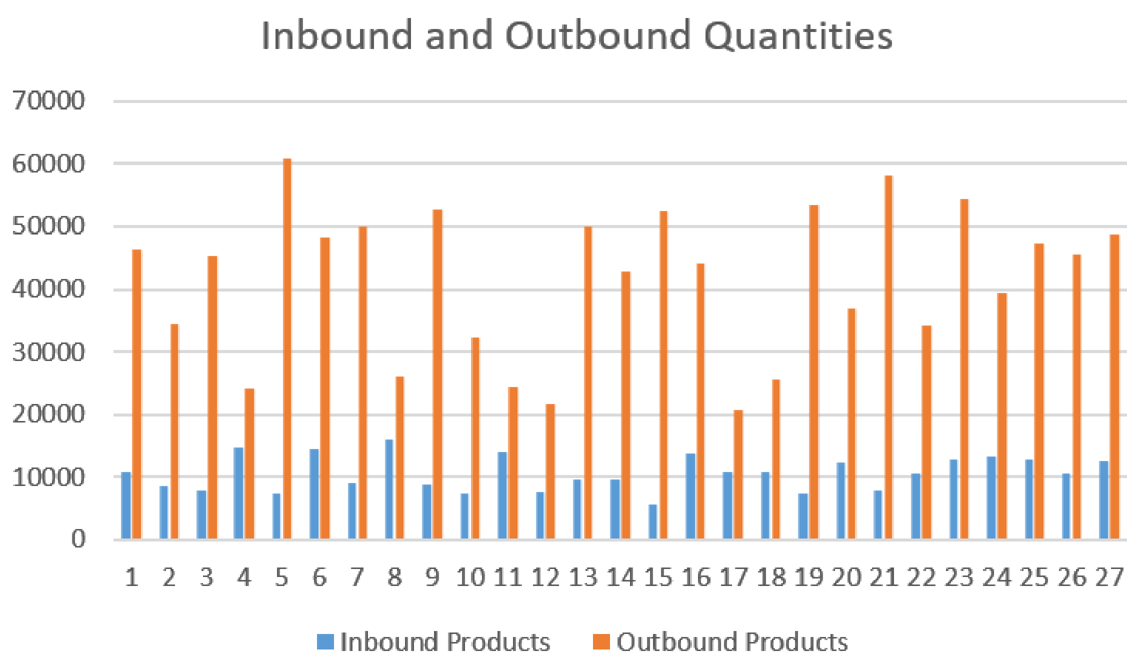

Figure 8: Inbound and Outbound Orders

As mentioned previously in this document (section 3), the capacity of the vehicle is 4 pallets. With this value it is possible to calculate the number of vehicles needed for each type of product.

$$\text{(19)} \quad Vehicles\ needed/product = \frac{Number\ pallets/product}{Capacity\ of\ vehicle}$$

Using the average values for both inbound and outbound quantity of pallets it was possible to determine the values shown in Figure 12.

Table 7:Average inbound and Outbound Truck Numbers

Average Inbound Pallets	416
Average outbound Pallets	1241

Inbound Trucks	
Truck Capacity	18
Trucks to be loaded per day	24
Outbound Trucks	
Truck Capacity	18
Trucks to be loaded per day	69

Assuming a single 8-hour shift per day, the time interval between vehicle arrivals in both the inbound and outbound areas can be determined using Equation 20, applying it with the respective number of vehicles calculated earlier.

$$\text{(20)} \quad Time\ between\ arrivals = \frac{8\ hours/shift}{Number\ of\ vehicles\ needed}$$

Since the arrival rate depends on the time between arrivals, it is now also possible to calculate the arrival rate accordingly.

$$\text{(21)} \quad \text{Arrival rate} = \frac{1}{\text{Time between arrivals}}$$

Both the service time (t_s) and the loading time (t_l) are predefined as 0.25 hours and 1.5 minutes per pallet, respectively. The operation time (t) can then be calculated based on these values and the number of pallets transported per truck (N_p^{lorry}).

(22) $t_k = t_s + t_l * N_p^{lorry}$

The service rate below has been calculated using the value obtained for operation time (t_k).

(23) Service rate = 1 / t_k

Now, we calculate the traffic intensity

(24) Traffic intensity = Arrival rate / Service rate

The minimum number of service channels is determined by rounding up the value calculated for traffic intensity.

(25) Min. number of service channels = roundup (Traffic intensity)

All of these values has been calculated in the table below:

Table 8: Key Characteristics

	Outbound	Inbound	Units
Time between arrivals	0.333333333	0.115942029	hours
Arrival rate	3	8.625	trucks/hour
Service time (ts)	0.25	0.25	hours
Operation time (tk)	0.35	0.35	hours
Service rate	6.55	6.55	trucks/hour
Traffic intensity	0.458015267	1.316793893	
Min service channels	1	2	channels

The number of trucks that can be loaded at the same time (n_1) can be calculated by using the peak period factor (alpha), which has a value between 2-2.5 and for this work 2.25 was assumed, operation time (t_k) and time of one shift (T_{sh}).

(26) $n_1 = \frac{Alpha * n_{lorry} * tk}{Tsh} = \frac{2.25*30*0.35}{8} = 3$ trucks

The selected type of loading area was the 90° backside parking, so the length ($L_{/a}$) is calculated using the width of the lorry *(b_l)*, the distance between two lorries (k), which is predefined as 1.5m and the safety distance at the end of the loading area *(l_s)*, also predefined as 1.5m.

(27) $L_{la} = n_1 * b_1 + k*(n_1-1)+2l_s = 3* 2.49 +1.5*(3-1)+2*1.5=13.47$

Now, the railway value has to be calculated. For this, the rails come once each 4 days. So, here the pallet demand should be multiplied by 4. Resulting in 4964 pallets for the railway. The railway type here is Gbs and the wagon capacity here is 30 pallets.

The width of the loading perform (B) is calculated by using the width of the forklift , which is also the width of the load (b), this has a fixed value of 1.2 meters. The security platform edge (c) has a fixed value of 0.2 meters.

(29) $B=2*b +3*c = 2*1.2+3*0.2= 3$ m

After this, we can calculate the length of the track with the number of freight wagons at the loading platform at the same time(n), this has also a fixed value, which is 2. The length of engine (L_{engine}) is predefined as 15m and the length of the Wagon (L_c) is defined by the railway type. This is 14m.

(29) $L_{Track}= n*L_c+ L_{Engine} + 10= 2*14+15+10= 53$ m

The useful length of the loading platform is as per below:

(30) $L_{lp}= n*L_c= 2*14= 28$ m

Now the track is smaller than the length of the building times and only one track is needed.

Now we can determine the AIM table by below figure:

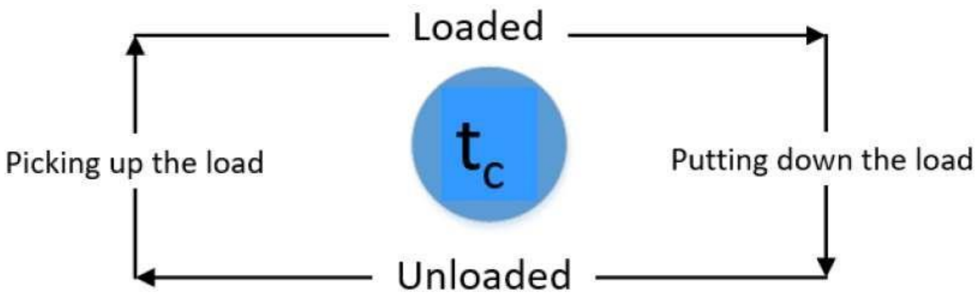

Figure 9: AIM Diagram

The values that were obtained from the AIM tables are shown in below table:

Table 9: AIM Values

Parameter	Value	Units
L	95	m
H_{up}	2480.5	mm
H_{down}	600	mm
m	830	kg
Loading time	0.9	min
Movement-loaded	0.86	min
Unloading time	0.3	min
Movement-unloaded	0.71	min
Cycle time (tc)	3.04	min

Here, the necessary time (Tn):

(31) $T_n = t_c * n_c = 3.04*119 = 6.04$ hours

The available time T_a is calculated like below. Here, the lost time in shift due to malfunctions (n_u) is 0.9 and the time lost due to organizational fault (n_e) is 0.8.

(32) $T_a = T_{sh} * n_u * n_e = 8*0.8*0.8 = 5.76$ hours

The number of forklifts are below:

(33) $N_{fl} = \frac{T_n}{T_a} + 0.99 = 2$ Forklifts

The calculations shows only 2 forklifts. But as per the requirements, 3 forklifts should be used at once.

For the road network design, we must consider the KRESZ law. As per this, the internal turning radius for or big size truck   are 6 to 10 meters and the external turning radius is 12.5 to 16 meters.

For the lorry parking, a width of 3m and a length of 6m were considered, as it involves 90° backside parking. The drawing shows 6 parking spaces for the lorries.

For cars, a different area was designed for parking space as it is safer to keep the freight and passenger traffic separated. The rule for the number of parking places is 1 for each 1500 meter square, so. The outside area has five parking spaces for cars with width of 2.5m and length of 6m and 1m is disabled for partner space with the width of 3.6 meter and the length of 6m. The below figure shows the rules for partners. The is for cars which the mentioned dimensions were based on.

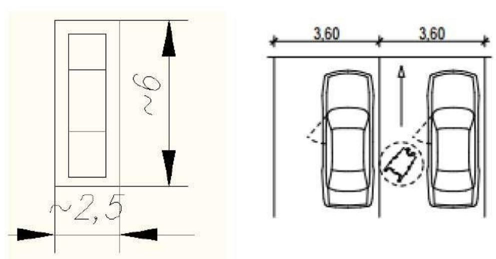

Figure 10: Parking Space for cars

We calculate the green area ratio of the warehouse, which is the 25% area of the warehouse.

5. List of Figures

6. List of Tables

7. References

[1] *Jungheinrich UK Ltd. (forklift manufacturer).* **EFG 213/215/216k/216/218k/218/220,** Li-Ion technology, (2016).

[2] *BITO-Lagertechnik Bittmann GmbH (rack manufacturer).* **Innovative Storage Solutions – instructions for assembly and use,** Pallet racking, (2006)