WAREHOUSE DESIGN FOR ELECTRICAL EQUIPMENT MANUFACTURER: A CASE STUDY

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ABSTRACT

Systems engineering approaches utilize systems thinking principles in complex projects such as computer chip design, robotics. However, this technique is also useful in proposing solutions to logistics systems, namely warehouse design. This paper will apply systems engineering in designing finished product warehouse for an electrical equipment manufacturer. Our results suggest a completed design addressing the needs of stakeholders and all likely aspects of the systems are considered and integrated into a whole. These solutions propose an optimal design for warehouse simultaneously utilize available resources of the manufacturer.

Keywords: warehouse design, systems engineering.

Cite this Article: Anh Nam Diep, Linh Y Thai and Mai-Ha Phan, Warehouse Design for Electrical Equipment Manufacturer: A Case Study. *International Journal of Mechanical Engineering and Technology*. 11(7), 2020, pp. 51-71.
<https://iaeme.com/Home/issue/IJMET?Volume=11&Issue=7>

1. INTRODUCTION

Systems engineering is a management technology to assist and support policy making, planning, decision making, and associated resource allocation or action deployment. It accomplishes this through quantitative and qualitative formulation, analysis, and interpretation of the impacts of action alternatives with reference to users' needs, values and institutional perspectives [1]. One way to understand the motivation behind systems engineering is to see it as a method, or practice, to identify and improve common rules that exist within a wide variety of systems. Keeping this in mind, the principles of systems engineering – holism, emergent behavior, boundary, et al. – can be applied to any system, complex or otherwise, provided systems thinking is employed at all levels [2].

Electricity is one of the energy pillars of every nation, takes the part of the lifeblood of modern industries. The development of any industry requires the expansion of the national power system as a prerequisite. Along with the shift of production to Vietnam in recent years

because of macroeconomic impacts, the demand for electricity for production is increasing and it is one of the biggest demands that the power industry has been very interested in.

Considering the consumption rate of electricity in 2019, Southern Vietnam witnessed the use of over 50% of the total power demand. While the figure for electricity consumption in the North is nearly 40% and in Central, it is nearly 10%. In terms of current power supply, nearly 60% of suppliers situate mainly in the North and the Central, the South can only generate less than 40% of itself. The power transmission system is said to be unable to meet. Electricity supply systems should be continually expanded and upgraded.

In this paper, systems engineering methodology is applied to design the finished product warehouse of an electrical equipment manufacturer, which wants to expand its production capacity to meet the need of expanding the national electricity grid. This requires the manufacturer to comprehensively develop its production capacity, distribution, and storage systems.

2. LITERATURE REVIEW

Logistics is one of the strong growing industries today. According to Christopher (2016), Logistics is defined as the process of strategically managing the procurement, movement and storage of materials, parts and finished inventory (and the related information flows) through the organization and its marketing channels in such a way that current and future profitability are maximized through the cost-effective fulfilment of orders [3]. Logistics deals with the planning and control of material flows and related information in organizations, both in the public and private sectors. Broadly speaking, its mission is to get the right materials to the right place at the right time, while optimizing a given performance measure and satisfying a set of constraints (Ghiani et al., 2004) [4].

In the logistics system, there are many studies focusing on warehouses. Good warehouse management will greatly assist businesses in matters related to reducing wastage or loss of goods and increasing capital efficiency. Therefore, studies often focus on issues such as: *How can warehouse managers deal with a large volume of goods and raw materials in an enterprise, How to ensure the smooth operation of import and export activities, limit the amount of inventory but still provide the necessary amount of goods for important activities...* These studies focus on addressing the arrangement of goods, locating goods in warehouses, arranging shelves; methods of preserving goods, the process of importing and exporting goods, and organizing the management of goods and books in warehouses ...

A warehouse is a point in the supply chain where raw materials, work-in-process (WIP), or finished goods are stored for varying lengths of time. Warehouse has some main functions:

- Receiving,
- Storage,
- Move goods from storage areas to where they are needed. [6]

Based on these main functions, warehouse operation process can be divided into 2 parts: internal and external processing as Table 1 lists below [7]. Distinguishing between internal and external processing showed that warehouse is a system of internal operations such as receiving, sorting, packaging, and internal storage along with external operations showing the correlation between the system and eco-environment of the supply chain in which warehouse is the key operating point. In this research, the authors applied systems engineering in designing warehouses in the manufacturing environment of the electrical equipment manufacturer.

Table 1 Distinguished warehouse processing

Internal processing	External processing
Receiving	Order and receiving
Quality inspect and control	Delay receiving
Pick up and packaging	Sorting and collecting
Storage	Packaging and shipping
	Importing
	Cross-docking

Warehouse management is not a simple task, it requires technical as well as scientific organization to help activities related to goods in the warehouse go smoothly. Traditionally, warehouse managers need to be proficient in a lot of operations, from arranging, preserving goods and supplies, to performing tasks related to importing, exporting and planning goods. The first is the arrangement stage, there are many people feel confused when entering the warehouse because the amount of goods is too much but do not know where to put. The arrangement of goods plays an important role to help the process of finding, transporting as well as importing and exporting goods in the warehouse be conducted more quickly and at the same time ensure the convenient control goods export. Not only that, the scientific arrangement of goods also contributes to save storage area. Next is the periodical inventory which determines the actual quantity of goods in the warehouse compared to the books and records of goods; inspect the quality of the goods (identify damage or deterioration of goods). This is also an important activity to ensure the continuous circulation of goods, avoid being worn and torn or reducing use value. Ensuring warehouse arrangement and inventory are the first two elements of an effective warehouse management method.

Warehouse design includes three basic categories: facilities, operation process and management method [5]. According to Felix Geuken et. al. (2017) [8], 8-step warehouse design process for fast-growing factories is based on practical conditions and planned into 3 stages to develop ideas, specific modules are as follows (Fig.1). This process is

Stage 1: Identify warehouse location in the business environment, needed SKU, current storage capacity and future expansion plan.

Stage 2: Consider current conditions of equipment and their impact on warehouse operation, simultaneously integrate data from Stage 1. Thence, propose general capacity parameters of the warehouse.

Stage 3: Propose design solutions and standards to evaluate and select the most suitable alternative to warehouse conditions. This sequence will be applied in Engineering development.

Figure 1 8-step visual process of developing warehouse systems for fast-growing factories

3. PROBLEM STATEMENT

ABC Company is one of the leading providers of equipment for electrical infrastructure in Vietnam. The 10-year plan estimated from 2020 to 2030, to meet the demand of expanding the national electricity grid and serve the industrialization process promoted nationwide, the factory needs to increase the output by 50% compared to the current production capacity. This

requires the factory to have comprehensive development of the manufacturer in terms of production capacity, storage systems, and distribution.

At present, the manufacturer has only a temporary warehouse with a roof in an area of about 480m². At its peak - April 2019 - with about 545 pallets of goods, the Warehouse Department had to arrange goods disorderly and utilize all the vacancies in the warehouse optimally. This made it difficult to move and tally in the warehouse. The current situation is inherently unable to meet the current needs of the factory. If the future production capacity increases, the current storage space will be more and more shortage. Therefore, the balance of production and storage will inevitably be difficult and affect plant productivity.

This is the main reason in addition to other auxiliary factors such as the demand to improve the quality of goods storage, protect the finished products from collisions during the transport process. This is also the premise for the Board of Directors of the manufacturer to make a real determination in deploying the construction of a new system of Electrical Equipment Finished Products Warehouse on the existing vacant land of the factory.

4. NEEDS ASSESSMENT

4.1. Current State

The factory has a total area of about 10,450m², the current construction area is about 6,000m² divided into 04 workshops as below:

- Measurement Laboratory (720m²),
- Manufacturing - Assembly Workshop (1,820m²),
- Electrical Panel Factory (950m²),
- Repair - Maintenance Workshop (1,140m²).

(1) Main gate – Security house; (2) Measurement Laboratory; (3) Manufacturing - Assembly workshop; (4) Cabinet - Electrical Panel workshop; (5) Repair - Maintenance workshop; (6) Chemical warehouse; (7) Temporary warehouse; (8) Planned warehouse location; (9) The garbage house; (10) Fire-fighting pumping station; (11) Power station.

Figure 2 The aerial photo of electrical equipment manufacturer and workshops

Figure 2 shows the aerial photo of electrical equipment manufacturer and workshops.

The existing warehouse is partially covered sufficient space of the entire products. This leads to a few problems during the peak production season.

- Conservation of product quality before delivery to customers: there are risks such as rust on accessories and product joints when carelessly stored that can indirectly cause unintended consequences for customers when they install non-standard equipment

(there are latent defects inside) because it can cause fire and explosion when the electrical systems are operating. This affects the company's reputation.

- Wooden frames used to package products put outside can lead to being decayed. The improper stack can break the frame and directly affect the inside products.
- Due to the lack of planning, at peak time, goods are arranged disorderly without leaving aisles and classifying. This leads to difficulty in tallying, which can cause confusion and omissions and waste time in tallying and counting.

4.2. Causes and Solutions

After observing and identifying the problem, the authors discussed with relevant divisions and identified a number of particular causes:

- The warehouse of the factory is a temporary warehouse with a roof which is not a real finished product warehouse. In the past, when the factory was established, the factory has a small production scale and quick supply to the market so products were only stored within a day, almost shipped right after production. Along with the continuous development of the factory, they have had larger orders for key construction projects, which led to an increase in production capacity and higher needs in storage.
- Goods exposes to the environment may cause tear to products, resulting in collisions between packages during transportation. This also makes products damage and unsafe.
- Because there is no official warehouse, the warehouse arrangement depends on the management experience of the storekeeper and warehouse staff. There is also no shelf equipped so goods are often put on the ground. With a large number of pallets arranged disorderly will affect and make it difficult to tally.

Previously, the Board of Management considered outsourcing to save costs and avoid affecting production, but encountered some reasons:

- Non-factory storage area makes it difficult to move and control.
- Warehouses in the area of Tan Phu Trung Industrial Park are mostly old renovated factories - not following the original, outdated construction, not suitable for modern transport facilities, and no guarantee of safety conditions.

The construction of a new warehouse for the company is needed to improve product storage quality and warehouse operating conditions, contribute to the overall capacity of the plant future growth.

4.3. Stakeholders Survey

System design will relate to investors, suppliers, customers and system operators. With the finished products warehouse for the electrical equipment manufacturer, there will be some stakeholders listed in Table 2.

Table 2 Identify stakeholders, features and potential impacts on system

Stakeholders	Features	Impacts
Company Leadership	<ul style="list-style-type: none"> - Play the role of investor, - Make important decisions, - Set development directions for the organization and make budget decisions. 	<ul style="list-style-type: none"> - Determine constraints, - Receive the final design, - Put the system into practice.
Warehouse and Material Department	<ul style="list-style-type: none"> - Directly operate the system, - Materials and Products storage management, - Know the principles of storage, 	<ul style="list-style-type: none"> - Direct department which uses and manages the system, - Receive information from the Sales Team - finished product input

	preservation and transfer of products.	information, - Receive finished products from the Production Department based on order, - Export finished products to the Shipping Team as ordered.
Operation Department	- Produce and know products features. - Packaging.	- Produce products, - Determine packaging method.
Sale Team – Planning Department	- The department directly works with customers and issues orders to the production department for processing, - Know the customer information and types of products needed, - Estimate future productivity and future expansion needs.	- Exploiting customers, proposing orders, - Support inventory counting and tally in storage.
Shipping Team – Planning Department	- Know the delivery process from the factory to the customer, - Get direct delivery orders from the Sales Team.	- Get finished products for shipping, - Support tally on delivery.

Stakeholders requirements play an important role in design orientation, any requests and concerns are received and dealt later. Table 3 shows Stakeholders requirements document.

Table 3 Stakeholders requirements document

Stakeholder	Requirements
Company Leadership	Final result: Finished Products Warehouse needs to be professionally organized, clean and safe, The total investment of less than 5 billion VND, Long-term use (10 years), Short construction time (≤ 3 months), Construction process does not affect the operation of the manufacturer.
Production Department	Quickly tally and store. Simply receiving – shipping procedures.
Warehouse Department	Manage inventory status easily (know the quantity, type, location in the warehouse). Machinery and tools (if any) are easy to manipulate and use. Warehouse procedure is quick and effective. Warehouse design is stable and safe to use. Daily inventory counting time is 10 minutes / time. Reduce the damage rate of wooden protective frames used to cover for products at least 50%.
Delivery Team	Simple and quick delivery procedures. Products are delivered must ensure intact packing condition, quality, right quantity and type. Operating procedures must save product search time. Time of delivery process, from receipt of goods request to complete delivery on truck is less than 60 minutes.
Sales, Planning and other Departments	Inventory status is determined with high reliability, fast and simple. There is fast inventory process. Data is backed up in real time on the company data system, easily accessed by warehouse staffs if needed for comparison.

5. CONCEPTUAL DESIGN

5.1. Operation Analysis

The Finished Product Warehouse must have five functions based on the round trip of the finished product in the warehouse of the factory: Receiving, Put-away, Storage, Picking and

Delivery. The main operation of the Finished Products Warehouse and implementation steps are listed below.

Receiving

Products produced at the workshops of the Production Department will be inspected by the Quality Department. After that, the product will be conveyed to the finished product warehouse. The Warehouse Department will confirm the quantity, product type, and receive them into the warehouse for storage. The important requirement at this stage is the strict procedure to ensure that the product quantity and type are not misleading. In the Finished Product Warehouse, some steps required to receive products:

- Receive the storage order,
- Tally finished products,
- Update to inventory data,
- Sign the goods delivery note;

Put-away

After warehouse manager accepts to receive inventory from the production department, the product will be considered and sorted into the appropriate position to ensure reasonable and optimal arrangement. This sorting process aims to optimize product storage, make it easy to find when needed, shorten the time to search for products as well as the distance to travel to pick up products from the placement. Three steps required to put goods away:

- Locate the vacant position by software and visually check,
- Update location to software,
- Move the finished product to the available shelf cell;

Storage

After determining the proper location, the product will be moved into shelf-cell in the warehouse. When the product is in stock until it is delivered to the receiving parties, it must ensure that the product is kept safe and the product quality including internal and visual specification is not affected during storage.

Picking

Upon receipt of a delivery request, the warehouse manager checks the amount of finished product stored in the warehouse whether meets the order, then determines the location of the products to be moved, and move to a predetermined assembly location. This process needs to be fast, accurate, and the transport of products must be safe. Some steps required to pick:

- Receive exporting order,
- Check inventory in software,
- Confirm sufficient response,
- Pick the goods from the shelves,
- Deliver goods to the loading bay.

Delivery

The product is transported to the loading bay, then will be transferred to the truck, handed over to the customer warehouse. This process requires fast, safe, complete legal procedures for transport and management. Some steps required to delivery:

- Tally finished products,
- Confirm status of the finished products,

- Load goods to truck,
- Sign the delivery note.

5.2. Functional Analysis

The design orientation is based on the requests of the relevant departments (stakeholder requirements) to determine the implementation direction and external aspects that may affect the system.

Table 4 shown as below lists stakeholder requirements and provides design directions from stakeholder requirements and system performance analysis.

Table 4 Stakeholders design requirements

Stakeholders	Requirements	Design Direction
Company Leadership	<p>The finished product - warehouse system performing professional, clean, safe, plays the presentation role of the company to introduce to customers.</p> <p>The total investment for the warehouse is about VND 5 billion.</p> <p>Estimated usage time is about 10 years.</p> <p>Construction period is short – about 03 months.</p> <p>The construction process of the warehouse does not affect the current occupation of the factory.</p>	<p>- Warehouse design must be compatible with the conditions of the factory, also economical, take advantage of available resources to save budget and operating costs.</p> <p>Choose a reputable construction contractor.</p> <p>Choose a reasonable starting time to avoid affecting the factory operation.</p>
Production Department	<p>Fast tally, quick confirmation and warehousing.</p> <p>Quick and simple delivery and warehousing procedure.</p> <p>Ability to store an average of 70 large products per day, 100 small products per day.</p>	<p>Building a process of stock in / out, rational and optimal warehouse operation.</p> <p>Apply current technology of management to the process.</p>
Warehouse Department	<p>Manage inventory status easily (know the quantity, type, location in the warehouse).</p> <p>Machinery and tools (if any) are easy to manipulate and use.</p> <p>Warehouse procedure is quick and effective.</p> <p>Warehouse design is stable and safe to use.</p> <p>Daily inventory counting time is 10 minutes/time.</p> <p>Reduce the damage rate of wooden protective frames used to cover for products at least 50%.</p>	<p>Warehouse management software has a function of visually monitoring inventory status, identifying each item in the warehouse containing certain types of items.</p> <p>Machinery is compact, easy to use, has a process of training, warehouse staffs must be trained thoroughly before putting into use.</p> <p>There must be reasonable and optimal warehouse process.</p> <p>Warehouse construction materials must be firmly and safe.</p>
Delivery Team	<p>There are simple and quick delivery procedures.</p> <p>Products are delivered must ensure intact packing condition, quality, right quantity and type.</p> <p>Operating procedures must save product search time.</p> <p>Time of delivery process, from receipt of goods request to complete delivery on truck is less than 60 minutes.</p>	<p>- There is reasonable and optimal warehouse operating procedure.</p> <p>- Warehouse has close structure, against dust, and other effects of the environment, ensure the product quality during storage.</p>
Sales, Planning and other Departments	<p>Inventory status is determined with high reliability, fast and simple.</p> <p>There is fast inventory process.</p> <p>Data is backed up in real time on the company data system, easily accessed by warehouse staffs if needed for comparison.</p>	<p>Warehouse management software (WMS) has the function of visually monitoring inventory status, identifying each item in the warehouse containing types of products, and amount.</p>

5.3. Functional Baseline

Based on the requirements of the stakeholders, after operating performance analysis steps to the addition of new steps or processes corresponding to the use of software and the application of modern warehouse management methods such as using barcode to identify on shelf-cell of product. A number of feasibility assessments and operational scenarios also have been developed to ensure the warehouse design can work in assumed scenarios such as urgent delivery followed customer requirements, in unexpected or periodical inventory checking, etc..

The collected data used to make basement for the functional baseline includes many forms - statistical data, hardcopy documents and actual recorded data based on expert method, current survey method and direct interview method. Depended on the collected data, the warehouse system is developed consisting of 06 main subsystem, there are 03 subsystems need to be designed including: Physical, Safety and Interface. Functional Baseline was built for the warehouse system shown in Figure 3.

Figure 3 Functional Baseline of the finished product warehouse

And System Specification are shown Table 5.

Table 5 System Specification

Items	Specification Contents
System Name	Finished product warehouse of electrical equipment manufacturer
System description	<p>Total floor area is about 1,000m²</p> <p>Investment capital is VND 5 billion</p> <p>The warehouse is designed to contain the finished products of the electrical equipment factory (capacitors, transformers, inverters), which can be combined with some raw materials at the time of empty storage – about 50 pallets of material.</p> <p>Capacity of the warehouses as required by the Warehouse Department is 1,000 PT-CT products; 1,000 medium voltage capacitors and 5,000 low voltage CT products.</p> <p>The warehouse has a solid construction structure.</p> <p>There is a suitable lighting and ventilation system.</p> <p>There are loading bays in both input and output doors according to the daily capacity of the factory, and the carrying capacity of vehicles.</p> <p>There is a packing area belong to management of Production Department, office corner used by warehouse staffs, document storage, charging area of forklifts.</p>

Items	Specification Contents
	<p>Warehouse doors are designed in accordance with forklifts moving goods in and out of the warehouse.</p> <p>Ensuring the safety of fire prevention and protection, there is a fire automatic alarm system, automatic fire-fighting system – auto hanging foam fire-extinguishers or wet sprinklers, adequate number of fire extinguishers and indoor hydrants.</p> <p>There are procedures of warehouse managing, maintaining and operating.</p> <p>There is a warehouse management software – WMS.</p> <p>The warehouse must take advantage of available equipment of the plant such as fire pump system, electrical system, forklift truck, barcode marking machine ...</p>
System Function	The Finished Product Warehouse has 05 main functions including: Receiving, Arranging, Storage, Delivery and Handover.
Effective Characteristics	<p>The ability to receive an average of 70 large products per day, 100 medium voltage products per day.</p> <p>Daily inventory checking period is about 10 minutes / time</p> <p>Time of delivery process - from receipt of delivery request to complete delivery on truck less than 60 minutes.</p> <p>Data is backed up in real time on the company's website system, easily accessible if needed for reconciliation when inventory.</p> <p>Reduce the rate of damaged wooden frames containing finished products by at least 50%.</p>

6. PRELIMINARY DESIGN

6.1. Allocation Matrix

Based on the above system specification table, there are 13 functional requirements of Finished Product Warehouse. The warehouse subsystem consists of 03 subsystems: Physical systems, Safety, and Interface.

- Physical systems include functions of physical structure such as: Construction structure, Layout, Doors, Steel-rack shelves, Pallets, Lighting system, and Ventilation system.
- Safety includes 02 items: Fire protection system, Automatic fire alarm system
- Interface includes the process of connecting between the relevant parts: Receiving process, Input and Output process, Delivery process, Maintenance process, Data information system.

The main functions of the Finished Products Warehouse, together operating in accordance, are presented in Figure 4.

To develop the subsystem of designed object, the data provided to support warehouse design includes a variety of types including: interview requirements mentioned in the direct interviews, input and output stock documents, local safety current industrial workshop design standards, etc... Therefore, they require many different approaches to apply these requirements in design practice.

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ALLOCATION MATRIX	PHYSICAL							SAFETY		INTERFACE				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Total floor area is about 1,000m ²	X	X		X		X	X	X	X	X	X	X		
2. Investment capital is 5 billion VND	X	X	X	X	X	X	X	X	X					X
3. The finished product warehouse is designed to contain the finished products of the electrical equipment factory (capacitors, transformers, inverters), which can be combined with some raw materials at the time of empty storage – about 50 pallets of material.	X	X		X	X									
4. Capacity of the warehouses as required by the Warehouse Department is 1,000 PT-CT products; 1,000 medium voltage capacitors and 5,000 low voltage CT products.		X		X	X					X		X		X
5. The warehouse has a solid construction structure.	X		X	X										
6. There is a suitable lighting and ventilation system.						X								
7. There are loading bays in both input and output doors according to the daily capacity of the factory, and the carrying capacity of vehicles.		X	X	X	X					X		X		
8. There is a packing area belong to management of Production Department, office corner used by warehouse staffs, document storage, charging area of forklifts.		X												
9. Warehouse doors are designed in accordance with forklifts moving goods in and out of the warehouse.		X	X											
10. Ensuring the safety of fire prevention and protection, there is a fire automatic alarm system, automatic fire-fighting system – auto hanging foam fire-extinguishers or wet sprinklers, adequate number of fire extinguishers and indoor hydrants.						X		X	X		X		X	
11. There are procedures of warehouse managing, maintaining and operating.										X	X	X	X	
12. There is a warehouse management software – WMS.										X	X	X		X
13. The warehouse must take advantage of available equipment of the plant such as fire pump system, electrical system, forklift truck, barcode marking machine ...		X	X	X	X			X	X					X

(1) Construction Structure; (2) Layout; (3) Doors; (4) Shelves; (5) Pallets; (6) Lighting System; (7) Ventilation System; (8) Fire Fighting System; (9) Fire Alarm System; (10) Receiving Stock Procedure; (11) Storage & Audit Procedure; (12) Outputting Stock Procedure; (13) Maintenance Procedure; (14) Data Information System.

Figure 4 Allocation Matrix

Figure 5 Method of development the subsystem

Design contents include many items related to many departments shown as Figure 5 many approaching ways to finish an accomplished explanation report submitted to factory's Board of Directors such as: amount of pallets, layout, fire-fighting, etc. Within the scope of the this

paper, one approach was chosen with three subsystems that are closely related to each other in calculations and they are also common basis for designing warehouses includes: Pallets – Layout – Racks.

According to [8], Felix Geuken and Louise Jager give us an overview of the steps needed to determine the design order, starts with determining store keeping unit - SKU (Step 3) to plan layout of the premises (Step 7) considered as one part of Preliminary Design shown as in Figure 6.

Figure 6 Warehouse design methodology applied in the paper

Table 6 Specification of finished product packaging procedure

Contents	PRODUCTS		
	PT & CT Products	Low Voltage CT Products	Medium Voltage Capacitors
Packaging Specification	CT & PT products packed in the plastic covers, arranged in wooden frame, 01 product per frame	Low voltage CT products are arranged 30 products per wooden tray	Medium Voltage Capacitors are packed in the plastic covers, arranged in wooden frame, 01 product per frame.

Storage handling unit	06 wooden frame/pallet ↔ 06 products/pallet	03 wooden overlapped trays/pallet → 100 products/pallet	02 wooden frames/pallet ↔ 06 products/pallet
Weight	45kg/product → 270kg/pallet	2kg/product → 200kg/pallet	40kg/product → 240kg/pallet

6.2. Pallets

Followed the above flowchart, then the storage handling units in the surveyed premise is identified and discussed. The current temporary storage mostly focuses on handling pallets, both in the flow to and from the warehouse, conducted by Packaging Team of Production Department will be occupied an area of the expected warehouse. Table 6 shows the product packaging specifications.

$$\text{Amount of pallet} = \frac{\text{Amount of each type of finished products}}{\text{Amount of the finished products arranged in each pallet}}$$

From the above formula, there is the table of the factory output within 03 years of 2017, 2018, 2019 and estimated to 2020 presented in Figure 7 (Assigned pallet type have standard size of 1.2m x 1m x 0.154m, commonly used in the factory).

Figure 7 Outcome of the factory within 2017 – 2019

Table 7 Peak-to-average ratio on stored pallets from 2017 to 2019

Year	Peak of the year (pallets)	Average (pallets)	Peak to average
Outcome 2017	545	113	4.8
Outcome 2018	258	71	3.6
Outcome 2019	302	148	2.0
Forecast 2024	560		

According to the production schedule, the factory will prioritize the procurement of raw materials and fulfill the main order for the parent company in January of each year. Therefore, inventories catch up peak within period of March to June. Based on the Table 7, in the period 2017-2018, there was a sharp decrease in the storage rate towards reducing storage peaks, making inventory turnover faster to reduce storage costs for the factory. But in the scale of paper, peak of 2017 was chosen for base of calculation based on requirement of warehouse managers. Combining together with the designed production capacity of the factory – 15 pallets per date used in cases of goods temporarily stored for objective reasons such as in an audit date or not in time for inventory. Therefore, new chosen storage peak is 560 pallets.

In the factory development orientation in next 05 years, the size of the future warehouse expansion is estimated to be about 20% in 2024 thanks to the application of expert method consulting the idea of production manager and owners of factory. The storage pallet amount

will be also increased accordingly with the production capacity to 20%, equivalent to 672 pallets.

6.3. Layout

The premises of the warehouse include:

- The outside design includes internal roads surrounding to the warehouse, the distance of the warehouse to adjacent factories and surrounding walls.
- The interior shows divisions of the warehouse space into different functional zones, related to storage racks and compartment walls.

The outside design is considered the requirement to take advantage of factory available equipment including floor area located inside the factory, internal roads... The expected warehouse will be located in the available land plot, not effected to the existing production buildings, has total land area is about 1,000m² in the behind of the factory, shown as below Figure 8.

Figure 8 Floor area is planned for the designed warehouse

Based on the number of pallets found out above and the standard size of the type of wooden pallet the company is using, we calculate the required storage area:

$$672 \times (1.2 \times 1) = 807\text{m}^2$$

The detailed arrangement of the inside floor area of the warehouse depends on many relevant factors. Expected warehouse will be divided into 06 functional areas, the design trend in the article is to satisfy the requirements of Stakeholders about the floor area of functional zones such as: Administrative Office, Packing Zone, Forklift Parking and Re-charging Zone, then based on the daily production capacity of the factory, and the capacity of loading and unloading of trucks to calculate the floor area of Receiving Bay and Shipping Bay. The remaining area after subtracting the calculated functional areas is the main storage area where racks are equipped and stored the finished products. Detailed result is shown in Table 8.

The remaining area used for storage will be divided into 03 parts:

- Storage area with many racks which have calculation will be shown in Figure 9.
- Dimension of walkways, forklift paths.
- Ensure a safe distance to surrounding wall to prevent fire spreading hazard.

Table 8 Floor area of functional zones of expected warehouse

Functional areas of the expected warehouse	Floor area (m ²)
(a) Administrative Office	6
(b) Forklift Parking and Re-charging Zone	20
(c) Packing Zone	28
(d) Receiving Bay	64
(e) Shipping Bay	64
Total land area of expected warehouse	1,000
(f) Remaining area used for main storage	818

Figure 9 Simple layout of the warehouse functional zones

Figure 10 Simple diagram of shelf design problem

6.4. Racks

The scope of the paper is only to estimate the appropriate number of shelves and walkways, specific calculations will be more detailed when going into the practical application case, so the problem here is to simplify indicators such as shelf sizes, pallets between pallets, number of shelves counted as double shelves taken from both sides with the between aisle - 2.5m (Figure 10). This method takes 01 edge of storage area with available size (43m or 16m) as a standard to calculate the number of shelves, the number of aisles then use the remaining edge to calculate the number of pallets on each shelf and the number of floors corresponding. The principle of estimation is that the number of floors will be inversely proportional to the shelf length, and no longer than the size limit.

6.4.1. Option 1 - Horizontal shelves

Figure 11 Design of horizontal shelves

Width of storage area: $20\text{m} - 4\text{m} - (2.5\text{m} \times 2) = 11\text{m}$.

- X - Number of shelves $\rightarrow$ Each shelf has a horizontal width of 1.2m, and with double shelf design $\rightarrow$ Shelf length = $2.4X$.
- Y - Number of aisles $\rightarrow$ The width of the aisle is 2.5m $\rightarrow$ The total width of the aisle = $2.5Y$.

Replace the parameter into the variable, there are 04 shelves and 01 aisle (Figure 11).

6.4.2. Option 2 – Vertical shelves

Figure 12 Design of vertical shelves

Width of storage area: $50\text{m} - 7\text{m} - (2.5\text{m} \times 2) = 38\text{m}$.

- X - Number of shelves $\rightarrow$ Each shelf box has a horizontal width of 1.2m, and with double shelf design $\rightarrow$ Shelf length = $2.4X$.
- Y - Number of aisles $\rightarrow$ The width of the aisle is 2.5m $\rightarrow$ The total width of the aisle = $2.5Y$.

$$\begin{cases} 2.4X + 2.5Y < 38 \\ X = Y + 1 \\ X > 1, Y > 1 \end{cases} \rightarrow \begin{cases} X = 7 \\ Y = 6 \end{cases}$$

Replace the parameter into the variable, there is: 14 shelves and 06 aisles (Figure 12).

Calculate the remaining dimension of the shelf together with the corresponding number of floors, are shown in Table 9 below, based on the total number of pallets that need to contain

672 pallets according to the calculation in Section 5.2. The number of pallets arranged in each shelf is calculated from the corresponding shelf length due to the width of the pallets is 01m corresponding to 01 shelf. The number of shelves increases, the shelf length is decreased, until it is smaller than the previously calculated storage area size limit of 43m x 16m.

Table 9 Calculate shelf lengths corresponding to the number of floors

	1 floor	2 floors	3 floors	4 floors	Limited distance
Option 1	168m	84m	56m	42m	43m
Option 2	48m	24m	16m	12m	16m

The loading and unloading time need to be shortened as much as possible, deducing the distance the forklift moves each time it needs to be shortened as much as possible. With Option 2, the distance to the warehouse doors is also shortened due to more moving paths. So, Option 2 has 14 rows of shelves and 06 aisles, each row has 4 floors, each floor contains 12 pallets.

Compared with the requirement that the building height of the warehouse is equal to the adjacent factories which are actually measured to be 12m, the height of 3 floors of 8m is also suitable.

7. DETAILED DESIGN

7.1. Construction

The warehouse will be constructed in the floor area of 1,000m², height of 12m, a steel core column, a standardized V-shaped steel of beam, box type of shape, a 100mm brick wall built 2m high, the upper part using a corrugated iron wall, a tole roof, combined with skylight panels in some positions to make advantages of the natural daylight and limit power consumption.

Because the new warehouse is located on the old ground of the existing warehouse with the existing concrete foundation, according to the information of the leadership board, it has saved about 20% of the construction value.

7.2. Facilities

Based on the calculation results as in section 5.2, we can refer to the design of rack system on the market and choose the appropriate type with the specifications and prices which are considered (Table 10). About pallets, there are some options in considering on Table 11.

Table 10 Shelves' specifications

Products	Technical specification	Price
Selective Shelves	Load capacity: 3500 kg / Pallet.	1,0 mil VND per unit → 672 VND for amount of rack system ≈ 28,600 USD
	Leg frame: Use omega foot to punch holes	
	Counter tops: Used Cross bar, tole, mesh, or plywood,	
	MDF, Okal ...	
	Method of loading: Forklift types	
	Standard paint colors: Blue - Orange - Gray (can change colors according to customer requirements)	
	Product warranty period: 07 years	

Table 11 Pallets' specifications

Option No.	Product name	Technical Specification	Price (mil VND per unit)
1	Wooden Pallet 1,1 × 1,1m (opening face)	- Wooden pallet - Size: 110×110×12cm - Load: Over 1000 kg	0.30
2	New trash wood pallet – new 100%: 1m × 1,2m	- Wooden pallet has 04 loading sides - Size: 1m×1,2m×13cm. - Load: Over 1500kg	0.32
3	Wooden Pallet 1,1 × 1,3m (hunched legs)	- Wooden pallet - Size: 110×130×15cm - Load: Over 1000kg	0.35

Option 1 - Wood Pallet has been chosen based on the cheapest price, meet the standards of weight and quality at the supplier, also in current used in the survey premise. Amount order is in batch of 1,000 units, so total price of pallets is about 300 million VND, equivalent to 12,800 USD.

Using Sketchup Software developed by Trimble Inc. – a 3D modeling computer program for a wide range of drawing applications such as architectural, interior design, landscape architecture, civil and mechanical engineering... A warehouse model has been built to help stakeholders easily visualize the details of the warehouse. The stimulated warehouse layout was shown as Figure 13, Figure 14 and Figure 15 below.

Figure 13 Panoramic background of warehouse

Figure 14 Receiving Zone and Packing Zone of warehouse

Figure 15 Shipping Zone of the warehouse

8. VALIDATION

The warehouse design alternative is based on the understanding of operational status of current warehouse including the normal operations such as receiving, ordering, picking orders, packaging and shipping processes. It also includes predictions for unexpected situations and future production expansion scenarios. The warehouse data collected in various forms is considered as basis for calculating the storage capacity and ancillary supports. The estimated cost for the design is also fully calculated. The results of design alternative using system engineering method combined together with new research on warehouse design process for fast-growing factories. After being presented, there was a high appreciation of BOD for its conformity with general plant conditions, requirements of related departments, and the correspondence between theory and practices. It will be a consideration in practice when conducting warehouse construction in the future.

9. CONCLUSION & RECOMMENDATION

From the views presented above, it can be seen that the ability to build this warehouse is feasible and highly referenced for similar projects have same occupancies. The design process is carried out in the order of system engineering procedure ensuring the following factors:

- Interested and meet most of the requirements of Stakeholders from storage capacity, moving space, administrative area
- Proposing to Board of Directors of factory the basic findings of the future construction objects - finished product warehouse of the factory at the current time. And considering the future development of the factory includes both production and storage capacity.
- Applying and combining modern warehouse development studies with the traditional ways of system engineering process thereby suggesting similar design applications.

All of these above views are aimed at developing knowledge of system engineering and suggesting the available design which is very effective in case of applying in the actual process of designing the facilities of the enterprise in the future to save time, effort, ensure technical factors, safety standards and labor regulations.

ACKNOWLEDGMENTS

This research is funded by Ho Chi Minh University of Technology (HCMUT), VNU-HCM, under grant number BK-SDH-2020-1870183.

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