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GROUP ASSIGNMENT

TOPIC: DOUBLE-DEEP REFRIGERATED AS/RS SYSTEM – A CASE STUDY OF VINAMILK

— Group 6 —

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LIST OF ABBREVIATIONS

AGV	Automated Guided Vehicle
AMR	Autonomous Mobile Robot
AR	Augmented Reality
AS/RS	Automated Storage and Retrieval System
CAGR	Compound Annual Growth Rate
EOQ	Economic Order Quantity
ERP	Enterprise Resource Planning
FILO	First-In-Last-Out
FIFO	First-In-First-Out
FEFO	First-Expired-First-Out
FDI	Foreign Direct Investment
FRS	Fixed Racking System
GDP	Gross Domestic Product
GSO	General Statistics Office (Vietnam)
HVAC	Heating, Ventilation, and Air Conditioning
IACSC	International Association for Cold Storage Construction
IARW	International Association of Refrigerated Warehouses
IoT	Internet of Things
JLL	Jones Lang LaSalle
MR	Mixed Reality
RGV	Rail Guided Vehicle
SKU	Stock Keeping Unit
VLM	Vertical Lift Module
VBM	Vertical Buffer Module
WMS	Warehouse Management System

INTRODUCTION

1. Background:

Vietnam's dairy market, in this day and age, has been dominantly characterized by its heavy dependence on effective storage and distribution systems to maintain the seamless flow of product quality and timely delivery. That’s why Vinamilk, as a leading enterprise in this industry, has consistently prioritized innovation in its supply chain operations to meet consumer demand and maintain its competitive edge by adopting the refrigerated double deep racking Automated Storage and Retrieval System (AS/RS), which has undoubtedly proven to be a transformative approach to manage such perishable goods.

Not only can the AS/RS technology integrate automation and cold chain logistics, enabling precise and efficient handling of temperature-sensitive products; but this system also ensures optimal storage conditions, minimizes human intervention, and enhances warehouse efficiency. In the case of Vinamilk, such deployment of this cutting-edge racking system represents a critically strategic investment in both operational excellence and sustainability, setting an excellent benchmark for other players in the food and beverage industry.

2. Research Objectives:

The primary objective of this study is to analyze the refrigerated AS/RS racking system implemented by Vinamilk and evaluate its role in enhancing warehouse performance and supply chain efficiency. This research aims to:

- Examine the structure and functionality of the refrigerated double-deep racking AS/RS.
- Assess its impact on product quality, operational efficiency, and cost management.
- Identify challenges faced during implementation and propose potential solutions for optimization.

3. Research Questions:

This research seeks to answer the following key questions:

1. What are the design and operational features of the refrigerated double-deep racking AS/RS racking system at Vinamilk?

2. How has the implementation of this system affected supply chain performance?

3. Which system could Vinamilk apply to enhance storage capacity, streamline operations, improve shipping efficiency, and ensure product quality for yogurt products growing demands?

4. Significance of the Study:

The study shall contribute to a deeper understanding of automated warehousing technologies, particularly in Vietnamese cold temperature-controlled environments so as to provide sục valuable insights into its current practical application of AS/RS systems in the broader food and beverage industry. By analyzing Vinamilk's experience, this research highlights the potential of utilizing this racking technology to address logistical challenges and achieve sustainability goals, offering a reference point for other companies considering similar innovations.

CHAPTER 1: OVERVIEW

1.1. Overview of Warehouse Operation

1.1.1. Definition of Warehouse Operations:

Warehouse operations encompass a system of tasks carried out on goods as they move through storage facilities, aiming to facilitate the exchange of goods at the lowest possible cost. Depending on the type of products, materials, stored goods, and warehouse models, warehouse operations may vary. However, every warehouse operation must go through three fundamental stages: Receiving, Warehouse Processing, and Shipping. (The Logistician, 2022)

Firstly, Receiving is the intermediary stage between procurement, transportation, and warehouse operations. It represents the economic and legal relationship between different business entities, including suppliers, logistics service providers, and commercial enterprises. Therefore, the Receiving process must meet the following requirements:

- Clearly define material responsibility between the supplier and the receiver.
- Ensure compliance with the company's receiving plan, and verify contract fulfillment for purchasing and transportation.
- Guarantee timely, accurate, and efficient receipt of goods.

Secondly, Warehouse Processing is the core and most complex stage, determining the overall efficiency of warehouse management. It includes the following key activities:

- ***Storage and Organization:*** Proper allocation and arrangement of goods within the warehouse ensure convenient access for storage, retrieval, and distribution while maximizing space utilization.
- ***Preservation and Maintenance:*** The amount and quality of stored products can be impacted by external variables. A complete management system that includes sanitation, pest control, fire prevention, security measures, and temperature and humidity control (ventilation, dehumidification) is necessary to maintain ideal conditions and avoid deterioration or loss. Reducing damage and loss is crucial. (Chris, 2024)

- ***Order Consolidation:*** This involves transforming and assembling goods into specific shipments based on customer orders. Since incoming goods are stored according to business contracts, while outgoing goods are prepared based on customer demand, order consolidation ensures proper product configuration.
- ***Shipping Preparation:*** Once orders are consolidated, the next step is to prepare them for transportation, ensuring they are ready for dispatch according to the delivery schedule. (Vietnambiz, 2019)

Shipping is the final stage of warehouse operations, reflecting the overall effectiveness of the entire process. It includes all activities required to transfer goods to recipients efficiently and accurately. (Logistics Management Textbook, 2024)

1.1.2. Global Scale:

The global market size of the warehouse and storage services market was valued at $536.26 billion in 2024 and is expected to reach from $569.35 billion in 2025 to $919.17 billion by 2033, growing at an annual growth rate of 6.17% during the forecast period (Straits Research, 2024).

The Asia-Pacific region is the largest participants in the global market for warehousing and storage services, and is expected to grow at a CAGR of 9.45% during the review period. Major consumption of perishable foods by the Asia-Pacific region drives the demand for refrigerated warehousing methods. During the life span of all types of foods, a significant rise in the number of food and beverage companies producing a range of frozen and perishable foods will also follow. For example, in 2019, an expansion in warehousing capacities of Rhenus Logistics to Asia-Pacific region, and recently in India, Greater China, Hong Kong, Philippines, Thailand, Singapore, Malaysia, and Vietnam, offering them full-service logistics, was announced.

1.1.3. Vietnam's Warehouse Industry: Current State and Growth Potential:

Vietnam's warehouse sector experienced rapid expansion in recent years, boosted by a growing pool of factories in Vietnam, increased foreign direct investment (FDI), and electronic commerce (e-commerce) growth. In 2023, Vietnam's transportation and storage sector increased at 9.18% (GSO,2023), with its

contribution to national GDP at 4.92% (Statista, 2024). There is both computerized and traditional modern warehouses in Vietnam's warehousing sector.

Due to an advantageous economic condition and supporting government policies, the prospect for the growth of the warehouse industry in Vietnam is promising. The strategic location in Southeast Asia makes it a key node in regional trade, especially at this point in time when global supply chains are moving toward Asia. And infrastructure development like constructing new highways, developing ports, and industrial parks by the government will surely boost up the logistics and warehousing sectors more.

The usage of automation technologies in warehouses, inclusive of AS/RS, is still in the very early stages in Vietnam but will see fast-tracked growth. According to a report by JLL Vietnam, the need for modern and automated warehouses has been on the rise, especially from multinational corporations and e-commerce companies, while noting that the warehouse automation market would realize a CAGR of 12% in the next five years (JLL Vietnam, 2023).

1.2. About Double-Deep Racking AS/RS:

1.2.1. Overview of Refrigerated Double-Deep Racking AS/RS:

1.2.1.1. Definition of double-deep racking AS/RS:

Generally, double-deep racking AS/RS is a high-density storage solution that integrates two essential components: double-deep pallet racking and AS/RS technology. When talking about double-deep pallet racking, Grupo Arania (2025) considers it as a storage configuration where unit loads are stored in a two-deep arrangement, requiring specialized forklifts to access the rear pallets by maneuvering along aisles parallel to the racking system. This setup alone can increase the warehouse's storage capacity by up to 40% compared to conventional single-deep racking while optimizing space utilization and reducing the number of aisles needed. However, because retrieving the back pallet requires first moving the front one, careful inventory planning and a First-In-Last-Out (FILO) inventory strategy are often necessary to maintain operational efficiency.

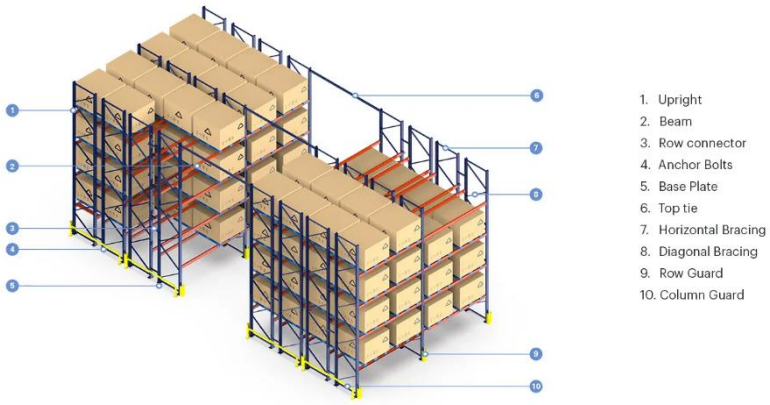

Figure 1: Double-deep pallet racking model from Craftsman Storage Systems (2023)

To tackle this issue and further enhance operational efficiency, accuracy, and inventory utilization in warehouses, AS/RS has become an advanced logistics solution using computer-controlled systems that automatically place and retrieve items from predefined storage locations with minimal human intervention via advanced robotics, conveyor mechanisms, and control software (Conveyco Technologies, 2020).

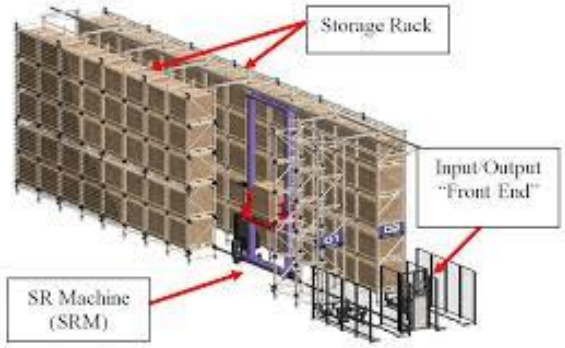

Figure 2: AS/RS technology model from Options Available with AS/RS Technology by Aaron Jones (2010)

1.2.1.2. <u>Explanation of double-deep racking AS/RS technology tailored for refrigerated environments:</u>

Despite traditional AS/RS being commonly used in dry warehouses, when applied to refrigerated environments, the systems play a crucial role in maintaining the integrity of perishable goods by meeting stringent temperature and hygiene requirements while optimizing operational costs (Daifuku, 2019). Additionally, the system's control software is also programmed to manage the unique challenges of

cold storage, such as frost accumulation and energy efficiency, when maintaining a consistent environment throughout the storage and retrieval process. By reducing reliance on manual labor and improving inventory accuracy, refrigerated AS/RS significantly contribute to the effectiveness of temperature-controlled supply chains in some industries such as food and beverage, pharmaceuticals, and biotechnology.

However, these warehouses present unique challenges, including temperature control, energy efficiency, structural integrity, and operational reliability, especially when maintaining stable temperatures between -30°C and 5°C is critical for frozen and chilled products whilst such facilities consume significant energy, necessitating optimized AS/RS designs to reduce power consumption. Additionally, each component for these systems must be resistant to moisture and corrosion caused by low temperatures and condensation in accordance with the International Association of Refrigerated Warehouses [IARW] & International Association for Cold Storage Construction [IACSC] (Global Cold Chain Alliance, 2015). That's why in order to address these challenges, the refrigerated AS/RS need to be integrated with specialized materials, insulation technologies, and software-driven environmental monitoring; along with automation to reduce the need for human labor in harsh conditions, thereby improving both safety and efficiency while maintaining product quality.

1.2.1.3. Types of AS/RS and their applications:

In practice, the AS/RS technologies on the market have to handle a variety of volumes, types, and velocities of non-palletized inventory at variable speeds to accommodate fluctuating throughput demands, thereby creating the need for different types of AS/RS (with three main categories according to Higginbothem (2024) as follows) designed to accommodate varying warehouse layouts, storage needs, and product characteristics:

- ***Shelf and Tray Picking AS/RS Technologies (Shelf-based Picking):*** An entire shelf or tray of product is delivered to an operator (for example: Vertical Carousel Modules, Horizontal Carousel Modules, & Vertical Lift Modules (VLMs))

- ***Bin and Tote Delivery AS/RS Technologies (Bin-based Picking):*** An individual bin or tote of product is delivered to the operator (for example: Crane-Based Mini-Load AS/RS & Vertical Buffer Modules (VBMs))
- ***Robotic Delivery AS/RS Technologies (Robotic Picking):*** Robots are used to deliver products to an operator (for example: Robotic Shuttle Systems, Robotic Cube Storage & Floor Robots (AGVs/AMRs))

In this case study, the Shelf-based and Bin-based Picking AS/RS can be upgraded to the double-deep racking systems while the Robotic Picking AS/RS is highly recommended to be more suitable in cubic racking systems.

AS/RS Types	Description	Application
Vertical Carousel Modules	Comprises of a series of carriers attached to a chain drive, a motor powers the carriers' bi-directional travel in a vertical loop around a track—similar to a Ferris wheel.	- Delivers slow- to medium-velocity items safely and quickly to an ergonomically positioned work counter at the operator's command. - Throughput: 100 to 400 lines per hour - Capacity: 1,430 pounds per carrier - Conclusion: A reliable and cost-effective solution that shouldn't be overlooked.
Horizontal Carousel Modules	Consists of highly dense storage bins mounted on an oval track which rotates horizontally to deliver slow- to medium-moving product storage locations to an operator.	- Delivers slow- to medium-velocity items - Throughput: 600 lines per hour - Capacity: 2,000 pounds per carrier - Conclusion: Offer excellent space utilization and high storage density.
Vertical Lift Modules (VLMs)	Consists of two columns of trays with an inserter/extractor in the center and is engineered to automatically adjust when your inventory changes.	- Stores trays of slow- to medium-velocity items from both columns and presents them to the operator - Throughput: 125 to 350 items per hour - Capacity: 2,200 pounds per tray - Conclusion: The most flexible technology choice for businesses with changing inventory sizes.
Crane-Based Mini-Load AS/RS	With a single, crane-mounted load handling device dedicated to each extremely dense rack aisle, mini-loads handle products in cases, totes or trays. The cranes travel either on rails or wheels with fast acceleration speeds to deliver product to the operator via a workstation located at the end of the aisle.	- Throughput: + Single deep storage: 60 to 100 lines per hour + Double deep storage: 120 putaways and 120 picks per hour - Capacity: + Single deep storage: 100 pounds + Double deep storage: 200 pounds - Conclusion: This is a great high-density storage solution.

AS/RS Types	Description	Application
Vertical Buffer Modules (VBMs)	Consists of an enclosed shelving system with a movable mast running down a center aisle for picking and storage of totes.	- The unit is designed to be able to work ahead of the operator and queue up the next pick for maximum throughput of the system. - Capacity: under 10,000 totes or 25,000 SKUs - Conclusion: A bin handling system designed for smaller applications that often can't cost justify a large, expensive system.
Robotic Shuttle Systems	Uses robotic shuttles to travel independently from level to level, riding on narrow rails at each storage level.	- Retrieves stored items at high speeds based on the number of robotic shuttles inducted into the system. - Throughput: 200 to 700 lines per hour - Capacity: 35 to 110 pounds - Conclusion: These systems are modular, scalable, and flexible by expanding with minimal structural modifications as business needs change.
Robotic Cube Storage	All inventory is placed into bins that are neatly stacked on top of each other inside a cube. Smart robots work at the top of the cube to shuffle, sort and retrieve bins and deliver them to a workstation (port) as needed.	- All robots work independently on the same grid (cube), wirelessly connected to the system and charge themselves when not in use
Floor Robots (AGVs/AMRs)	Stores inventory on portable storage shelving that is retrieved and transported from storage to an operator access area by a fleet of autonomous, mobile robots.	- Ideal for slow to medium velocity inventory and is dependent on the number of robots in the system. - Throughput: 100 to 300 lines per hour - Capacity: 1,000 pounds per shelving system

Figure 3: Types of AS/RS and their applications

When it comes to the Saigon plant of Vietnam Dairy Products Joint Stock Company (Vinamilk), a unit load AS/RS (which are categorized in VBMs and designed to handle large, heavy loads by cranes or guided vehicles) was introduced as a pre-shipment storage facility.

1.2.2. Components of Refrigerated Double-Deep Racking AS/RS:

According to the report of (Smart Kingmore, 2024), the double-deep AS/RS racking system consists of three primary components: automated storage and retrieval machines, a control system, and a racks & shelves system. The AS/RS machines are automated cranes, conveyors, or robotic systems to handle the movement of goods within the storage area. Those machinery would be controlled and coordinated under one integrated system, also the inventory master data would be tracked and traced

through the process of moving goods. Finally, the racks and shelves would be customized on both sides for goods handling and storage.

The physical racking system is assembled with different structural elements such as beams, frames, and additional accessories like support bars and supports to optimal durability, flexibility, and security. Furthermore, safety features such as frame and upright protectors, fall-arrest meshes, reinforcements, and pallet backstops are incorporated to enhance stability and protection. About the frame, each consists of two uprights, diagonal braces, baseplates, and fixing elements such as bolts and nuts. A galvanized finish is usually offered with frames to provide superior durability and resistance to harsh environmental conditions compared to painted finishes. Additionally, uprights and beams feature a pioneering traceability system that immediately identifies their design, composition, and origin, ensuring full traceability. Additional frame components together with their aligned usage include galvanized uprights for enhanced durability, baseplates for load distribution, welded baseplates for greater loads and heights, and shims for leveling the storage system on uneven floors.

Another important component of a double-deep racking system is beams which act as horizontal supports for unit loads while connecting the frames. These beams run parallel to the work aisle and include connectors that securely fit into the drill holes of the uprights. The connectors are designed to create an extremely firm and secure joint system formed between the beam and the upright, increasing the load capacity and the duration of the system. Those beams are the Orange 2C Beam, Orange Light Beam, and Hot Dip Galvanized Beam with different purposes and roles but overall provide different storage demands and environments. These beams are designed to support different load capacities and offer enhanced corrosion resistance for specific warehouse conditions.

To ensure operational safety, several additional protective elements are included in the system namely pre-galvanized standard pins which are used to secure beams to uprights, preventing accidental displacements; racks and panels to reinforce the storage structure and support unit loads, support bars and container for additional reinforcement and adaptability, accommodating various storage needs. Also,

preventive measures like pallet backstops, upright protectors, corner protectors, and signage components would play a role in ensuring the safety and operation of the warehouse working environment.

1.2.3. Conditions for Setting up a Double-Deep Racking AS/RS:

1.2.3.1. Product considerations:

Dairy products need to be stored under strict conditions to guarantee their quality and safety. Fresh milk, for instance, needs to be stored between 1°C and 4°C in order for bacterial growth to be inhibited without freezing (Cold Storage Solutions for Milk and Dairy Products, n.d.). Ice cream should be kept at temperatures of -20°C to -30°C (-4°F to -22°F) to avert melting and keep its texture (ThePackagingPortal.com, 2023). For cheese, storage conditions will vary; for example, cheddar cheese is usually stored at colder temperatures between 4 and 8°C at relative humidity under 80% to allow proper ripening ("Cheese Ripening and Aging," n.d.). Correct humidity plays a major role in preventing spoilage and maintaining integrity. Humidity that is too high can result in mold on cheeses, whereas too low can dry out products (Grotto, 2022). The other important consideration is to maintain the suitability of the packaging materials against cold storage conditions to avoid moisture losses and against contamination.

1.2.3.2. Equipment specifications:

Implementing a Double-Deep AS/RS in a refrigerated environment requires careful selection of equipment to ensure efficiency and product integrity. Energy-efficient refrigeration systems, such as those utilizing CO_2 or ammonia-based refrigerants, can reduce operational costs and environmental impact (Piselli et al., 2024). Implementing backup power supplies and redundant refrigeration units ensures temperature control is maintained during power outages or equipment failures.

The storage rack design should employ a double-deep configuration to increase storage density by storing pallets two deep in each location, effectively accommodating the stabilized high demand and fast-moving nature of dairy products, as well as the demand variations across different subcategories such as butter, yogurt, and drinking milk (Double-deep AS/RS - Godrej Koerber, 2024). Racks must be

constructed with materials suitable for low-temperature environments to prevent structural issues (MRacking, 2022). Automated cranes or shuttles should be selected for their capability to operate efficiently in cold storage conditions, featuring low-temperature lubricants and anti-freezing materials. It is essential that these automated systems can handle the specific load sizes and weights of the products. Conveyor systems designed for low-temperature operations should be integrated to facilitate smooth movement of products within the warehouse, utilizing materials and components that can withstand cold temperatures to prevent malfunctions (Kapelou, 2024). A WMS offering real-time tracking of inventory, integration with temperature monitoring systems, and automated alerts for any deviations is also crucial (Think Inventory Solutions, 2024).

1.2.3.3. Operational workflow for inventory & shipment management:

Efficient operational workflows are essential for maintaining product quality and ensuring timely distribution. Upon arrival, dairy products should be promptly unloaded, and their temperatures checked to ensure they meet specified requirements. The WMS should assign storage locations based on product type, expiration date, and required storage conditions to optimize space utilization and maintain product quality. Utilizing RFID or barcode systems allows for continuous monitoring of product locations and statuses (Wang et al., 2015). Implementing First-In-First-Out (FIFO) or First-Expired-First-Out (FEFO) strategies ensures older stock is used first, reducing waste (Håo, 2024). The double-deep AS/RS would further optimize FIFO and FEFO by enabling efficient storage and retrieval of dairy products based on their expiration dates. With the double-deep configuration, pallets can be stored two deep in each location, increasing storage density while ensuring that older stock is readily accessible for retrieval in compliance with FIFO or FEFO. The WMS should be configured to notify staff of upcoming expiration dates, low stock levels, or temperature deviations, enabling proactive management. Automating the retrieval of products based on orders ensures that the correct items are selected and prepared for shipment efficiently. Maintaining the cold chain by ensuring that products are loaded into refrigerated transport promptly and that vehicles are pre-cooled to the appropriate

temperatures is also critical (What Is Cold Chain Logistics and Why Is It Important to Maintain Your Refrigerated Trailers? | Cartrack Zimbabwe, n.d.).

CHAPTER 2: REFRIGERATED AS/RS RACKING SYSTEM: VINAMILK APPLICATION

2.1. About the Case Study:

2.1.1. Overview of Vinamilk's Warehouse and Traditional Fixed Racks:

Vinamilk is considered as a prominent and influential company in the competitive dairy industry. Guided by its vision "To become a world-class food and beverage company that people trust for healthy products "(Vinamilk, 2023)."A record annual net revenue figure of VND61.78 trillion ($2.46 billion) was achieved by the company last year, reflecting a 2.3% increase relative to the prior fiscal period. They offer a wide range of products, nearly 250 products, to meet the different needs of consumers of all ages. Vinamilk is present throughout Vietnam (see Figure 1), with 13 modern factories across the country that can produce 3 million glasses of milk per day(Vinamilk, n.d.). Their efficient warehousing system is key to providing their diverse range of high-quality products with large quantities. Vinamilk warehousing system within two main distribution centers, strategically located in Ho Chi Minh City (32 Dang Van Bi Street, Thu Duc City) and Hanoi (Km10 National Highway 5, Gia Lam District). These facilities are key to ensuring timely delivery of fresh products to consumers across Vietnam, serving the southern and northern regions, respectively (Vinamilk Việt Nam, n.d.).

Vinamilk's advanced warehouse uses an AS/RS with tall racks. Automated cranes and AGVs seamlessly transport goods to their designated locations. The facility has a capacity of 27,168 pallets and is built to resist seismic activity. Eight rows of racking are supported by the latest Exyz cranes, enabling faster, lighter, and more energy-efficient operations. Vinamilk's investment in advanced technology includes an RGV system for pallet logistics. This system features 15 dynamic loading cranes running along 370 meters of track, with each crane able to handle two pallets. The warehouse design maximizes space and efficiency, incorporating conveyors to assist with loading/unloading, automated pallet management (sorting and picking) and a 16-lane roller conveyor sortation system in the shipping area.

Vinamilk leverages advanced technology and strategic planning for its inventory management. Their state-of-the-art smart warehouse, the pioneer and

largest in Vietnam, can handle almost 30,000 product batches, ensuring both efficiency and quality. Vinamilk's storage process begins with raw materials like fresh milk and milk powder, which are managed using a FIFO system and stored in a cool environment. A computerized system tracks the location of materials on multi-level shelves, streamlining retrieval. Finished goods are also systematically organized by product type. When storage capacity is an issue, finished goods are given preference in Vinamilk's own warehouses, with raw materials moved to rented facilities. Interdepartmental coordination is crucial for the key processes of receiving, internal transfer, and shipping. To manage their extensive distribution network, Vinamilk likely employs models like EOQ to optimize ordering. Their multi-tiered system integrates automated distributor replenishment through Solomon, sales data from supermarkets, and a comprehensive ERP system for tracking and managing their diverse inventory, including specialized coding and labeling.

2.1.2. Specific Challenges Faced with Traditional Warehousing Methods:

Vinamilk's warehousing operations face critical challenges directly linked to its rapid growth and expanding production. The limitations of the previous fixed racking system became acutely apparent as production volumes increased, quickly reaching its storage capacity. This constraint not only created immediate space limitations but also likely hindered efficient stock rotation and retrieval, impacting overall warehouse throughput. As production continued to climb, the fixed racking system, no longer adequate for the scale of operations, became a significant bottleneck.

Compounding the capacity issue, shipping operations became increasingly labor-intensive and time-consuming. The original warehouse design, likely optimized for a smaller scale of operations, struggled to handle the increased volume of outgoing shipments. This surge in activity likely overwhelmed existing manual processes, leading to delays, increased labor costs, and a higher risk of errors in order fulfillment. The combination of limited storage capacity and inefficient shipping operations created a significant strain on the entire warehousing process.

These combined inefficiencies directly impacted Vinamilk's ability to meet the growing demands of its expanding production. Bottlenecks in storage and shipping translated to delays in getting products to market, potentially impacting customer

satisfaction and hindering the company's ability to capitalize on market opportunities. The inability to efficiently manage the increased flow of goods through the warehouse created a ripple effect throughout the supply chain, impacting production planning, distribution, and ultimately, Vinamilk's ability to maintain its competitive edge in the rapidly expanding dairy market. These interconnected challenges, stemming from the limitations of the previous system and the increasing demands of production, underscore the need for a comprehensive overhaul of Vinamilk's warehousing strategy.

2.1.3. Key Problems:

With those aforementioned challenges relating to the limitations in storage capacity, labor force and overall inefficient operations, The question to be addressed for Vinamilk is:

Which system could Vinamilk apply to enhance storage capacity, streamline operations, improve shipping efficiency and ensure product quality for yogurt products growing demands?

2.1.4. Implementation of The Refrigerated AS/RS System

To solve this problem and cope with further growth, Vinamilk has implemented a double-deep automated pallet AS/RS refrigerated system as a pre-shipment storage facility. The 20.5-meter-high automated warehouse effectively uses the ceiling space, securing a storage capacity of 3,520 pallets, about four times that of the previous system in a limited space. This system has the combination of a conventional double-deep pallet racking system and the AS/RS automated system. In the double-deep elements, the pallets are stored at two depths, thus achieving higher storage density, while access to the pallets remains simple and relatively quick. Unlike adjustable pallet racking, in double-deep pallet racking, the operator does not have direct access to all the pallets stored. Also in the AS/RS system, its integration with various technological software facilitates the automation of material handling and retrieval, thereby optimizing in both spaces and manual workforce (AR Racking Solutions, 2024).

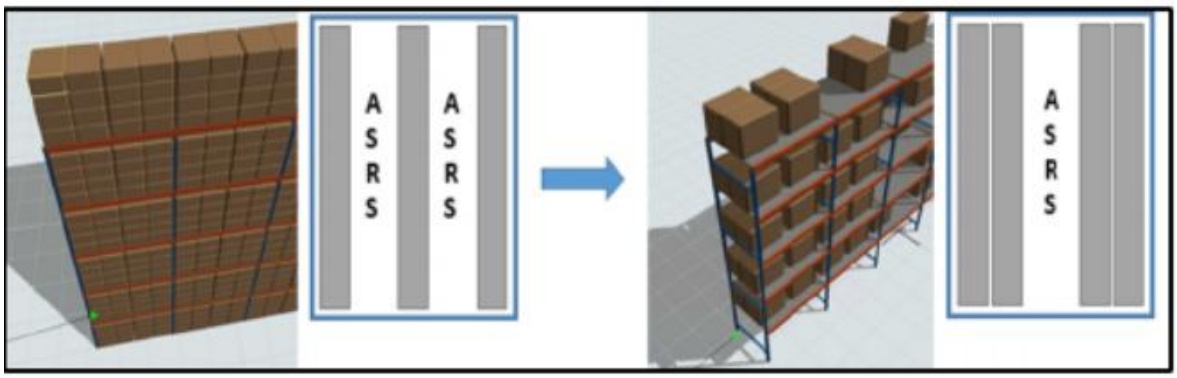

Figure 4: Single deep AS/RS racking system to double deep AS/RS racking system (Zakka Ugih Rizqi et al., 2023)

It is a highly efficient and robust system, with easy assembly and regulation of load levels. Furthermore, it is both adjustable pallet racking and racking perfectly adapted to goods of different weight or volume. About the working principles of this model, the AS-RS warehouse is completely free from or requires very little human involvement in case of the installation of automated conveying belts. Automated Storage and Retrieval Systems work by using computer-controlled systems to automatically deposit and retrieve loads from a defined storage area. A system of conveyors and or automated guided vehicles is sometimes part of the AS/RS system. These take loads into and out of the storage area and move them to the manufacturing floor or loading docks. To store items, the pallet or tray is placed at an input station for the system, the information for inventory is entered into a computer terminal and the AS/RS system moves the load to the storage area, determines a suitable location for the item, and stores the load. As items are stored into or retrieved from the racks, the computer updates its inventory accordingly. (SRSI, n.d) Vinamilk applies AS-RS into inventory activities: Vinamilk applies AS-RS (Automated storage and retrieval system) shelves to optimize warehouse area. This method combines a rack with a motorized crane. An automatic crane system can be used to pick up items instead of manual forklift, therefore allowing the shelf height to be raised to its maximum. Since Vinamilk needs to preserve dairy products under more challenging storage conditions than typical products, the entire transportation system run by software is more ideal than humans.

2.1.5. Cost Breakdown for Setting up: Analysis of Capital Investment

According to the previous section, all of the requested components for the capital investment have been mentioned. After that, we develop a complete Cost Breakdown Structure of the racking system for only the initial investment, not including the operational cost, labour cost, etc.

DOUBLE-DEEP AS/RS RACKING SYSTEM INVESTMENT

	Item	Number Requested	Cost Per Item	Total Cost	
1	Automated Storage and Retrieval Machines (AS/RS) | Equipment & installation	1	$3,000,000.00	$3,000,000.00	
2	**Software & Control System (WMS, ERP...)**	1	$500,000.00	$500,000.00	
3	**Racks & Shelves System**				
3.1.	**Frame**				
3.1.1.	Uprights	1000	$6,000.00	$6,000,000.00	
3.1.2.	Diagonal braces	1000	$3,000.00	$3,000,000.00	
3.1.3.	Baseplates (standard or welded for heavier loads)	1000	$2,000.00	$2,000,000.00	
3.1.4	Fixing elements (bolts, nuts)	1000	$1,500.00	$1,500,000.00	
3.1.5.	Shims (for leveling)	1000	$350.00	$350,000.00	
3.1.6.	Frame and upright protectors (for safety)	1000	$2,000.00	$2,000,000.00	
3.1.7.	Traceability system (for identifying design, composition, and origin)	1	$12,500.00	$12,500.00	REF
3.2.	**Beams**	1000	$6,500.00	$6,500,000.00	
3.3.	**Accessories and Safety Features**				
3.3.1.	Pre-galvanized standard pins (for securing beams)	1000	$1,000.00	$1,000,000.00	
3.3.2	Racks and panels (for reinforcement and load support)	1000	$3,500.00	$3,500,000.00	
3.3.3.	Support bars and containers (for additional reinforcement and adaptability)	1000	$2,500.00	$2,500,000.00	
3.3.4.	Pallet backstops (to prevent pallets from falling)	1000	$1,500.00	$1,500,000.00	
3.3.5.	Corner protectors	1000	$1,000.00	$1,000,000.00	
3.3.6.	Fall-arrest meshes	1000	$1,000.00	$1,000,000.00	
3.3.7.	Reinforcements	1000	$3,500.00	$3,500,000.00	
3.3.8.	Signage components	1000	$500.00	$500,000.00	
4	**Operational equipment**				
4.1	Bin	10,000	2	16500	Link
4.2	Rack	1,000	30	30000	Link
4.3	Conveyor	30	200	6000	Link
4.4	Vertical Z Conveyor	2	900	1800	Link
4.5	Tag making machine	12	200	2400	Link
4.6	Handheld scanner	20	350	7000	Link
4.7	Conveyor scanner	24	143	3432	Link
4.8	Trolley	25	135	3375	Link
4.9	Lighting	1,000	24	24270	Link
4.10	Ventilation	50	60	3000	Link
4.11	Safety equipments	225	24	5373	
4.12	Barrier	50	25	1250	
4.13	CCTV	1	3,270	3270	Link
5	MRO (Buffer 20%)	n+	-	1000000	
			Grand Total:	$40,470,170.00	
			Grand Total (VND):	$1,011,754,250,000.00	

Figure 5: Single deep AS/RS racking system to double deep AS/RS racking system (Zakka Ugih Rizqi et al., 2023)

2.2. Comparative Analysis with The Fixed Racking System:

Criteria		Fixed Racking System	AS/RS	Explanation
Storage Capacity	Space Utilization	Lower	Higher	With a storage capacity of 3,520 pallets, which is a four-fold increase in storage capacity within the same (or a very similarly sized) space (approximately 880 pallets), the application of the AS/RS system has directly addressed Vinamilk's challenge of limited space, optimizing vertical space and reducing aisle space.
	Storage Density	Lower	Higher	
	SKU Capacity	Potentially limited	Potentially improved through better organization	
Efficiency	Retrieval/ Put-away Time	Slower, manual process	Faster, automated retrieval/ put-away	With fixed racking systems, the items were located and retrieved by people, possibly using forklifts or other manual equipment. This process was inherently slower due to human involvement, travel time, and potential errors. The AS/RS automation system significantly reduces retrieval, storage, and order fulfillment times by eliminating manual search and travel time. This leads to significantly faster and more accurate retrieval, improving operations and increasing throughput.
	Order Fulfillment Time	Longer	Shorter	
	Throughput	Lower	Higher	
	Accuracy	Lower	Higher	
	Energy Consumption	Lower	Higher	Traditional fixed racking primarily relies on human labor and simple equipment, which might consume energy (electricity or fuel), the overall energy consumption is potentially lower compared to a highly automated and running constantly like AS/RS. However, overall, the energy usage of AS/RS equipment in the warehouse could be lower in the long run operation.
Quality Control	Product Damage	Higher	Lower	AS/RS systems are generally better at protecting products from damage. Machines are established and programmed to move and store items precisely and consistently, reducing the chance of impact drops or errors from humans that can cause damage.
	Inventory Accuracy	Lower	Higher	By using fixed racking systems, data entry is often manual, leading to potential errors such as incorrect recording or misplaced items. It also lacks real-time updates due to the delay in updating inventory information or records may not reflect the current stock levels. Therefore, AS/RS

				systems, integrated with WMS can help the company to gain real-time tracking and improve their inventory accuracy.
Others	Initial Investment	Lower	Higher	Typically, the company will have to pay an initial cost to purchase and install the complex machinery and systems for AS/RS. At the same time, the planning, design, installation, and commissioning of AS/RS require technical and project management expertise, adding to the initial cost. However, in the long run, the long-term maintenance costs of a fixed racking system are potentially higher due to: wear and tear from manual handling, collisions with forklifts or other equipment accidents, labor-intensive maintenance, etc.
	Equipment Maintenance	Higher	Lower	
	Safety	Lower	Higher	AS/RS systems, by automating many of the tasks previously done manually, significantly reduce the risks of accidents from falling heights objects or lifting/moving heavy items.
	Integration with other systems	Harder, more challenging	Easier	AS/RS systems are designed to integrate seamlessly with modern WMS and ERP systems. Data and information are exchanged electronically and automatically, providing real-time visibility into inventory levels, location, and movement, allowing for more efficient operations, better data accuracy, and improved visibility across the company's supply chain.

Figure 6: Comparative analysis of Vinamilk's warehouse operations: Fixed racking system vs. AS/RS

In general, Vinamilk's implementation of an AS/RS system has significantly enhanced its operational efficiency since it offers several advantages over traditional fixed racking systems, including density, space utilization, and flexibility concerning warehouse operations. Besides, speed and accuracy are also considerations that can be improved by implementing an AS/RS (Baker and Halim, 2007). Other aspects such as reduced labor requirements and improved ergonomics can constitute further advantages of AS/RS. Although the implementation of an AS/RS represents a high investment cost, and that the company also needs to face continuous costs such as maintenance and expansion of the system, the long-term benefits often outweigh these initial costs, leading to a significant return on investment over time.

2.3. Financial Analysis:

The main function of this cost analysis is to (1) compare the cost structure of the current applied racking system - double-deep AS/RS racking system and the previously applied one which is a fixed racking system. In addition it also (2) elaborates deeper into each smaller element which possibly contributes to the total cost of operating those systems. Finally, the cost analysis acts as a (3) visualization of the right decision of Vinamilk in transforming their warehouse operations by using data from the industry, research and consultation from Vinamilk experts.

To make our calculations more unified realistic and data-driven, there are some estimations based on further research and expert consultation. Those general assumptions will be added to the table below:

No.	Assumptions
1	The exchange rate between USD and VND is 1 dollar = 25,000 VND
2	Monthly revenue: 200 bil VND (estimated by Mr. Vin)
3	Each month has the same selling amount.
4	Mostly all the operational expenses, investment cost would be collected from market and articles.

Figure 7: Assumption for further calculation

Each system would be calculated based on three sections: monthly revenue, monthly operating costs and total investments. First, the monthly revenue is estimated at 200,000,000,000 VND by Mr. Vin, because this figure is difficult to identify based on various external factors such as buying power, market consumption, competitors, company operations, etc. About the double-deep racking system, the total initial investment cost is calculated at over 1,011 billion VND which is primarily due to the high purchasing cost of the equipment for the global standard double-deep model collaborated by the AS/RS integration system. Those equipment consists of 5 main parts: Automated Storage and Retrieval Machines (AS/RS); Software & Control System (WMS, ERP...); Racks & Shelves System (beams, frames, safety features), Operational Equipment. Whereas the fixed racking system initial investment is lower, at 757 billion VND due to the lower quantity purchased equipment to purchase for the setup of the system, as well as there is no installation of the AS/RS system.

DOUBLE-DEEP AS/RS RACKING SYSTEM INVESTMENT					
	Item	Number Requested	Cost Per Item	Total Cost	
1	Automated Storage and Retrieval Machines (AS/RS) | Equipment & installation	1	$3,000,000.00	$3,000,000.00	
2	**Software & Control System (WMS, ERP...)**	1	$500,000.00	$500,000.00	
3	**Racks & Shelves System**				
3.1.	**Frame**				
3.1.1.	Uprights	1000	$6,000.00	$6,000,000.00	
3.1.2.	Diagonal braces	1000	$3,000.00	$3,000,000.00	
3.1.3.	Baseplates (standard or welded for heavier loads)	1000	$2,000.00	$2,000,000.00	
3.1.4	Fixing elements (bolts, nuts)	1000	$1,500.00	$1,500,000.00	
3.1.5.	Shims (for leveling)	1000	$350.00	$350,000.00	
3.1.6.	Frame and upright protectors (for safety)	1000	$2,000.00	$2,000,000.00	
3.1.7.	Traceability system (for identifying design, composition, and origin)	1	$12,500.00	$12,500.00	REF
3.2.	**Beams**	1000	$6,500.00	$6,500,000.00	
3.3.	**Accessories and Safety Features**				
3.3.1.	Pre-galvanized standard pins (for securing beams)	1000	$1,000.00	$1,000,000.00	
3.3.2	Racks and panels (for reinforcement and load support)	1000	$3,500.00	$3,500,000.00	
3.3.3.	Support bars and containers (for additional reinforcement and adaptability)	1000	$2,500.00	$2,500,000.00	
3.3.4.	Pallet backstops (to prevent pallets from falling)	1000	$1,500.00	$1,500,000.00	
3.3.5.	Corner protectors	1000	$1,000.00	$1,000,000.00	
3.3.6.	Fall-arrest meshes	1000	$1,000.00	$1,000,000.00	
3.3.7	Reinforcements	1000	$3,500.00	$3,500,000.00	
3.3.8.	Signage components	1000	$500.00	$500,000.00	
4	**Operational equipment**				
4.1	Bin	10,000	2	16500	Link
4.2	Rack	1,000	30	30000	Link
4.3	Conveyor	30	200	6000	Link
4.4	Vertical Z Conveyor	2	900	1800	Link
4.5	Tag making machine	12	200	2400	Link
4.6	Handheld scanner	20	350	7000	Link
4.7	Conveyor scanner	24	143	3432	Link
4.8	Trolley	25	135	3375	Link
4.9	Lighting	1,000	24	24270	Link
4.10	Ventilation	50	60	3000	Link
4.11	Safety equipments	225	24	5373	
4.12	Barrier	50	25	1250	
4.13	CCTV	1	3,270	3270	Link
5	MRO (Buffer 20%)	n+	-	1000000	
			Grand Total:	$40,470,170.00	
			Grand Total (VND):	$1,011,754,250,000.00	

Figure 8: Double-deep AS/RS Racking System Investment (Source: The Author Compilation)

FIXED RACKING SYSTEM INVESTMENT

	Item	Number Requested	Cost Per Item	Total Cost	
1	**Software & Control System (WMS, ERP...)**	1	$500,000.00	$500,000.00	
2	**Racks & Shelves System**				
2.1	**Frame**				
2.1.1	Uprights	800	$6,000.00	$4,800,000.00	
2.1.2	Diagonal braces	800	$3,000.00	$2,400,000.00	
2.1.3	Baseplates (standard or welded for heavier loads)	800	$2,000.00	$1,600,000.00	
2.1.4	Fixing elements (bolts, nuts)	800	$1,500.00	$1,200,000.00	
2.1.5	Shims (for leveling)	800	$350.00	$280,000.00	
2.1.6	Frame and upright protectors (for safety)	800	$2,000.00	$1,600,000.00	
2.2	**Beams**	800	$6,500.00	$5,200,000.00	
2.3	**Accessories and Safety Features**				REF
2.3.1	Pre-galvanized standard pins (for securing beams)	800	$1,000.00	$800,000.00	
2.3.2	Racks and panels (for reinforcement and load support)	800	$3,500.00	$2,800,000.00	
2.3.3	Support bars and containers (for additional reinforcement and adaptability)	800	$2,500.00	$2,000,000.00	
2.3.4	Pallet backstops (to prevent pallets from falling)	800	$1,500.00	$1,200,000.00	
2.3.5	Corner protectors	800	$1,000.00	$800,000.00	
2.3.6	Fall-arrest meshes	800	$1,000.00	$800,000.00	
2.3.7	Reinforcements	800	$3,500.00	$2,800,000.00	
2.3.8	Signage components	800	$500.00	$400,000.00	
4	**Operational equipment**				
4.1	Bin	10,000	2	16500	Link
4.2	Rack	1,000	30	30000	Link
4.3	Conveyor	30	200	6000	Link
4.4	Vertical Z Conveyor	2	900	1800	Link
4.5	Tag making machine	12	200	2400	Link
4.6	Handheld scanner	20	350	7000	Link
4.7	Conveyor scanner	24	143	3432	Link
4.8	Trolley	25	135	3375	Link
4.9	Lighting	1,000	24	24270	Link
4.10	Ventilation	50	60	3000	Link
4.11	Safety equipments	225	24	5373	
4.12	Barrier	50	25	1250	
4.13	CCTV	1	3,270	3270	Link
5	MRO (Buffer 20%)	n+	-	1000000	
			Grand Total:	$30,287,670.00	
			Grand Total (VND):	$757,191,750,000.00	

Figure 9: Fixed Racking System Investment (Source: The Author Compilation)

In terms of the monthly operation, it seems that the monthly operation of double-deep AS/RS is relatively lower due to the optimization of operational flow using integrated system with high level of autonomy, and labor workforce. Whereas the fixed racking system needs more manual operation in limited space and high level of workforce to handle those tasks compared to the double-deep AS/RS which can increase up to 4 times for storage capacity with high level of automation (Daifuku, 2019). Due to the limited storage capacity of fixed fixed-racking system, it can not handle the demand variations in peak season, which is the reason why hiring the overflow warehouse would be considered in this case. Those monthly operational cost of the double-deep AS/RS and the racking system are standing at 27,5 billion VND and 51 billion respectively. The operating cost would be assessed based on four

perspectives: Transportation expenses; Material Handling Cost; Utility Cost; Maintenance, Depreciation, and Interest Tax Rate as the tables have illustrated below.

		Average price per unit (VND)	Number of products	Total (VND)
1	**Transportation expenses**			8,610,250,000
1.1	Fuel Costs	6,427,500,000		6,427,500,000
1.2	Labor cost	1,400,000,000		1,400,000,000
1.3	Logistics Management Costs	782,750,000		782,750,000
2	**Cost of material handling**		7,000	15,291,666,667
2.1	Equipment Costs: $500,000	500,000	1	12,500,000,000
2.2	WMS Costs: $20,000	20,000	1	500,000,000
2.3	Labor Costs: $1,000,000 annually	83,333	1	2,083,333,333
2.4	Energy Consuption: $100,000 annu	8,333	1	208,333,333
3	**Electricity, water**	1,250,000,000	-	1,250,000,000
4	**Maintenance, Depreciation, Inter**	-	-	2,395,833,333
4.1	Maintenance Costs: $200,000 to $300,000 annually.	25,000		625,000,000
4.2	Depreciation: $100,000 to $200,000 annually, depending on asset value and depreciation method.	16,667		416,666,667
4.3	Interest Costs: $500,000 annually for a $10 million loan at 5%.	41,667		1,041,666,667
4.4	Property Taxes: $50,000 to $150,000 annually, depending on location.	12,500		312,500,000
	Grand Total			$27,547,750,000

Figure 10: Monthly Operating Cost of Double-Deep AS/RS Racking System (Source: The Author Compilation)

C.Monthly operational expenses (for one WH only)			*$33,232,681,250*	*VND*
		Monthly Overflow WH (8.5%)	*$57,134,597,917*	*VND*
		Average price per unit (VND)	Number of products	Total (VND)
1	**Transportation expenses**			8,610,250,000
1.1	Fuel Costs	6,427,500,000		6,427,500,000
1.2	Labor cost	1,400,000,000		1,400,000,000
1.3	Logistics Management Costs	782,750,000		782,750,000
2	**Cost of material handling**		7,000	15,291,666,667
2.1	Equipment Costs: $500,000	500,000	1	12,500,000,000
2.2	WMS Costs: $20,000	20,000	1	500,000,000
2.3	Labor Costs: $1,000,000 annually	83,333	1	2,083,333,333
2.4	Energy Consuption: $100,000 annu	8,333	1	208,333,333
3	**Electricity, water**	1,250,000,000	-	1,250,000,000
4	**Maintenance, Depreciation, Inter**	-	-	8,080,764,583
4.1	Maintenance Costs (10% of initial investment)	75,719,175,000		6,309,931,250
4.2	Depreciation: $100,000 to $200,000 annually, depending on asset value and depreciation method.	16,667		416,666,667
4.3	Interest Costs: $500,000 annually for a $10 million loan at 5%.	41,667		1,041,666,667
4.4	Property Taxes: $50,000 to $150,000 annually, depending on location.	12,500		312,500,000
5	**Overflow Warehouse (8.5% increase rate)**			57,134,597,917
5.1	Warehouse Space (10000 square fc	0.663		165,833,333
5.2	Labor Cost	41,667		41,667
5.3	Utilities	2		150,000,000
5.4	Insurance and Taxes	5,000		125,000,000
5.5	Operating Expenses (per sqr ft)	0.33333		8,333
	Total			57,134,597,917

Figure 11: Monthly Operating Cost of Fixed Racking System (Source: The Author Compilation)

Last but not least, the Net Present Value (NPV) analysis will be provided to evaluate the amount of cash flow that could be gained back. The planning horizon would be 06 years with an interest rate of 4.5% (Trading Economics, 2024). The 0 year would be the final 2024 and the final year 2029. According to the report of (Hà Anh, 2023), the revenue has achieved a moderate growth of 6% CAGR on the annual basis, so this growth rate would be included in our calculations. The two table below show formulas used for the estimation and the overall of the financial analysis outcome. As can be seen in the figure, the NPV of applying double-deep AS/RS is projected to get 11,800 billion VND, even though there is a slow return in the first two years after the investment cost, compared to the the 8,670 billion VND is the NPV revenue counted of the fixed racking system.

Revenue growth in n year	= 0 year revenue + 0 year revenue * growth rate^n
Total operating cost & investment in the 0 year (n% You increase)	= initial investment + operating cost (A)
Total operating cost & investment in the n year (a% You increase)	= (A) * (1 + a%)^n
Combined cash flow	= Revenue + Total operating cost & investment
NPV	$= \frac{\text{Net cash flow}}{(1+\text{discount rate})^n}$ (n: time of cash flow)

Figure 12: Formulas used (Source: The Author Compilation)

Planning horizon	6	years
Interes rate	4.50%	

Cash flow for 6 years ahead started from year 0 (2024-2029)						
End-of-Year	0	1	2	3	4	5
Revenue: 6% CAGR	2,400,000,000,000	2,544,000,000,000	2,696,640,000,000	2,858,438,400,000	3,029,944,704,000	3,211,741,386,240
Double-Deep AS/RS Racking System (3% YoY increasing rate)	-1,342,327,250,000	-350,407,380,000	-371,431,822,800	-393,717,732,168	-417,340,796,098	-442,381,243,864
Fixed Racking System (3% YoY increasing rate)	-327,215,600,000	-1,211,245,718,268	-1,278,270,429,353	-1,350,992,240,880	-1,429,895,406,388	-1,515,505,340,963
Combined cashflow of Double-Deep AS/RS	1,057,672,750,000	2,193,592,620,000	2,325,208,177,200	2,464,720,667,832	2,612,603,907,902	2,769,360,142,376
Combined cashflow of Fixed Racking System	2,072,784,400,000	1,332,754,281,733	1,418,369,570,647	1,507,446,159,120	1,600,049,297,612	1,696,236,045,277
Cummulative rate at interest ra	**1**	**0.96**	**0.92**	**0.88**	**0.84**	**0.80**

Discounted cash flow (with revenue accounted) started from year 0 (2024)						
Discounted cash flow at End-of-Year	0	1	2	3	4	5
Double-Deep AS/RS Racking System	-1,342,327,250,000	-335,318,066,986	-340,131,244,981	-345,013,511,655	-349,965,858,712	-354,989,292,091
Fixed Racking System	-327,215,600,000	-1,159,086,811,739	-1,170,550,517,939	-1,183,869,912,788	-1,199,055,013,178	-1,216,118,846,833
Double Deep (revenue accounted)	1,057,672,750,000	2,099,131,693,780	2,129,262,770,724	2,159,826,351,165	2,190,828,643,287	2,222,275,944,387
Fixed Rack (revenue accounted)	2,072,784,400,000	1,275,362,949,026	1,298,843,497,765	1,320,969,950,032	1,341,739,488,821	1,361,146,389,645

Net present value (NPV) analysis from year 0 (2024) to year 4 (2028)						
	NPV to year 0 (2024)	NPV to year 1 (2025)	NPV to year 2 (2026)	NPV to year 3 (2027)	NPV to year 4 (2028)	NPV to year 5 (2029)
Double deep (cost implications only)	-1,342,327,250,000	-1,677,645,316,986	-2,017,776,561,966	-2,362,790,073,621	-2,712,755,932,334	-3,067,745,224,425
Fixed Rack (cost implications only)	-327,215,600,000	-1,486,302,411,739	-2,656,852,929,679	-3,840,722,842,466	-5,039,777,855,645	-6,255,896,702,478
Double deep (revenue accounted)	**1,057,672,750,000**	**3,156,804,443,780**	**5,286,067,214,504**	**7,445,893,565,669**	**9,636,722,208,956**	**11,858,998,153,343**
Fixed Rack (revenue accounted)	**2,072,784,400,000**	**3,348,147,349,026**	**4,646,990,846,792**	**5,967,960,796,824**	**7,309,700,285,645**	**8,670,846,675,290**

Figure 13: Financial analysis of both racking system (Source: The Author Compilation)

2.4. Challenges & Risk Management Plan:

Installing a double-deep Automated Storage and Retrieval Systems (AS/RS) might be a challenging strategy for the company, therefore, a detailed risk management plan should be developed.

Huge initial investment is one of the biggest challenges for a double-deep racking system installation. The upfront costs for a double-deep racking system can be substantial, as it requires a greater number of rack components compared to traditional systems. This includes not only the racks themselves but also specialized forklifts designed to access deeper pallets. The initial investment can deter businesses, especially smaller operations, from adopting this system, leading to potential financial strain if the return on investment (ROI) is not carefully evaluated.

The second risk related to the structural failure of the material, arising from overloading weights and poor design or installation. Storing more weight than the racking system is designed to handle can lead to catastrophic failures. Racking systems are at risk of serious, even catastrophic, failure when they are loaded beyond their intended weight limit. This overloading gradually weakens the rack's structure, making a collapse more likely. Signs of overloading may include visible sagging, unusual noises, or stress on the components. To mitigate this risk, the company shall implement regular inspections and adhere to load limits. Implementing weight sensors and load indicators, like clear signs of each rack’s maximum weight capacity, can protect against overloading.

Besides, inadequate design or improper installation of racks can compromise stability and racks collapse. Warehouses face a significant danger from using racking systems that are damaged or made up of incompatible parts. Racks with structural issues, such as cracks, dents, or bent components, compromise their load-bearing capacity. The combination of different types or brands of racks can also lead to uneven weight distribution and instability. Therefore, it is crucial to follow manufacturer guidelines and conduct thorough site assessments before installation. Routine inspections are crucial for identifying and rectifying damaged racks promptly. A comprehensive inspection process should include checks for visible damage, corrosion, and any signs of wear. By using standardized types and brands of

racks in a warehouse, you can significantly reduce the chances of having incompatible setups.

Over time, racks that are incorrectly installed or put together can become a hidden danger, resulting in unexpected accidents. Even top-quality racks can turn hazardous if they are not installed according to the manufacturer's instructions. Key elements such as alignment, levelness, and proper anchoring are vital to maintaining system stability. Hiring skilled professionals for rack installation guarantees precision, preventing future safety concerns. Regularly auditing the installation process and following best practices are crucial parts of a robust safety strategy.

Finally, during the process of storage and retrieval, operation risk including accidents may occur and disrupt the warehouse functions. Improperly stacked goods or equipment failure can lead to items falling from heights, posing safety hazards to personnel. Implementing safety measures such as protective barriers and regular training for staff can help reduce this risk. The movement of cranes and other machinery in tight spaces increases the likelihood of collisions. Utilizing advanced control systems and sensors can enhance operational safety by preventing such incidents.

CHAPTER 3:

3.1. Summary of Key Findings:

The report has provided case studies into the evolution of Vinamilk, a primary dairy company in Vietnam, changing from traditional FRS to AS/RS in its warehouses. Switching to AS/RS has seen significant enhancements in many key areas. First, the system has vastly increased storage space-up to four times-ways of 3,520 pallets into the same physical site at better vertical utilization. In efficiency, AS/RS system automated retrieval-putaway, thereby lessening labor cost and expediting order fulfillment, leading to reduced throughput of goods and less inventory error. Further, quality control became better with reduced product damage which arose from human error, thus enabling constant conduct towards sensitive dairy products. Though the investment in AS/RS could allow for faster returns, it was less energy-consuming over time whereas FRS-people-driven ones-used energy more intensively. Another area of improvement due to WMS integration is inventory accuracy, thanks to real-time updates thus eliminating human error. Challenges of implementing AS/RS exist-stiff initial costs, risks of structural failure from overloading, and safety threats during storage and retrieval operations. Such risks identify the need for a full-scale risk management plan, including repeat inspections and proper installation of the system; this will play a big role in determining if the system survives in the long run.

3.2. Trends & Implications:

The future trends of warehousing involve low carbon strategies and intelligent innovation, which are key to meeting environmental concerns and the evolving needs of the market. Advances in next-generation information technology (including IoT, blockchain, AI, etc.) have significantly accelerated the modernization of automation in warehousing operations. Meanwhile, attaining these dual objectives of a low-carbon footprint and intelligent innovation requires cooperation between national regulators, industry, consumers, and interdisciplinary experts.

The characteristics of a low-carbon warehouse mainly involve low energy consumption, low carbon emissions, low pollution, and environmental friendliness.

Warehousing represents an energy-intensive industry that consumes a significant amount of energy and produces copious carbon emissions from lighting, climate control, material handling equipment, and transportation to and from the facility. Meanwhile, continuous operational monitoring, waste from packaging and damaged goods, and traffic congestion due to warehouse activities contribute substantially to energy consumption and environmental pollution. In addition, as can be seen from the research interest in each aspect of warehouse operations and the current status thereof, environmentally friendly and energy-saving innovations concern all facets of warehousing. Therefore, a low-carbon warehousing industry has attracted significant attention from government, enterprises, professionals, and residents, and reducing energy consumption and carbon emissions has become a ubiquitous trend in the warehousing industry.

These are the two main lines of research for reducing the carbon footprint of warehousing: a line of research focusing on improving the technology (e.g., energy-efficient lighting systems, HVAC, material handling equipment, and renewable energy integration), and another line of research focusing on improving operations and management practices (e.g., optimized storage layouts, efficient order picking, transportation routing, and waste reduction strategies). However, government subsidies, carbon-emissions trading, and environmental policies also strongly influence the transformation of the warehousing toward lower energy requirements and reduced emissions. In addition, the balance between short-term profitability (e.g., corporate profits and social welfare) and long-term environmental sustainability (carbon emission reductions) should also be considered as an important factor for promoting the development of a low-carbon warehouse

3.3. Limitations of the Research:

This report's analysis of AS/RS for Vinamilk's warehouses faces some potential constraints. Firstly, reliance on secondary data risks outdated insights, especially for Vietnam's evolving warehouse sector, and the absence of internal Vinamilk metrics (e.g., current storage capacity, labor costs) restricts actionable conclusions. Secondly, the narrow focus on AS/RS excludes emerging technologies like AI-driven robotics or IoT integration, which could synergize with automated storage solutions.

Assumptions about AS/RS benefits lack empirical validation and overlook implementation risks, such as cybersecurity vulnerabilities or scalability challenges. Market projections, while current, may shift due to Vietnam's rapid industrialization or global supply chain disruptions. To strengthen future research, incorporate primary data (e.g., interviews with Vinamilk's logistics teams), benchmark against AS/RS case studies in similar industries, integrate risk-assessment frameworks, and adopt a dynamic approach to track technological and economic trends. Expanding the scope to address sustainability (e.g., energy-efficient AS/RS designs) could also enhance relevance for long-term planning.

CONCLUSION

The implementation of the Refrigerated Double-Deep Racking AS/RS at Vinamilk has significantly enhanced the company's warehousing operations by integrating intensive automation and advanced storage solutions to optimize warehouse space, improve efficiency, and maintain product quality in a highly competitive dairy industry. The transition from traditional fixed racking systems to AS/RS technology has resulted in a fourfold increase in storage capacity, streamlined inventory management, and improved overall supply chain performance.

Despite the high initial investment costs, the long-term benefits of double-dêp racking AS/RS technology, including reduced labor requirements, increased throughput, and improved inventory accuracy, justify its adoption. Additionally, the integration of AI-powered WMS has enabled real-time tracking, error minimization, and enhanced decision-making capabilities. However, challenges such as maintenance, energy consumption, and safety considerations must be continually monitored and managed to ensure sustained efficiency.

As the logistics and warehousing industry in Vietnam continues to evolve, the adoption of automated solutions like double-deep racking AS/RS will become increasingly crucial for businesses seeking to maintain a competitive edge. Vinamilk's success with this technology serves as a benchmark for other companies in the food and beverage industry looking to modernize their warehousing operations. Moving forward, continuous improvements, integration of AI-driven analytics, and sustainability measures will be essential for maximizing the full potential of automated warehousing solutions.

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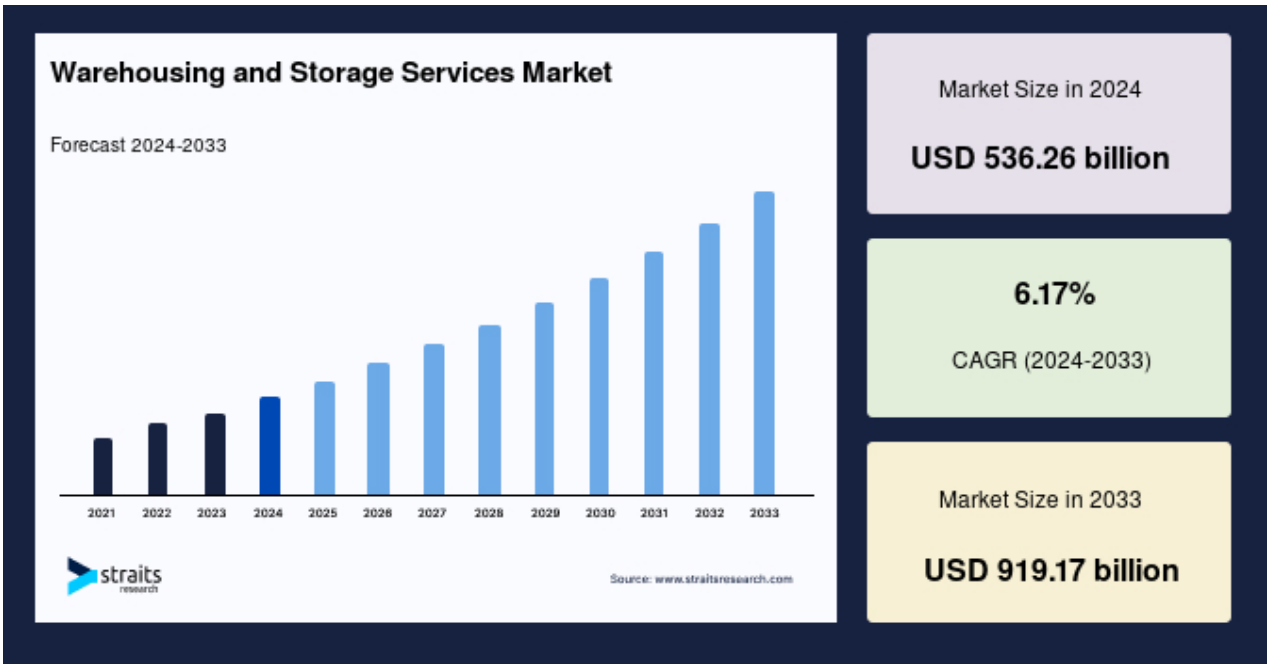
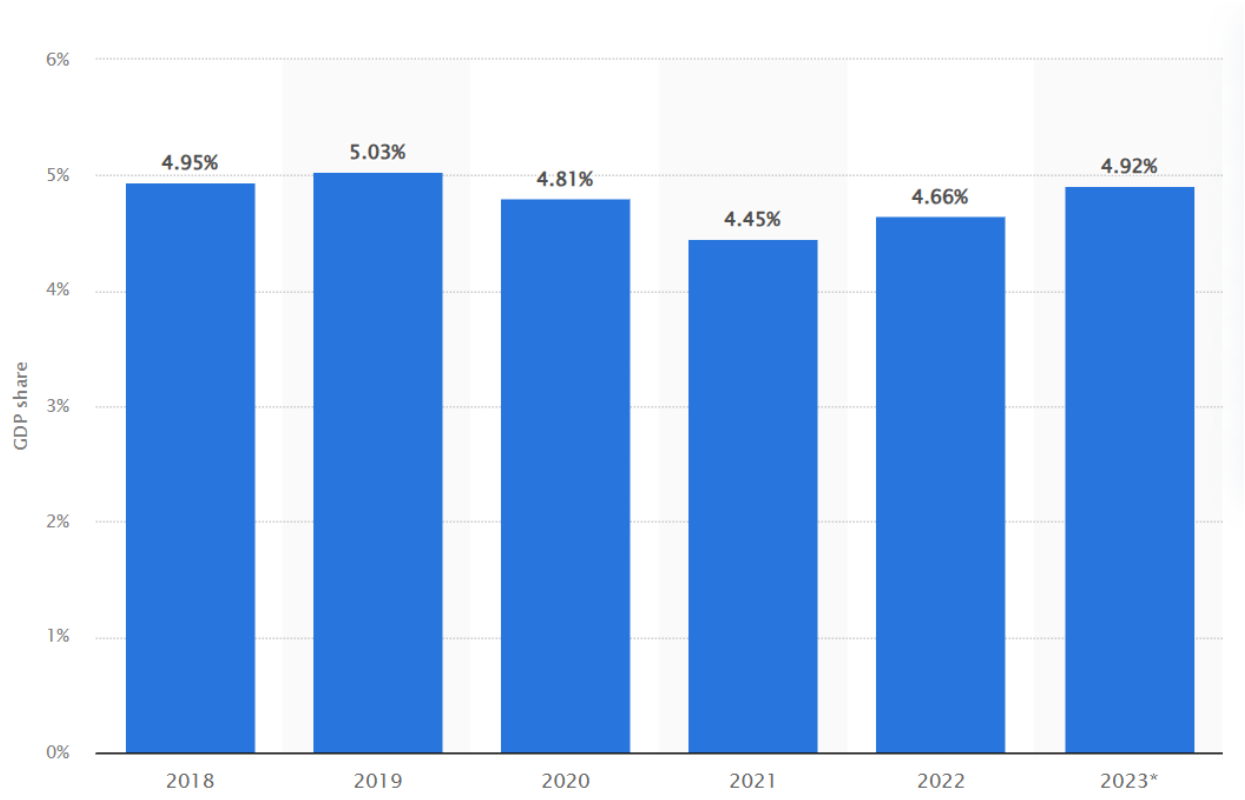
APPENDICES

Appendix 1: Warehousing and Storage services market in the period 2021-2033 (Straits Research, 2024)



Appendix 2: GDP contribution of the transportation and storage sector in Vietnam from 2018 to 2023 (Statista, 2024)



Appendix 3: Questions for Mr. Vin - International Business Manager @ Vinamilk

Questions	Answers
What is the estimated average monthly revenue generated by a warehouse when products are ordered from it?	Just estimated 200 billion VND
What is the estimated initial investment range for a smart warehouse at Vinamilk? **What is the storage capacity (in square meters) of Vinamilk's warehouse? What is the monthly overflow percentage?** **What is the annual range of slow-moving inventory (SLOB) in the warehouse?**	It would be better and more convenient if you guys should assume for the data, because they are relatively confidential.
What are the benefits of switching to a double-deep racking system in warehouse management, material handling, and product quality?	Implementing a double-deep racking system enhances warehouse efficiency by increasing storage density, reducing the number of aisles, and optimizing space utilization. In material handling, it streamlines operations by minimizing travel distances for forklifts, improving overall efficiency, though it requires specialized equipment like telescopic reach trucks. Regarding product quality, it reduces direct handling, minimizing the risk of damage while ensuring better inventory organization, particularly for FIFO-based stock rotation.
How does AS/RS help Vinamilk optimize warehouse operations in terms of labor and goods movement time?	AS/RS significantly enhances Vinamilk’s warehouse efficiency by reducing manual labor dependency and increasing automation in goods retrieval and storage. Automated systems minimize human errors, optimize storage space, and accelerate the movement of goods, leading to faster order fulfillment. Additionally, AS/RS reduces travel time for materials inside the warehouse, ensuring a more streamlined and responsive supply chain while lowering overall operational costs.
What key metrics or product data does AS/RS require for automation?	AS/RS relies on several critical data points to function effectively, including SKU characteristics (size, weight, storage requirements), inventory turnover rates, demand forecasting, and product shelf life for optimized stock rotation. Additionally, real-time tracking data, order frequency, and slotting optimization parameters help ensure that products are stored and retrieved efficiently, reducing unnecessary movements and improving overall warehouse performance.

Can you explain how WMS, RFID, and AS/RS are integrated to automate picking, storing, and moving goods in a warehouse?	WMS, RFID, and AS/RS work together to create a fully automated warehouse by enabling real-time inventory tracking, automated picking, and seamless goods movement. RFID tags provide instant product identification and location updates, while WMS processes this data to optimize storage and retrieval operations. AS/RS then executes precise movements based on WMS instructions, reducing manual intervention, improving accuracy, and enhancing overall efficiency in warehouse operations.
What are your thoughts on future warehouse trends? Which key metrics or criteria will be prioritized (e.g., sustainability, optimization, resource efficiency)?	Warehouse optimization is the top priority, focusing on JIT, inventory cost reduction, and response time improvement.