TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

OPTIMIZATION OF WAREHOUSE OPERATIONS BY LEAN TECHNIQUES AND AUTOMATION

LAOTEENUSTE OPTIMEERIMINE KULUSÄÄSTLIKU LÄHENEMISVIISI JA AUTOMATISEERIMISE ABIL

MASTER THESIS

Student: Eren Kösedağı

Student code: 177227 MARM

Supervisor: Kashif Mahmood, Engineer

Tallinn, 2020

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Department of Mechanical and Industrial Engineering

THESIS TASK

Student: Eren Kösedağı, 177227 MARM

Study programme: MARM, Msc. Industrial Engineering and Management

Main speciality: Industrial management

Supervisor(s): Engineer, Kashif Mahmood, PhD, +372 620 3253

Consultants: ……………………………………………………………………(name, position)

…………………………………………………………………… (company, phone, e-mail)

Thesis topic:

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Thesis main objectives:

1. To describe lean techniques and warehouse operations management
2. To conduct literature research and analysis for optimization of warehouse management
3. To implement lean techniques and RFID-based automation to warehouse operations

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Student: Eren Kösedağı .... “.......”...................202….a

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PREFACE

Optimization of warehouse operations is a key milestone for global supply chain companies by providing cost reduction, enhanced performance and productivity and moreover it is important to stay innovative in order to have sustainable market share and business. Therefore, the main target of this thesis is to analyse and understand traditional warehouse operations, afterwards define and eliminate the existing wastes by usage of suitable lean and automation techniques.

First of all, I would like to appreciate head of the department, Mr. Kristo Karjust for providing me this opportunity to study my master’s degree in Taltech, secondly, I am very grateful and thankful to my supervisor Mr. Kashif Mahmood for supporting and assisting me in every step of my thesis and thirdly, I would like to thank my family and my partner Ms. Triin Roos for supporting me whenever I need.

Keywords: Lean Warehousing, Warehouse Operations, Value Stream Mapping, RFID Automation

List of Abbreviations and Symbols

AIDC: Auto ID data capture

AIV: Absolute importance vector

AS/RS: Automated storage and retrieval system

ASN: Advanced shipping note

C/T: Cycle time

CI: Continuous improvement

CSM: Current state map

CSS: Customized specific solution

CV: Correlation vector

EPC: Electronic product codes

ERP: Enterprise resource planning

FSM: Future state map

GPS: Global positioning system

GSM: Global system for mobile communications

HF: High frequency

IOT: Internet of things

ISO: Organization for standardization

JIT: Just in time

KPI: Key performance indicator

LAN: Local area network

LF: Low frequency

MAS: Multi-agent system

MF: Microwave frequency

MV: Muda vector

NNVA: Necessary non-value added

NVA: Non-value added

ONS: Object name service

PML: Physical markup language

PO: Purchase order

PV: Priority vector

RFID: Radio-frequency identification

SKU: Stock keeping unit

SMED: Single minute exchange of dies

SPG: Stored packed goods

TPL: Third-party logistics

TPS: Toyota production system

TT: Takt time

UHF: Ultra-high frequency

UML: Unified modelling language

VA: Value added

VSM: Value stream mapping

WIP: Work in progress

WMS: Warehouse management system

WSN: Wireless sensor network

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1. INTRODUCTION

Lean management is one of the most important ideologies in order to eliminate unnecessary wastes and inefficient steps in an organization. It was invented by Toyota Motor Company during 1970's and has been using in many industries on daily basis.

Lean tools and techniques could be adjusted for any industry and can provide effective roadmap to how to evaluate, detect and remove non-value added activities in the organization and warehouse operations management is one of the important steps in global supply chain and the impact of the improvement of warehouse operations' yield is crucial for cost reduction and increase of productivity in a supply chain company. Moreover, together with lean management, automation of warehouse operations is also very effective technique. RFID and IOT based automation applications can optimize manual human touch steps easily.

In this thesis, firstly author conducts literature research from various resources in order to explain lean tools and techniques and warehouse operations management. During the research, author analyses warehouse operations and decides the most suitable lean optimization techniques for these operations. Afterwards, the author investigates and specifies feasible automation technique for the warehouse operations. In the final part, a Supply Distribution HUB analysis is conducted and the author monitors, assesses and prioritizes its current operations and try to optimize them by usage of value stream mapping lean technique, Genba-Shikumi method and RFID-based automation.

Optimization of warehouse operations is an important milestone in the supply chain for its lowered overall costs and enhanced efficiency and effectiveness. In this study, author aims to define and analyse the current inefficiencies and wastes and recommends improved processes by the help of lean techniques and RFID-based automation.

2. LITERATURE REVIEW

2.1 Introduction to lean management

Lean idea was born in Toyota Motor Company in Japan in order to develop a system which can increase the productivity at Toyota. It was inspired by Henry Ford's book "Today and Tomorrow". Ford's continuously moving assembly line structured the basis for Toyota Production System (TPS). After several trials, TPS was invented and improved between 1945 and 1970 and is still continuing today all around the world. The primary stressed idea of the system is to optimize the consumption of crucial resources that add no value to the final product [9].

Lean concept was first shown by Womack, Jones and Roos (1990) in order to identify the working techniques of the Japanese car manufacturers and especially the Toyota Production System (TPS). It was mainly focused on a specific approach for continuous process improvement. This approach includes elimination of waste and non-value added (NVA) activities and connects the all value added (VA) steps [1].

Lean principles indicate the value of the goods as considered by the customer and organizing the flow with the customer pull and endeavour for perfection through continuous improvement to eliminate waste by detecting the value added (VA) activities and optimizing the non-value added (NVA) steps. The reasons for the NVA steps could be overproduction, excess inventory, over processing, transportation and defects [4].

2.1.1 Key definitions of lean concept

The lean concept is to strive in value streams by removing wastes in order to decrease cost, generate capital, increase sales and stay competitive in a growing global market. The value stream is described as primary activities within the supply chain which is needed for design, order and ensure a certain product or value [9].

Lean focuses on removing wastes and utilizing processes that add value from the customer point of view. From the customer’s viewpoint, value is equal to anything that could be paid for relevant the service. Therefore, the removal of waste is the basic concept of lean management [9].

Seven forms of waste; there are seven significant wastes and they are firstly identified in TPS and reported by Womack and Jones [2].

It includes [1]:

1) Overproduction: it occurs when operations continue after they should have stopped. It causes an important excess of goods, goods which are produced too early and increased unnecessary inventory.

2) Waiting: it occurs when there are successive inactive steps in the process. Materials and components do not move properly and it means that time is not used in production line efficiently and leads to idle time.

3) Transportation: it is the movement of materials which are unnecessary, such as work in progress (WIP) goods being sent from one station to another. Transportation time should be minimized as it is non-value added activity and may causes handling unit damages in the facility.

4) Extra processing: they are operations such as rework, reprocessing and overproduction.

5) Inventory: it is stock that is not required to fulfil the current customer orders. It includes extra raw materials, WIP goods and the finished goods and is considered as waste because of extra cost which is spent on them.

6) Motion: it indicates the unnecessary steps taken by workers and equipment to suit inefficient layout. Motion takes time and adds no value to the goods.

7) Defects: it involves wastes which cause costs related to warranty and repairs. These types of finished goods do not meet the customers expectation and result bad reputation to the company.

Waste resources are connected to each other and removal of one source of waste could lead to either getting rid of or decline in another waste. The most important waste might be the inventory. Finished goods and work-in-process (WIP) parts stock do not add any value to a product hence elimination of it is needed. Once the stock level is decreased, invisible issues can appear and necessary action could be taken. There are several ways to decrease the stock level, one of them is to reduce production lot sizes. Decreasing lot sizes should be followed by setup time decrease in order to utilize the cost per unit. Other way to decrease the stock level is by striving to minimize machine downtime. It could be removed by stable maintenance schedule [9].

Transportation time is another important element of waste. Transferring parts from one side to another side of the building does not add any value to the finished goods. Therefore, it is crucial to minimize transportation time within the related process [9].

Lean ideology extends its limits to its employees, partners and suppliers in order to obtain value to customer. It strives to sort and coordinate the value adding processes for the finished goods or services through the value stream. It continuously checks all the steps to present a new product from order to delivery and from raw material to finished goods. In order to achieve it, complete examination is needed among the entire organization against the customer’s description of value and non-value added activities. Organizations have three different types of activities [9];

1) Value added activities (VA): it indicates all the activities that customer considers as valuable in a finished good or a service.

2) Necessary non-value added activities (NNVA): it shows that the activity does not add any value to finished good or service, but it is necessary phase under the current circumstances. It could be waste that hard to be removed suddenly and can be aimed for longer-term substitute.

3) Non-value added activities (NVA): it has zero value from the customer perspective and pure waste for the entire organization and should be targeted for sudden removal.

2.1.2 Key principles of lean concept

The concept of lean is defined and shown by five key principles [1]:

1) Specify value: find the value from the viewpoint of the end customer according to selected product with selected capabilities offered at a certain time.
2) Describe value streams: define the whole value stream for each product or product family and eliminate the waste.
3) Plan value flow: plan the remaining value generating steps flow.
4) Let the customers decide the value: organize and provide what the customers desire only when they want it.
5) Follow-up perfection: make an effort for perfection by constantly removing consecutive layers of waste.

Figure 1: Five Lean Principles [3]

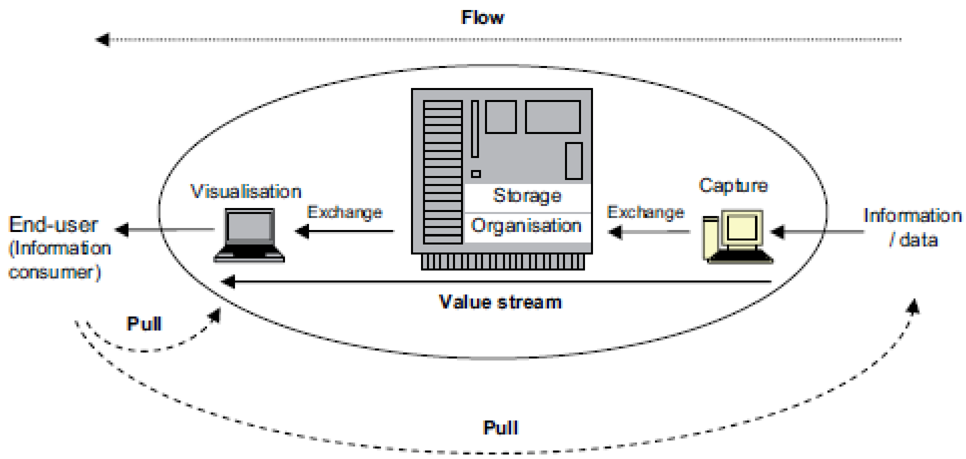

Figure 2: The value-flow model as applied to information management [1]

Lean philosophy depends on the identification and elimination of waste which should be understood in order to efficiently spot and apply the different lean techniques. These techniques are such as Kaizen, value stream mapping and 5S to remove waste and make improvements in needed areas [1].

2.2 Lean tools and techniques

The best effort of the manufacturing systems could be succeeded through successful implementation of the lean tools. Majority of the analyses on lean tools focuses on two techniques or combination of three techniques. For well-done implementation of lean, combination of several lean tools is needed [4].

Table 1: Lean principles with corresponding practices and tools [7]

Principles	Practices	Techniques
Specify value from the end customer view	• Source information on customer need • Value chain analysis and end customer focus	• Customer involvement • Value Stream Mapping (VSM)
Map value to expose and eliminate waste	• Value chain analysis • Waste reduction	• VSM • JIT, TPM, small lot size, 5S, SMED
Establish flow	• System organization • Strong and effective relationship • Waste reduction	• 5S, Cellular manufacturing • Supplier integration • JIT, TPM, small lot size, 5S, SMED
Let the customer pull the products	• Production of exact customer needs only when needed • Strong and effective relationship	• JIT, Pull/Kanban system • Supplier integration
Strive for perfection	• Problem search • Problem solving	• VSM, 5Whys, employee involvement • Training,5Whys, employee involvement

2.2.1 Value stream mapping (VSM)

Value stream is identified as the combination of all the particular actions required to bring a particular product through the three significant management tasks of any business: problem solving, information management and physical transformation. Value stream mapping considers material and information flows altogether and coordinates the processes performed by manufacturers and suppliers to deliver goods to customers. Firstly, a current state map is drawn from the identified wastes and its findings for the chance of implementing different lean techniques. Secondly, drawing a future state map based on development plan is needed. VSM shows the lead time, waiting time, inventory, process time etc. from which we can easily see bottleneck cycle time against Takt time [4].

VSM can become the main factor for improving a development plan by showing a whole picture of the included processes. It could be used to create a vision of what the wanted future state condition should look like. The VSM process mainly has four steps which are preparation, current state mapping, future state mapping and improvement plan [6].

Current state map (CSM): it is the first step that includes in the selection of a product family as the goal for the development and the creation for the chosen product value stream. It should be based on the data which is collected directly on the shop floor and should be specified with usage of CSM icons below [10].

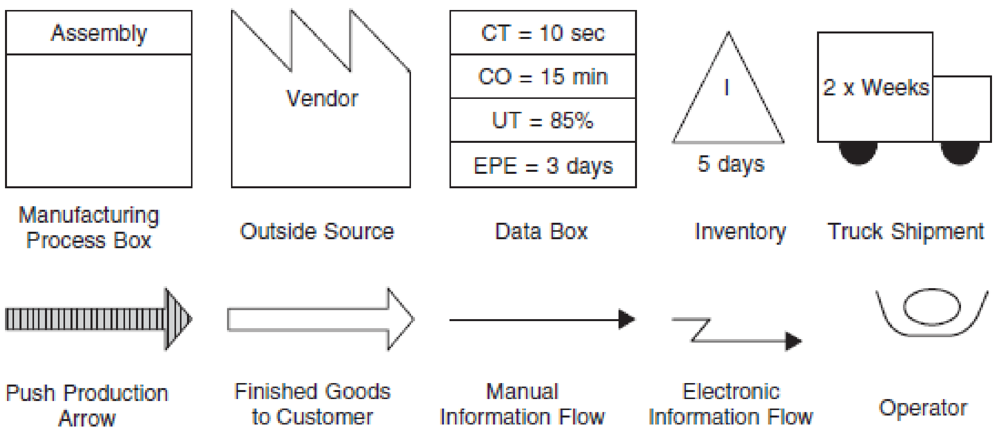

Figure 3: Current state map icons [10]

Future state map (FSM): after the CSM, FSM is designed to show the ideal production process without removal of wastes and it should be created the usage of FSM icons below [10].

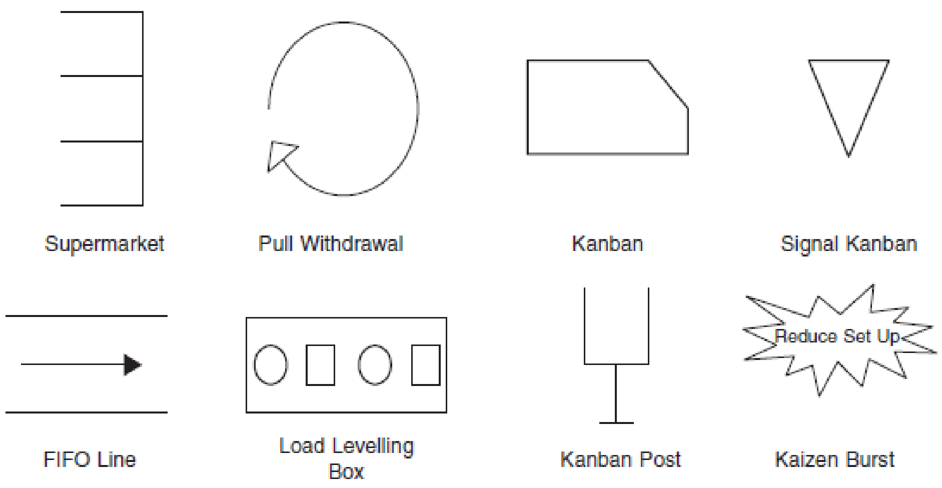

Figure 4: Future state map icons [10]

Improved VSM process: it is based on the set of seven steps that are shown below [10]:

- Selection of the product family
- Identification of machine sharing
- Identification of the main value stream
- Mapping of the critical path
- Identification and analysis of wastes
- Mapping the future state for the critical path
- Identification of the new critical path

2.2.2 Takt time

Takt time refers to the lead time of component must be manufactured to meet customers' demand. It is connected to monthly production demand, if the demand rises Takt time decreases, if the demand decreases Takt time rises which shows the outcome gap increases or decreases [4].

Takt time indicates that how often a unit should be manufactured based on customer demand. It is calculated by the formula below [9]:

$$Takt\ time\ (TT) = \frac{\text{Available work time per day}}{\text{Customer demand per day}}$$

2.2.3 Bottleneck process

It is defined by deciding the maximum cycle time (C/T) in the entire process therefore the production capacity is decided by the bottleneck cycle time. If bottleneck C/T < Takt time, then customer demand will be met, if bottleneck C/T > Takt time, in this case customer demand will not be met. From the past data, future demand can be forecasted and the Takt time is defined for the production system. With the defined Takt time, the bottleneck process could be identified from Value stream mapping (VSM), interval between capacity and demand is calculated and based on the interval, lean plan can be executed [4].

2.2.4 Single minute exchange of dies (SMED)

It is based on the changeover (C/O) time into internal and external setup time. The activities which can stop machines in the production line are called internal setup time and on the contrary the activities which can stop the production without stopping the machines are called external setup time. Based on conducted analysis internal setup time is transformed to external setup and internal setup time is regulated by changeover time to single minute. In the end the sustainability of setup time developments is succeeded by standardization [5].

2.2.5 Kanban

It is a subsystem of the lean production system which was built to control inventory levels and the production. It has a card signal system that specifies when and where more material is needed for the better internally and externally production flow. Kanban system gives a mixed model production with optimal inventory level which comes up with result in shorter lead time in product delivery and efficient utilization of sources such as machine, man etc. [4].

2.2.6 Heijunka - production levelling

Fluctuation in customer demand leads to variability in manufacturing. To be able to overcome the fluctuation, customer demand should be levelled. This levelling will avoid any machine and man idle times, breakdowns and quality problems. It is a kind of production time plan and sequence in order to produce products/parts in smaller batches [4].

2.2.7 Kaizen – continuous improvement

It helps us to receive ideas and proposals from every class of an organization for continuous improvement (CI) of processes in order to eliminate wastes. Kaizen tools are required to specify the root cause of inefficiencies and implement solutions to remove these wastes. The management of company has to develop stable personnel and believe their dedication for quality. It has competitive advantage for a company to have sustainable position in the market and its achievement comes from employee perception, teamwork, training and the leader engagement [4].

2.2.8 Just in time (JIT)

It is the technique for producing and providing the raw material to the production site when it is needed by customer. It is an efficient inventory strategy to decrease the waste and excess stock by receiving the material when it is needed for the production which also decreases the inventory costs.

JIT is significance tool to design the external activities of a company such as procurement and distribution. It could be considered as comprising three elements: JIT production, JIT distribution and JIT procurement. It eliminates unnecessary work-in-process units and reduce the waste of storage area in warehouse [9].

2.2.9 5S

It is workplace management strategy which utilizes the work environment, human factor and shop floor operations' yield. 5S represents the 5 elements of the technique, which are sorting, set in order, shine, standardize and sustain. It also helps to eliminate the loss of time and waste movements [8].

2.3 Warehouse operations management

Warehousing occupies up to 5% of the cost of sales of a company and with nowadays' competitive global market, organizations are indicating return on assets and therefore optimizing the warehousing costs became a primary business purpose. Everyday many companies start to automate their warehouse operations to succeed cost effective and healthy inventory turnover. Various elements could affect the warehouse tasks such as layout of the warehouse, product handling method, picking and packing system, product types, demand fluctuation and space requirements [11].

The warehouses with many order lines and high amount of stock keeping units (SKUs) could be best supported by customized management systems. It is obviously hard to update all daily operations of the inventory, location of the equipment and SKUs by using manual-based storehouse management systems. Implementation of WMS will ensure reduction in employee costs and increase the customer service level by decreasing cycle times of the operations. WMS will provide both unnecessary stock level reduction and optimization of the storage capacity [11].

Typical warehouse operations comprise receiving, storing, replenishment, order picking, sorting, packing, cross-docking and shipping processes [11].

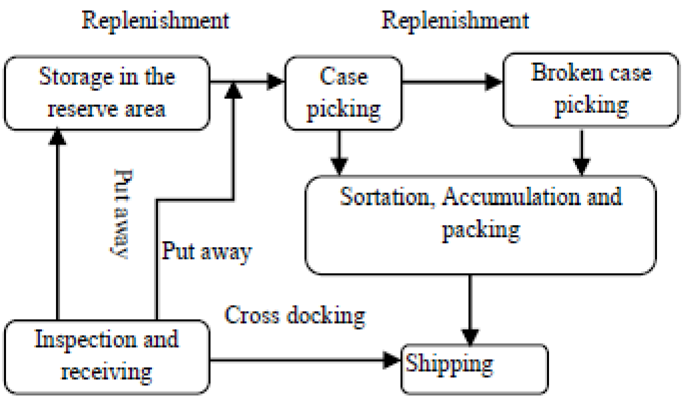

Figure 5: Typical warehouse processes [11]

2.3.1 Warehouse management systems

Warehouse management system (WMS) primarily targets to check the motion and storage of the goods within the warehouse and process-oriented transactions; covering receiving, shipping, storing and picking. WMS is a database-based computer application is to develop the efficiency of the storehouse by having the precise inventory by recording the storehouse transactions. The systems also conduct and optimize inventory based on real-time data about the status of warehouse utilization. It usually utilizes Auto ID Data Capture (AIDC) technology, such as wireless LANs (Local area network), barcode scanners, mobile computers and radio-frequency identification (RFID) to adequately check the flow of the goods. When the data is updated, there can be batch sync or real-time wireless flow to the central database and it can provide reports regarding the latest status of the products in the storehouse [11].

The main function of a WMS is to get data from the upper level control system and convert it for daily operations. Prevalent goal is to provide a situation where storehouse workers never have to reuse data because it already exists in one system. Warehouse control system is often interface that is used to control processes, workers and equipment on operations [11].

There are three types of WMSs [11];

1) Basic WMS: it is only for supporting stock and the location control and primarily used to record the information.

2) Advanced WMS: it is able to plan resources and operations to sync the flow of products in the storehouse and the main focus on throughput, inventory and capacity check.

3) Complex WMS: it provides optimization of group of warehouses. Data is available regarding the each good's location and destination.

Warehouse system could be customized by the goods (SKUs) that have to be placed and picked, the processes to place and pick these goods and its requested orders for delivery. Warehouse complexity is increased by the number of stored SKUs, order lines and operations. The majority of storehouse work is in order picking. Task complexity can be separated into three points [12];

- The number of different units (SKUs) are stored in the warehouse,
- The number of separate processes are conducted by the warehouse,
- The number of order lines exist in the warehouse per day.

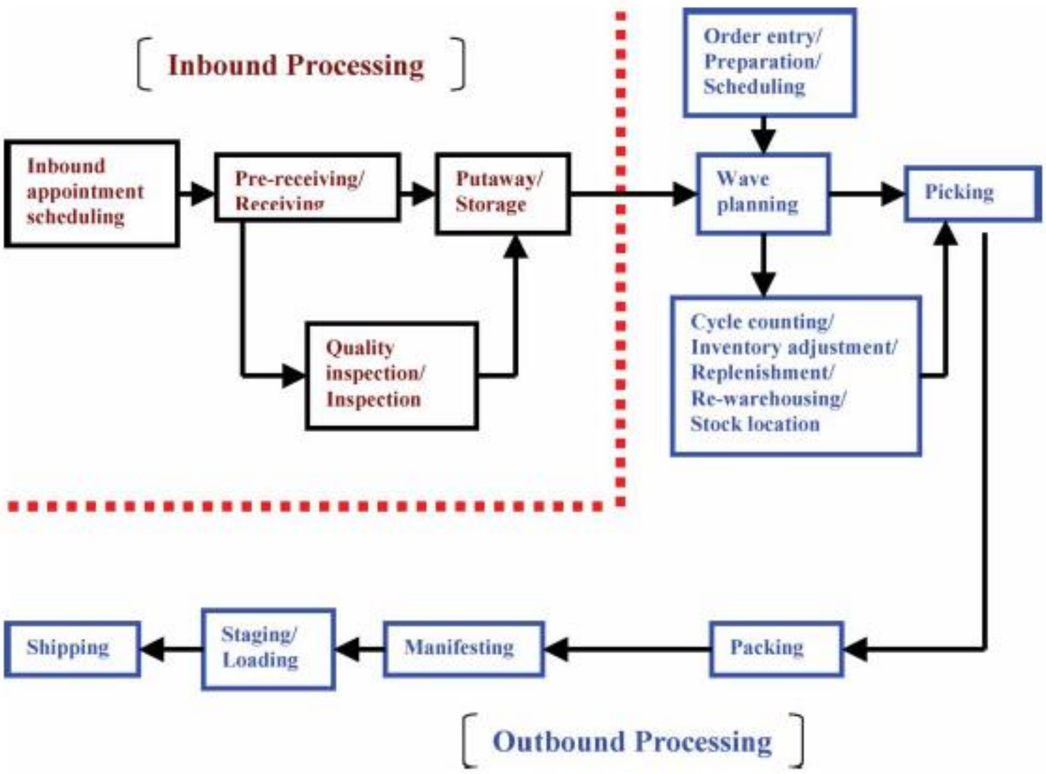

Figure 6: The schematic diagram of WMS functionalities [13]

The most important criteria of WMS are system integration, ease of use, compatibility with software, supporting different functionalities and customization. The ease of use is the most significant for choosing a particular WMS software [13].

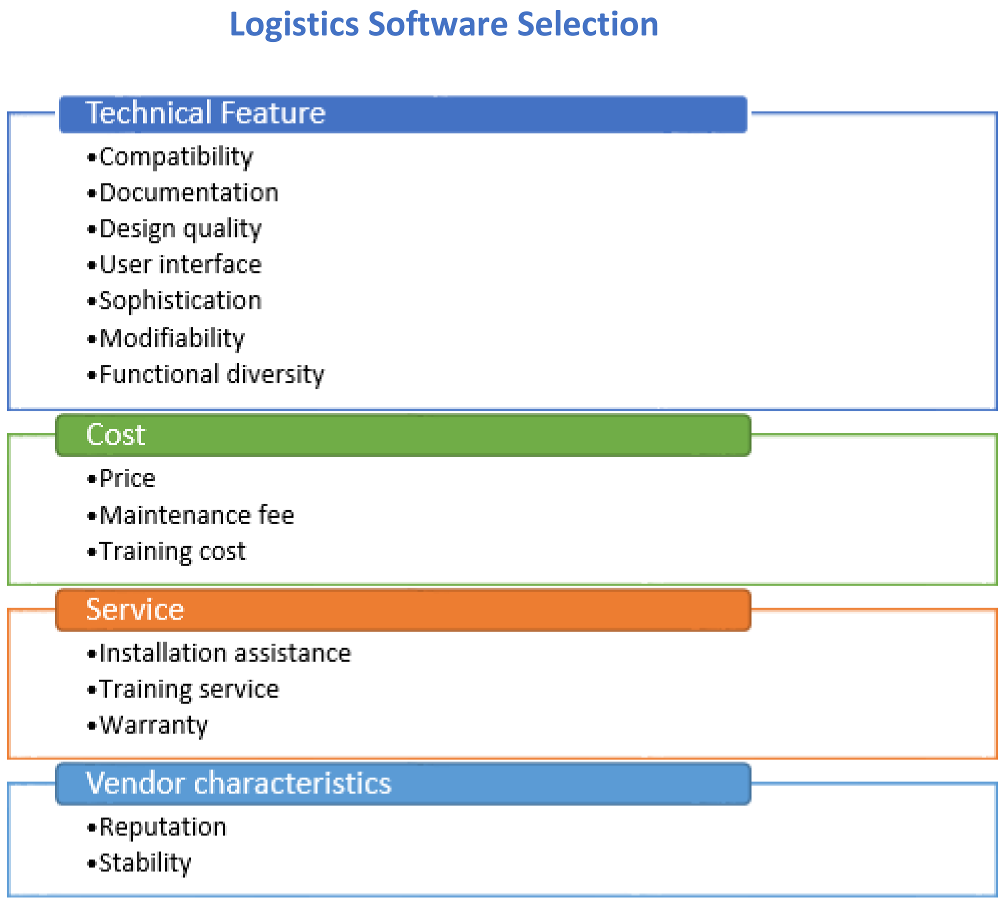

Figure 7: The generic criteria for selecting the WMS [13]

2.3.2 Warehouse performance measurement

Warehouse measurement techniques are important for managers by providing potential problems and opportunities for developments. If warehouses plan to be part of value-added supply chain then their performance should be measured by relevant performance metrics. These metrics splits into three groups which covers warehouse productivity, stock management and order fulfilment [11].

Table 2: Performance metrics of warehouse [11]

Category	Measure	Definition
Order fulfillment	On time delivery	Orders delivered on time per customer requested date
	Order fill rate	Orders filled completely on first shipment
	Order accuracy	Order picked, packed and shipped perfectly
	Line accuracy	Lines picked, packed and shipped perfectly
	Order cycle time	Time from order placement to shipment
	Perfect order completion	Orders delivered without changes, damage or invoice errors
Inventory management measures	Inventory accuracy	Actual inventory quantity to system-reported quantity
	Damaged inventory	Damage measure as a % of inventory value
	Storage utilization	Occupied space (square footage) as a % of storage capacity (square footage)
	Dock to stock time	Avg. time from carrier arrival until product is available for order picking
	Inventory visibility	Time from physical receipt to customer service notice of availability
Warehouse productivity	Orders per hour	Avg. number of orders picked and packed per person/hour
	Lines per hour	Avg. number of order lines picked and packed per person/hour
	Items per hour	Avg. number of orders items picked and packed per person/hour
	Cost per order	Total warehousing costs Fixed: space, utilities and depreciation Variable: labor / supplies
	Cost as a % of sales	Total warehousing cost as a percent of total company sales

2.3.3 Warehouse layout optimization

Order execution performance in warehouses is a significant step in the order management period in a supply chain. Due to the competition for higher market share and customer satisfaction, on-time customer deliveries are very important for the success or failure of a company. Therefore, there is an encouragement for companies to have products available at well-designed and efficiently managed warehouses. Stock transportation and warehousing costs occupy large part of the total logistics costs. Any investment and development on warehouses can reduce overall logistics cost and improve customer service level in the supply chain [14].

The real order execution process begins the moment that order is placed by customer is forwarded to the relevant warehouse and it is processed by WMS and released to the shop floor for order picking. Among the many activities in warehouses, order picking has the most important effect on the customer order fulfilment hence the warehouse design should be carefully chosen for the effective and efficient order picking process [14].

A layout of the warehouse must be decided such that each system can succeed the wanted performance. In the figure below, the layout of the area includes number of parallel pick aisles and cross-aisles are located at the front and back of the storehouse and are used to split aisles into sub-aisles. A set of parallel sub-aisles create a block. Incoming goods need to have a storage location specified and workers need to receive location instructions to complete relevant customer order. The main idea of ABC storage technique is to allocate the most commonly required goods to the best accessible locations. The most demanding fast-moving goods indicate A-items and next fast-moving goods are called B-items and the lowest demanded goods are specified as C-items. Each class is defined different part of the order-picking area. There are several ABC storage policies, such as [14];

- Within-aisle storage: it suggests that whole aisles are reserved to one category; A, B or C.
- Across-aisle storage: it suggests the allocation of an equal amount of A, B and C locations in each aisle.
- Nearest sub-aisle storage: it offers the allocation of A-items to the closest to the depot and C items to the farthest from the depot but allocates all sub-aisles to a specific category.
- Nearest location storage: it allocates all A-items closest to the depot and all C-items farthest from the depot without any other restrictions.

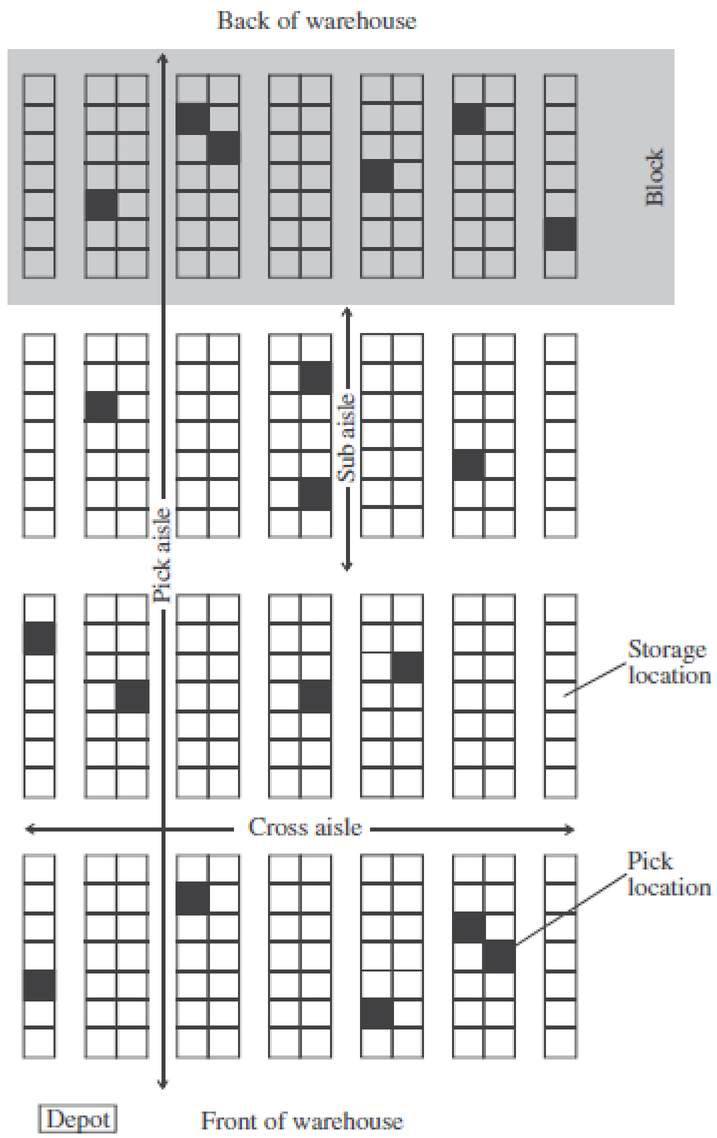

Figure 8: Illustration of a typical order-picking area [14]

Warehouse design includes five main decisions such as [15];

- To decide the overall warehouse structure,
- To decide the sizing and dimensioning of the warehouse with its departments,
- To determine elaborative layout within each department,
- To select desired warehouse equipment,
- To select operational strategy.

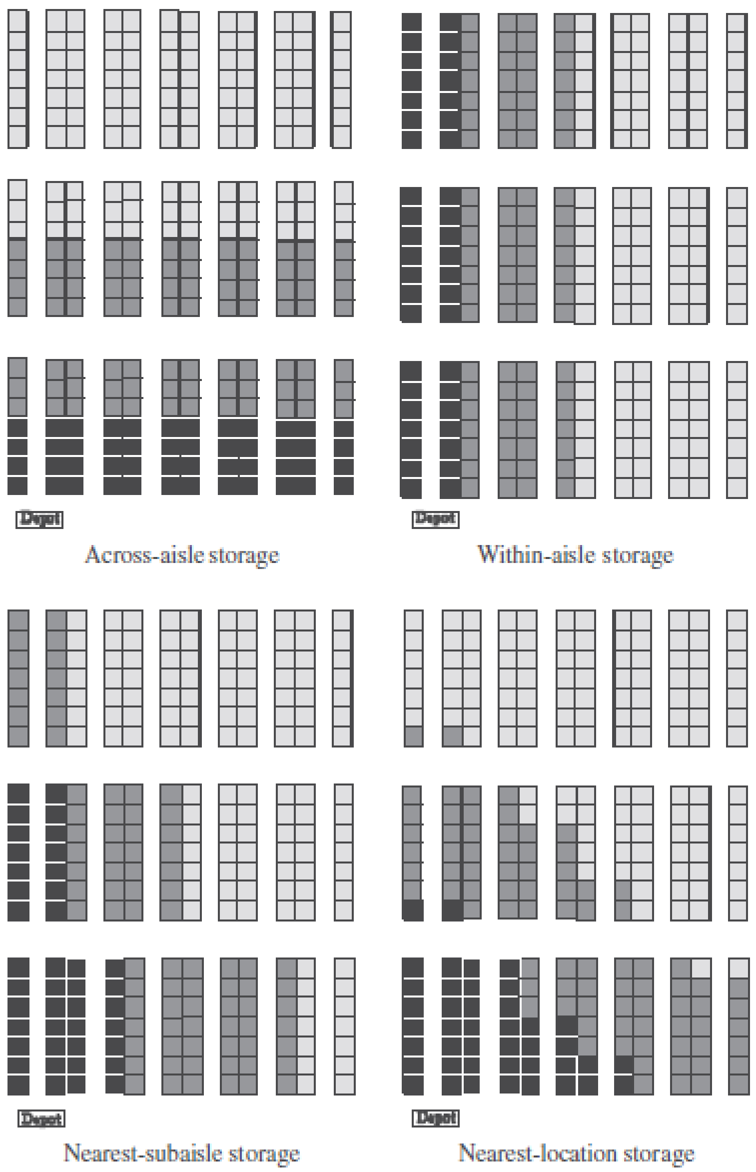

Figure 9: Example of four ABC storage assignment policies [14]

The overall structure of a warehouse defines the functional departments (e.g. number of storage departments, order assembly techniques, used technologies). In this phase of design, problems are to meet storage requirements and cost reduction which could be optimized value of investment and future management costs [15].

Sizing and dimensioning of the warehouse has an impact on stock holding, material handling and replenishment costs. It defines the storage capacity of the storehouse and there are two ways in modelling; firstly stock levels can be decided externally and warehouse will not have direct control regarding the arrival of future shipments and their quantities (e.g. third-party warehouses) and secondly the warehouse can directly check the stock policy (e.g. wholesale distributor) [15].

The storage terms below help to decide the correct layout for the warehouses [15];

- Pallet block-stacking model: pallet placement angle with regards to the aisle, storehouse lane depth, stack height, number of lanes for each depth,
- Storehouse department layout: number of aisles, door location, length and width of aisles,
- Automated storage and retrieval system (AS/RS) configuration: number of cranes, positioning and size of storage racks.

The warehouse equipment selection indicates the level of automation and the employment of material handling and the storage type. It can affect overall storehouse investment and performance. There are two main issues for the selection of equipment; identification of equipment alternatives which are suitable for storage/retrieval requirements and how to decide among the suitable alternatives [15].

Table 3: Description of warehouse design and operation problems [16]

Design and operation problems			Decisions
Warehouse design	Overall structure		• Material flow • Department identification • Relative location of departments
	Sizing and dimensioning		• Size of the warehouse • Size and dimension of departments
	Department layout		• Pallet block-stacking pattern (for pallet storage) • Aisle orientation • Number, length, and width of aisles • Door locations
	Equipment selection		• Level of automation • Storage equipment selection • Material handling equipment selection (order picking, sorting)
	Operation strategy		• Storage strategy selection (e.g., random vs. dedicated) • Order picking method selection
Warehouse operation	Receiving and shipping		• Truck-dock assignment • Order-truck assignment • Truck dispatch schedule
	Storage	SKU-department assignment	• Assignment of items to different warehouse departments • Space allocation
		Zoning	• Assignment of SKUs to zones • Assignment of pickers to zones
		Storage location assignment	• Storage location assignment • Specification of storage classes (for class-based storage)
	Order picking	Batching	• Batch size • Order-batch assignment
		Routing and sequencing	• Routing and sequencing of order picking tours • Dwell point selection (for AS/RS)
		Sorting	• Order-lane assignment

2.3.4 Inbound and outbound operations

Many companies have accepted postponement strategy in order to be more responsive to customers and it indicates different value-adding activities (e.g. order assembly, kitting, package customization) that happen in the warehouse and they have to be planned and integrated in order-picking process. The main warehouse activities are receiving, transferring, putting away, order picking, cross-docking, sorting and shipping [17].

Warehouses mainly receive bulk shipments and redistribute it in smaller quantities. When customer orders arrive, employees retrieve and sort SKUs and ship it out. We can split warehouse operations into two groups below [18]:

- Inbound processes;
  - Receiving / unloading goods
  - Product data / quality / quantity check
  - Storage of goods
- Outbound processes;
  - Order picking operations
  - Cross-docking activities
  - Packing and shipping

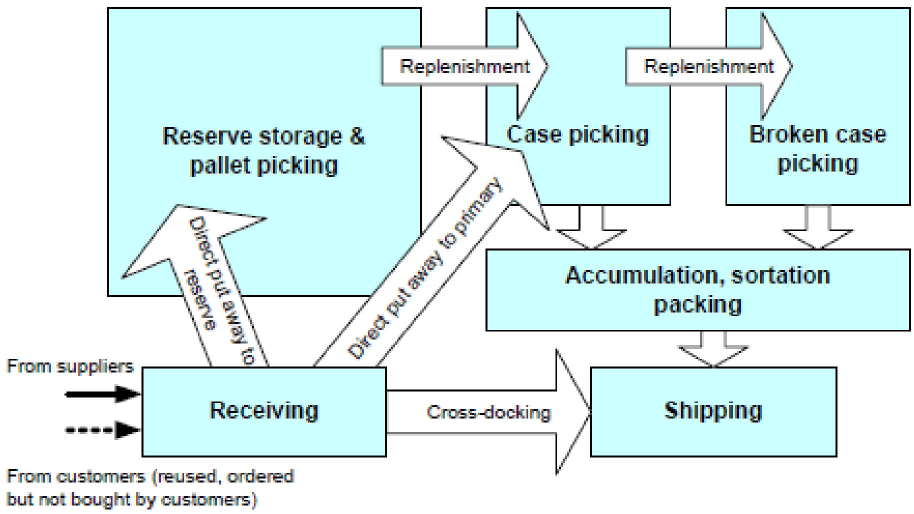

Figure 10: Typical warehouse functions and flows [17]

First activity starts with receiving, it covers the unloading of goods from the logistics carrier, updating the stock data, inspection for product information, quality and quantity. Afterwards warehouse workers transfer the incoming goods to storage locations. The order picking is the main activity and it includes the process of picking the necessary amount of the selected goods for its customer orders. After that sortation of the picked orders is the next activity, they should be grouped by customer orders. Cross-docking could be performed when the picked goods are directly transferred to the shipment area. Picking activity ends with packing and storing the packed goods to the shipment zone [17].

Order picking comprise the process of grouping and planning the customer orders, designating stock to order lines, sending orders to the floor, picking the units from its storage location and delivery of the picked units. Each customer order line includes unique product or SKU. Majority of warehouses have human power for order picking process and these order pickers either walk or drive forklift through the aisles to take the goods. Over 80% of all order picking activities involve in low-level, employing humans picking strategy. The remaining, less than 20% includes high-level picking AS/RS systems [17].

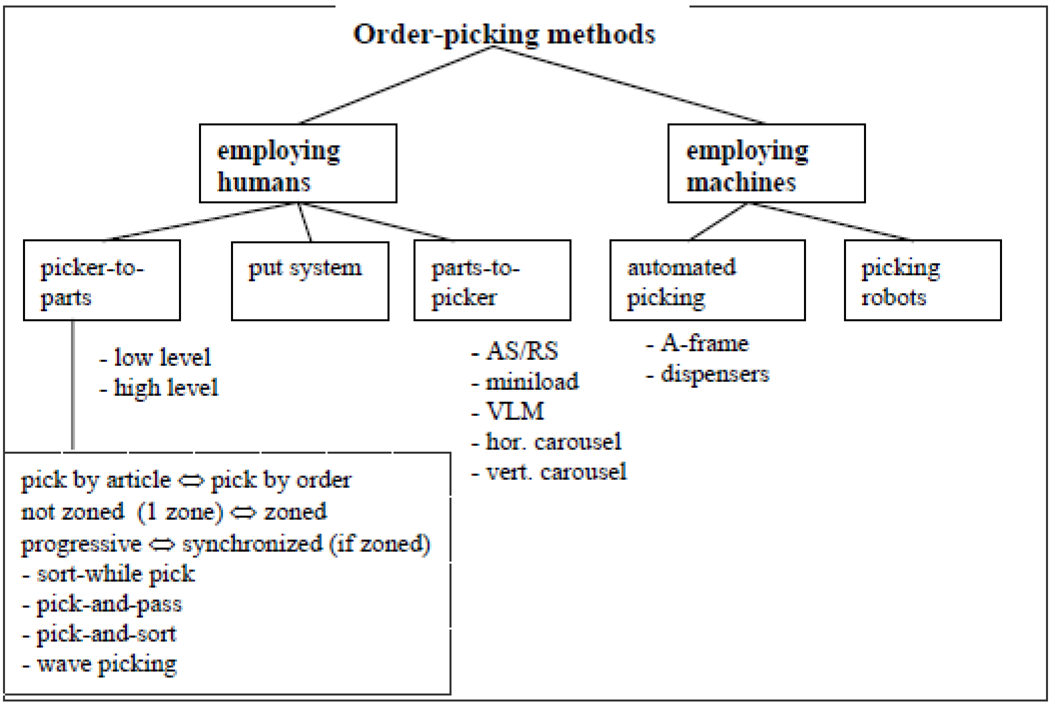

Figure 11: Classification of order-picking systems [17]

Order-picking activity occupies approximately 55% of the all warehouse operating costs and its breakdown can be shown below [18];

Table 4: Order picking time breakdown [18]

Activity	% Order-picking time
Traveling	55%
Searching	15%
Extracting	10%
Paperwork and other activities	20%

The operational and organizational strategies mainly include five elements; storage, routing, zoning, batching and order release mode. In the figure below, the farther a system is placed from the origin, the harder the system is to plan and control [17].

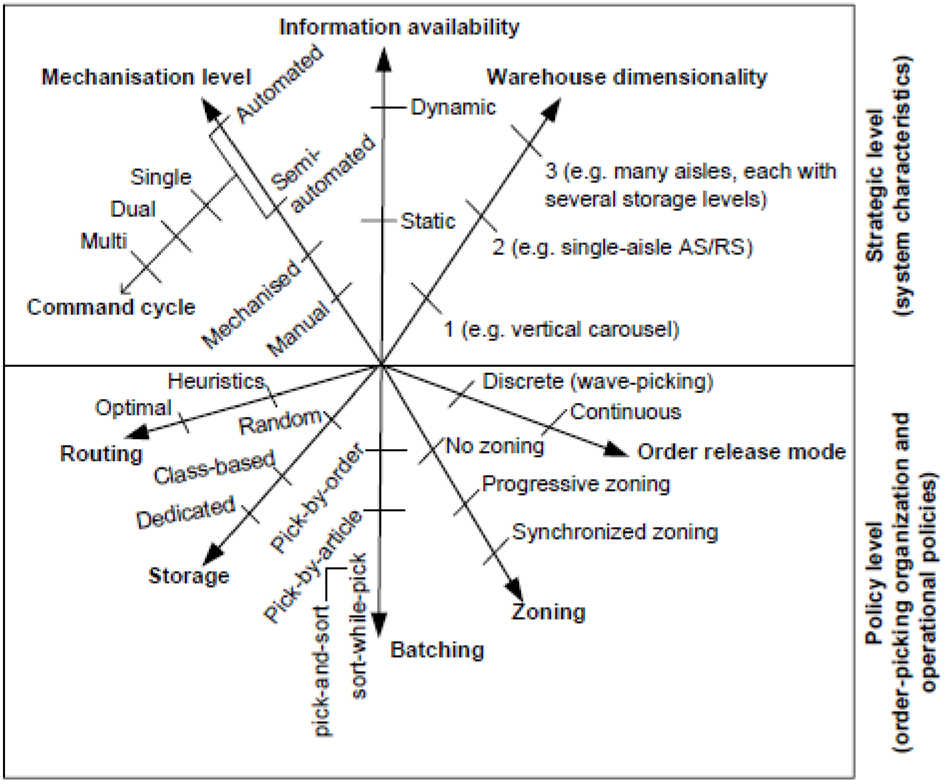

Figure 12: Complexity of order-picking systems [17]

Common decisions for design and control of order picking systems are either on operational or tactical level [17].

- To assign orders to pick batches into work zones (batching and zoning, tactical and operational level)
- To designate units to storage locations (storage assignment, tactical and operational level)
- To design and dimension the layout of the warehouse (tactical level)
- To decide order picking route (routing, operational level)
- To align the picked goods per order and grouping them (order sortation, operational level)

There are five ways to assign units to the storage locations [17];

1) Random storage: it assigns the incoming goods to the randomly selected available empty locations. It allows high space utilization on the increased transportation expense.

2) Closest open location storage: it allows order pickers to decide the location for storage by themselves. The worker will choose the first available location to store the goods. It will cause to fill the closest racks to the depot and slowly replenish the further racks in the back.

3) Dedicated storage: if the products are stored to the fixed locations only, then it is called as dedicated storage. It can have disadvantage on the reserved locations for the out of stock products. However, in this storage method, order pickers can become familiar with unit locations. It can also assist on storage of different weight goods; heavy goods can be stored on the bottom of the pallet and the light ones on the top.

4) Full-turnover storage: it allows a distribution strategy for the storage area based on product turnover rate. Units with the highest sales are located to the most accessible racks, mostly very close to depot. With the same logic, slow moving units are located further back of the storehouse.

5) Class-based storage: it is the idea of grouping goods into classes when fast moving class comprises only about 15% of the goods stored but contributes 85% of the turnover. Each class is assigned to specific areas and the storage within these areas is random. Fast moving goods are decided as A-items and next fastest moving goods are called B-items and it continues similarly.

Methods below were created for single-block warehouses, but they could be used for multiple-block warehouses with some changes. There are six routing methods designed for single-block warehouses; s-shape, return, mid-point, largest gap, combined and optimal method [17].

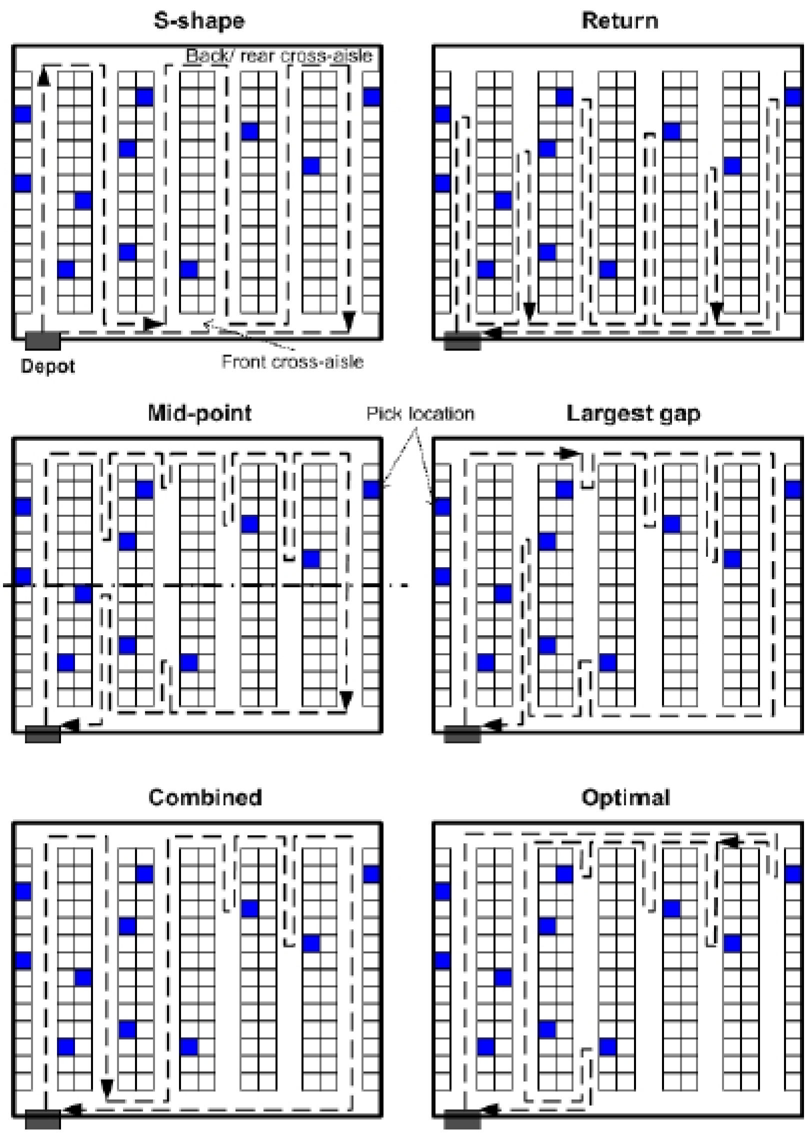

Figure 13: Routing methods for a single-block warehouse [17]

Cross-docking: after receiving the requested item in warehouse, it can directly be sent to shipping zone without storage for its customer. Therefore cross-dock items can be moved quickly through the warehouse and management can save some costs [18].

Batching and zoning: batching decides that which orders are released together therefore it decreases the average transportation time per order by sharing same picking route. Zoning divides the pick are into sub-zones, one or few pickers are assigned to these sub-zones and it provides travel time reduction in the warehouse due to the familiarity of the pickers with the zones and less warehouse congestion [19].

Order accumulation and sorting (A/S): after batching the products, splitting batches and consolidation of it could be needed for some customers and these processes are mainly described as accumulation/sorting. Order pickers follow the pre-defined routes to pick the goods and deliver it to the transportation conveyor and the goods are transferred to the sorter. The goods which are in circulation conveyor, go to the defined shipping lane in case of the preceding order is completed for that shipping lane, if not it re-circulates around the circulation conveyor [17].

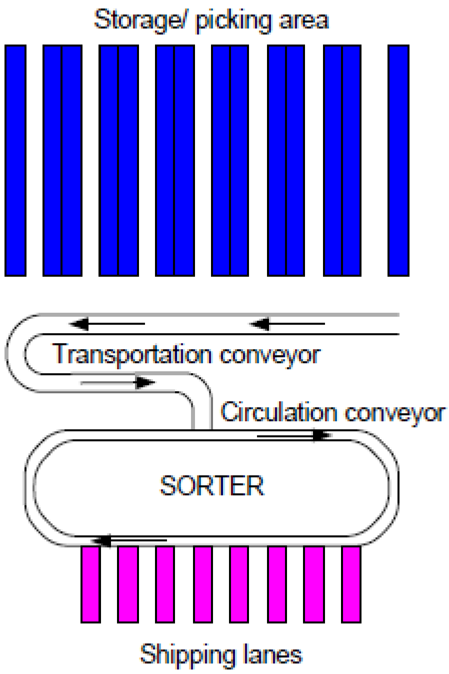

Figure 14: A typical accumulation/sorting system [17]

2.4 Optimization of warehouse management

Logistics gains value on production due to elements of rapid market changes, high productivity, competition and reduction of time-to-market. Therefore new series of analysis on warehousing systems obtained interest on its design, planning and the control. Warehouses can be identified as product handling station for receiving, storage, order-picking, clustering and shipping of units and it could be categorized by three types of warehouses: contract, production and distribution warehouses. Decisive role of optimization of warehouse management is aimed internal logistics, material and information flow for profit maximation. With the increased customer demand and global competition, many industrial manufacturers should continuously observe and improve their warehouse processes. Moreover many customers require to receive the desired goods on time with the lowest price and higher quality. In order to meet the manufacturer and customer requirements, warehouse operations have to be monitored, optimized and made cost-efficient by eliminating the possible wastes [21].

2.4.1 Lean implementation to warehouse operations

Many companies applied lean techniques to develop their yield and competitiveness over the past decades. Starting with Toyota Production System (TPS), lean management allows production and warehouse to connect different tools to remove waste and add value by improving the quality, decreasing the cost, stock level, equipment downtime and the lead time [20].

Value stream mapping is being used to implement lean procedure by mapping a productive process and defining waste for development. Current state map should be created by checking the actual process and identifying the waste and bottlenecks among the routine works. After elimination of waste and inefficiency, a future state map should be built and improved. With the adaptation of new lean methods into warehouse systems, we can tighten stock control and decrease response times and provide continuous improvement processes [20].

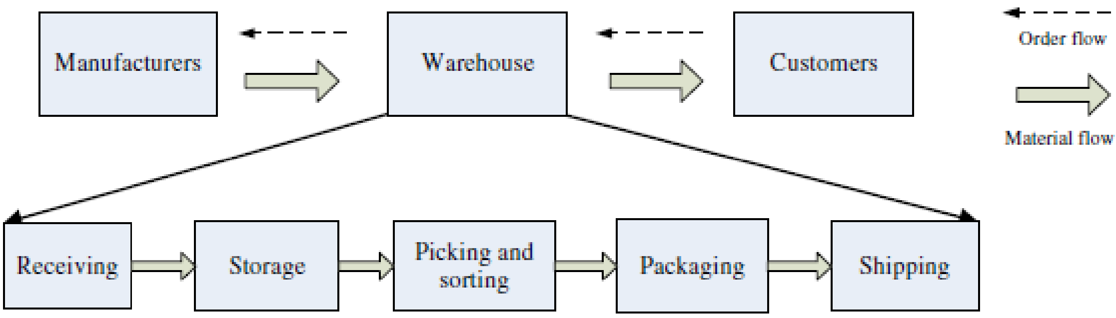

Figure 15: Example of basic current process of the warehouse operations [20]

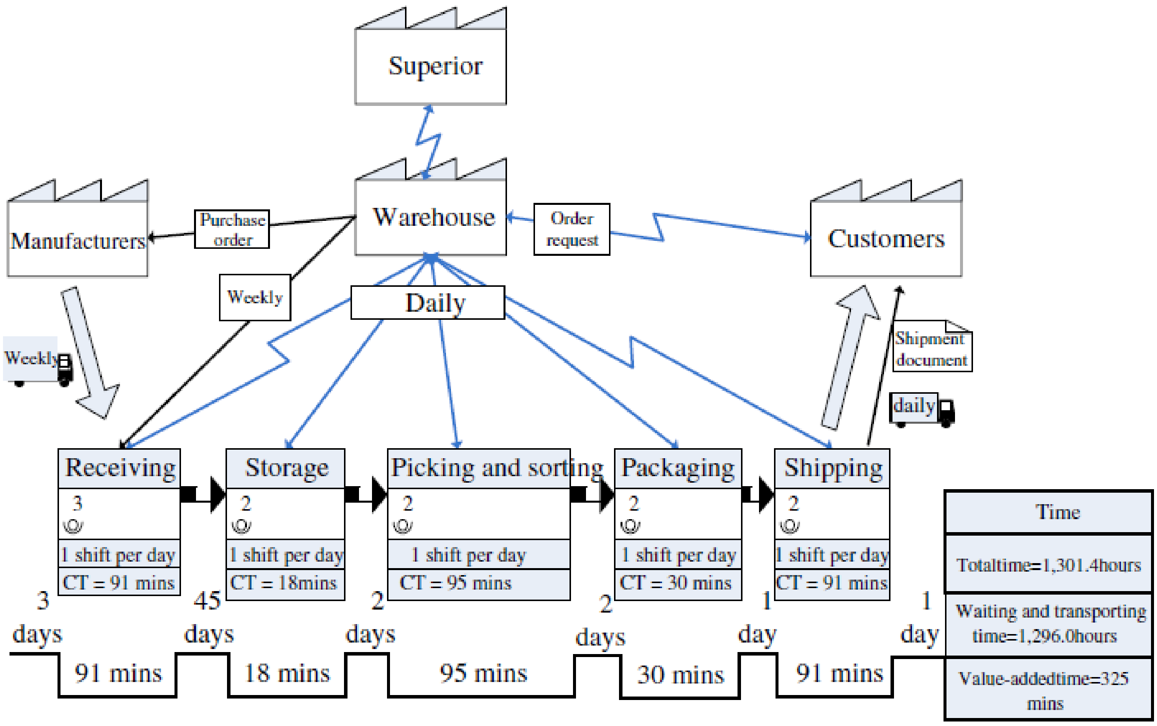

Figure 16: Example of basic current state map of the warehouse operations [20]

In the figure above, VSM technique analysis is used to create a current state mapping with material, information and time flow in order to define warehouse operations' issues and bottlenecks. Some operations are neither necessary or nor value-added and typical TPS seven wastes tool can be conducted in the warehouse. In this example two wastes are identified; waiting and unnecessary motion.

The current state value stream map indicates the number of opportunities to decrease lead time of the operations in the warehouse, such as [22];

- Decrease in material handling time in putaway, picking and packing operations,
- Removal of reliability problems on metal detection machines,
- Reduction in lorry loading time,
- Reduction in stock location and aging checking time.

The aim of using the current state map is to create future state map in order to make the flow continuous and to remove as much waste as possible. Hence the lead time is reduced as much as possible via implementing the lean tools. The future state map flow is created around the takt time or how often a unit should be finished to meet customer expectation. Takt time basically calculates whole working time divided by the rate of customer demand. Once the future state map is ready, improvement plan must be created to change the current state into future state. Priority list should be prepared and the improvement plan should be designed to finish the majority of the tasks within six months [22].

Unified Modelling Language (UML)

Unified modelling tool is integration of the VSM lean manufacturing tool and the Genba Shikumi philosophy. Genba is a philosophy that suggests managers to spend their time on production floor rather than their office. UML method is designed to define and analyse the warehouse activities. VSM shows the location of waste and Genba philosophy can rank the analysed waste and decides the most important ones to remove. Its scope is accepted by reapplying the VSM and UML tools in order to reengineer processes. This iterative method is part of kaizen, the continuous improvement method to reduce inefficiencies [21].

Figure 17: A scheme of the proposed approach for warehouse analysis and optimization [21]

1) UML: describe and detail the warehouse; UML is standardized general-purpose modelling language, acknowledged by International Organization for Standardization (ISO) as an industrial standard. It has set of graphical tools to define, visualize, modify and document a system and it can be used in any processes to suggest a standard way to visualize system's infrastructure. UML diagrams are similar to flowcharts and it also indicates critical points in each activity which is in the system workflow. The main elements to create these diagrams are described below [21];

    i. The first and final activities which are represented by solid black circle and solid encircled black circle,

    ii. Activities, represented by rounded rectangles,

    iii. Arrows, showing the flow from the start to the end,

    iv. Forks and joins, represented by thick bar, forks indicate actions and joins indicate ending point of actions,

    v. Decisions,

    vi. Swim lanes, divides the diagram in columns to show the responsibilities.

2) VSM: identify the anomalies; all issues and anomalies which are occurred in the warehouse are spotted with the aim of eliminating source of errors and inefficiencies. The main target is to define all the existing interactions between the areas which structures the warehouse processes in order to standardize and optimize it. VSM visualize the wastes by graphical mapping of all processes of the workflow. We can describe the VSM procedure into three steps [21];

i. Identification of the product group for mapping: firstly, value stream map to be improved and defined with starting and ending points,

ii. Drawing the current state map of the value stream map: a team can observe the manufacturing processes and document every facts (e.g. cycle times, buffer sizes) and define the system with standardized icons.

iii. Evaluating the current state map: every process is assessed to check either it is value adding or not, therefore we can identify the system anomalies. Each anomaly in the flow is signalized by means of a "*bomb*" icon.

3) Genba-Shikumi: quantify and rank the anomalies; the main aim of Genba method is to go to field to check for waste and opportunities for the visible problems in lean manufacturing. Therefore, if there is any issue occurs on field, management can go and check and gather data from all valid sources. We can check the list of major anomalies which were marked in the previous VSM step via "*bomb*" icons. The first step is *muda* matrix which is mathematical formulation of the Genba philosophy [21].

Table 5: Example of muda matrix and vector [21]

#	Observed problems	Waste 1	Waste 2	[...]	Waste *w*	MV
1	Problem 1					**1**
2	Problem 2	1			1	**2**
...	[...]		1			**1**
p	Problem *p*		1	1		**2**

Stating by *p* the number of bombs in the state map and *w* the number of defined waste types, muda matrix $\mathbf{M} = \{m_{ij}\} \in \{0,1\}$ could be identified as a binary matrix, mij for *i* = 1,...,*p* and *j* = 1,...,*w* [21].

- $m_{ij} = 1$, if the *i*th defined issue has effect on the *j*th type of waste.
- $m_{ij} = 0$, if the *i*th defined issue does not have effect on the *j*th type of waste.

Muda vector $\mathbf{MV} = \{mv_i\} \in Z^p$ is calculated so that each mv_i is equal to the sum of the items in the *i*th row.

$$mv_i = \sum_{j=1}^{w} m_{ij} \text{ for each } i = 1,...,p.$$

Correlation matrix $= \{c_{ij}\} \in \{0,1\}$, could be identified as a binary matrix (number of detected bombs), c_{ij} for *i j* = 1,…,*p* and $i \neq j$,

- $c_{ij} = 1$, if the *i*th defined issue is correlated with the *j*th one.
- $c_{ij} = 0$, if the *i*th defined issue is not correlated with the *j*th one.

Correlation vector $\mathbf{CV} = \{cv_i\} \in Z^p$ is calculated so that each mv_i is equal to the sum of the items in the *i*th row.

$$cv_i = \sum_{j=1}^{w} c_{ij} \text{ for each } i = 1,\dots,p.$$

Each **CV** element quantifies the correlation of each bomb with others; the higher correlation, the higher the element. Consequently, priority matrix $\mathbf{P} = \{p_{ij}\} \in Z^{pxk}$ is calculated to evaluate the impact of per *k* chosen performances [21].

The generic element p_{ij} of **P** for *i* = 1,…,*p* and *j* = 1,…,*k* is described as below;

- $p_{ij} = 2$, if the *i*th defined issue has high impact on the *j*th chosen indicator.
- $p_{ij} = 1$, if the *i*th defined issue has low impact on the *j*th chosen indicator.
- $p_{ij} = 0$, if the *i*th defined issue has no impact on the *j*th chosen indicator.

Table 6: Example of correlation matrix and vector [21]

#	Observed problems	Problem 1	Problem 2	[…]	Problem *p*	CV
1	Problem 1		1			1
2	Problem 2	1		1		2
…	[…]		1		1	2
p	Problem *p*	1				1

Table 7: Example of priority matrix and vector [21]

#	Observed problems	KPI_1	KPI_2	[…]	KPIk	PV
1	Problem 1	1	1	0	0	2
2	Problem 2	1	1	1	1	4
…	[…]	1	0	0	0	1
p	Problem *p*	0	0	2	1	3

Priority vector $\mathbf{PV} = \{pv_i\} \in Z^p$ and $pv_i = \sum_{j=1}^{k} p_{ij}$ for each i = 1,…,p.

The priority vector elements evaluate how each waste impacts on the selected performance indicators: the higher the priority, the higher the related vector element.

AIV = MV + CV + PV

Elements in the AIV vector measure the severity of each assessed criticism in the state map: the greater such elements, the greater the need for resolving the connected problem [21].

Table 8: Example of absolute importance matrix vector [21]

#	Observed problems	MV	CV	PV	AIV
1	Problem 1	1	1	2	4
2	Problem 2	2	2	4	8
…	[…]	1	2	1	4
p	Problem *p*	2	1	3	6

4) UML-VSM-Reengineering: verify, update and reengineer the redesigned warehouse; future state map should be drawn and warehouse is redesigned by eliminating non-value adding activities in the order of importance which was gained in the previous step. Consequently, UML method is reapplied to monitor the warehouse activities regarding the redesigned state map. To ensure a continuous development strategy and verify the implementation plans, this offered approach for warehouse analysis and optimization should be repeated once a year [21].

2.4.2 RFID based warehouse automation

RFID is generic technology style that offers to use of radio waves to define objects. A microchip and an antenna are both RFID tags, the microchip is used to store article data such as product serial number and the antenna provides the microchip to transfer product information to a reader which converts the data on the RFID tag to understandable format via computers. RFID is designed to be used for automated information collection to ERP (enterprise resource planning) system activities. It can be thought as development over the barcode system which needs to be read by scanners. RFID tags could be active, passive or semi-passive. Active RFID tags have battery to broadcast signal to the reader, passive tags do not have any battery and they are powered up by electromagnetic waves transmitted by a reader to cause a current in tag's antenna. Semi-passive tags can use both battery and waves which are sent by the reader. For higher valued products, active and semi-passive tags are used for longer distance scans. The chip in the tag could be either read-write or read-only. Read-only chips are used for tracking cheap items and read-write chips are for more expensive items [23].

RFID systems work on four different frequency bands; low frequency (LF), high frequency (HF), ultra-high frequency (UHF) and microwave (MF). Use of UHF passive tags in supply chain applications are the most common and it has the lowest unit cost. RFID system offers unique visibility in the supply chain by providing product data (e.g. manufacturing and expiration date), history data, unit group data (e.g. dimensions, definitions) and entity data (e.g. telephone and address) [24].

Table 9: Operating frequencies and performance characteristics [24]

	Low frequency (LF)	High frequency (HF)	Ultra high frequency (UHF)	Microwave frequency (MF)
Frequency range[a]	125–134 KHz	13.56 MHz	860–930 MHz	2.45 GHz
Tag type*[b]	Passive	Mainly passive	Active and passive	Active and passive
Read range (passive*)[a,b,c]	<0.5 m	1.0 m	3.0 m	10 m
Tag size (passive*)[c]	Larger	Larger	Smaller	Smaller
Data transfer rate[a,b,c]	Slow	Medium	Fast	Fastest
Ability to read near metal or wet surface[a,c]	Best	Better	Worse	Worst
Tag cost[c]	High	Lower than LF tags	Lowest	High
Typical application[a,c]	Livestock tracking, card-key access control, beer keg tracking, Exxon Mobil Speedpass	Airline baggage handling, library book tracking, electronic article surveillance	Supply chain tracking, warehouse management	Electronic toll collection, railroad monitoring

Potential benefits of RFID technology

There are fifteen separate benefits of RFID usage into two groups: the benefits that could be assessed throughout the supply chain and the benefits could be understood by major supply chain attender [24].

The benefits throughout the supply chain;

1) Reduced shrinkage: shrinkage can happen in various ways; spoilage, misplacement, shoplifting and RFID can reduce it by two-thirds.

2) Reduced material handling: it helps to decrease material handling and inspection time. RFID provides decline in goods receiving, loading/unloading and waiting time and moreover it prevents human labour related manual data entry failures.

3) Increased data accuracy: it can improve stock records by removing human errors in material handling and the accuracy of the shipment data.

4) Faster exception management: it provides on-time obtained data and better sync of material and data flows.

5) Improved information sharing: it would increase the product data sharing among the companies.

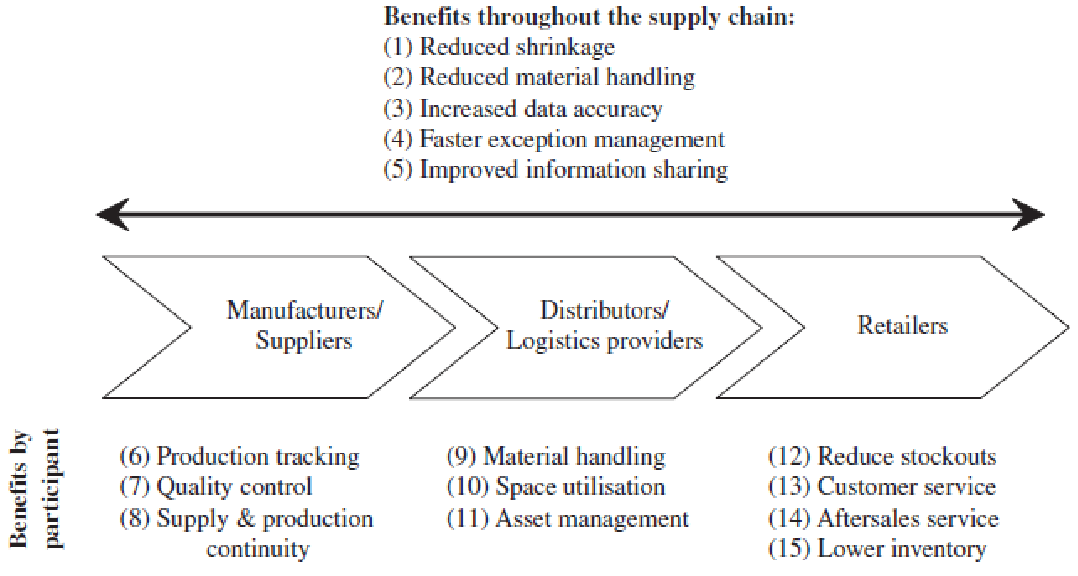

Figure 18: RFID benefits across the supply chain [24]

The benefits for manufacturers and suppliers;

6) Production tracking: it allows tracking of raw materials, WIP stock and finished products.

7) Quality control: it can be used to decrease product imperfections and defects.

8) Supply and production continuity: it can ensure continuity in production by developing material tracking through the production process.

The benefits for distributors and logistics providers;

9) Material handling: warehousing operations' material handling process can be decreased easily, since 50-80% of the cost is labour related.

10) Space utilisation: better material handling can utilise space usage in the warehouse.

11) Asset management: RFID would effectively manage various huge volumes.

The benefits for retailers;

12) Reduced stockouts: it increases the accuracy in finished goods stock therefore it reduces possible stockouts.

13) Customer service: usage of RFID helps to count inventory efficiently, decrease stockout possibilities and enhance staff availability for customer assistance.

14) Aftersales service: it can improve warranty process and returns handling by effectively retrieving data, such as service history.

15) Lower inventory: it could reduce safety stock by developing inventory data and preventing stockouts.

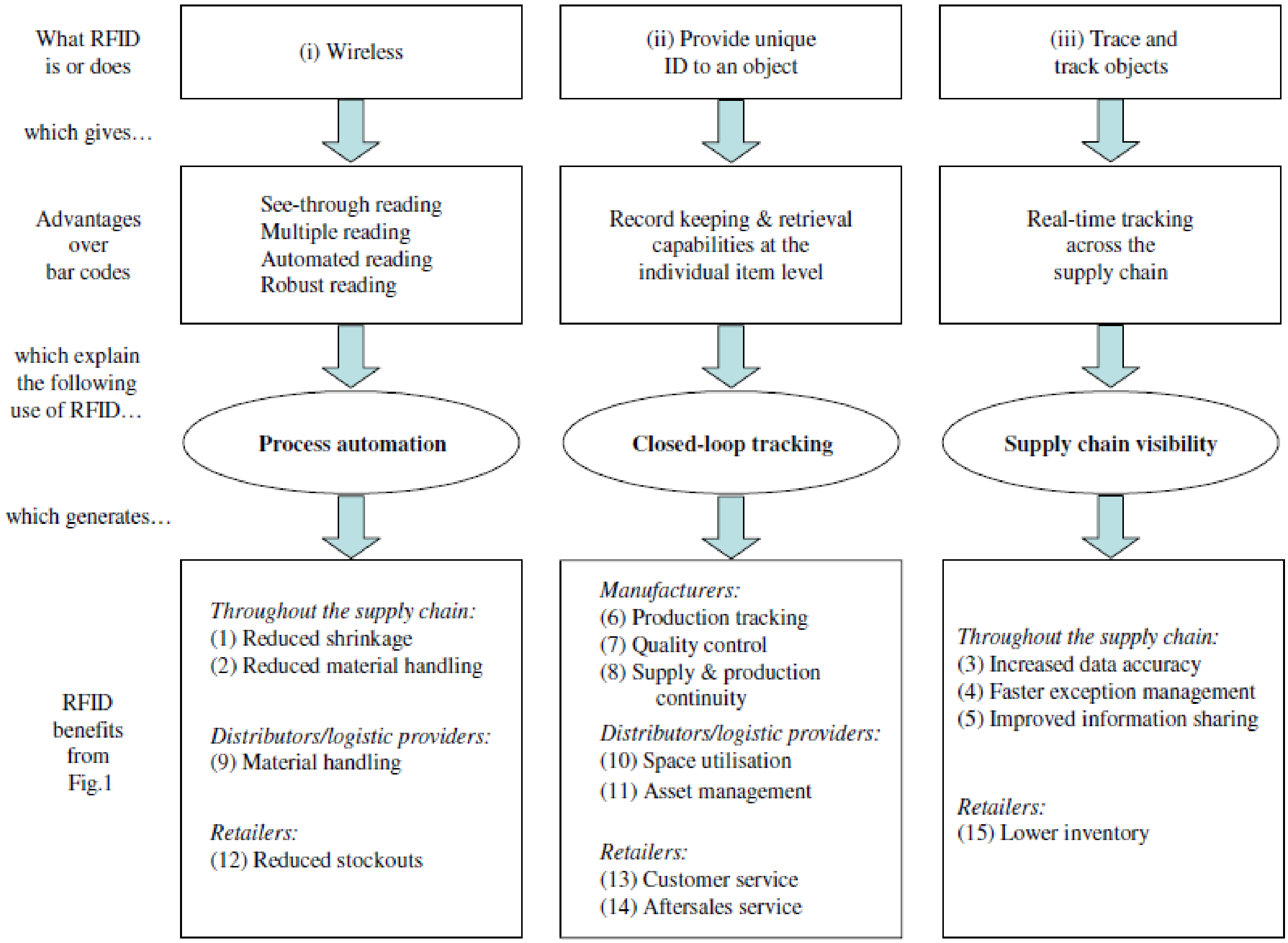

Figure 19: Alternative framework RFID benefits [24]

RFID in warehouse operations

Receiving and check-in: RFID portals which could be placed in specific corners of the warehouse can be used to read tags and automatically update stock levels while tagged pallets enter the warehouse. Therefore, incoming products will be matched against the relevant purchase order very easily [23].

Putaway and replenishment: by having Auto-IDs, putaway drivers will automatically find the defined storage locations without scanning unit barcodes. Moreover, replenishment operators will also be freed from scanning goods [23].

Order filling: order pickers will be automatically leaded to the identified picking locations and once the items are picked up the system will automatically verify that the picked quantities and remove them from actual inventory [23].

Shipping: RFID will enhance shipping operations by avoiding the scanning of the physical goods for loading to trucks [23].

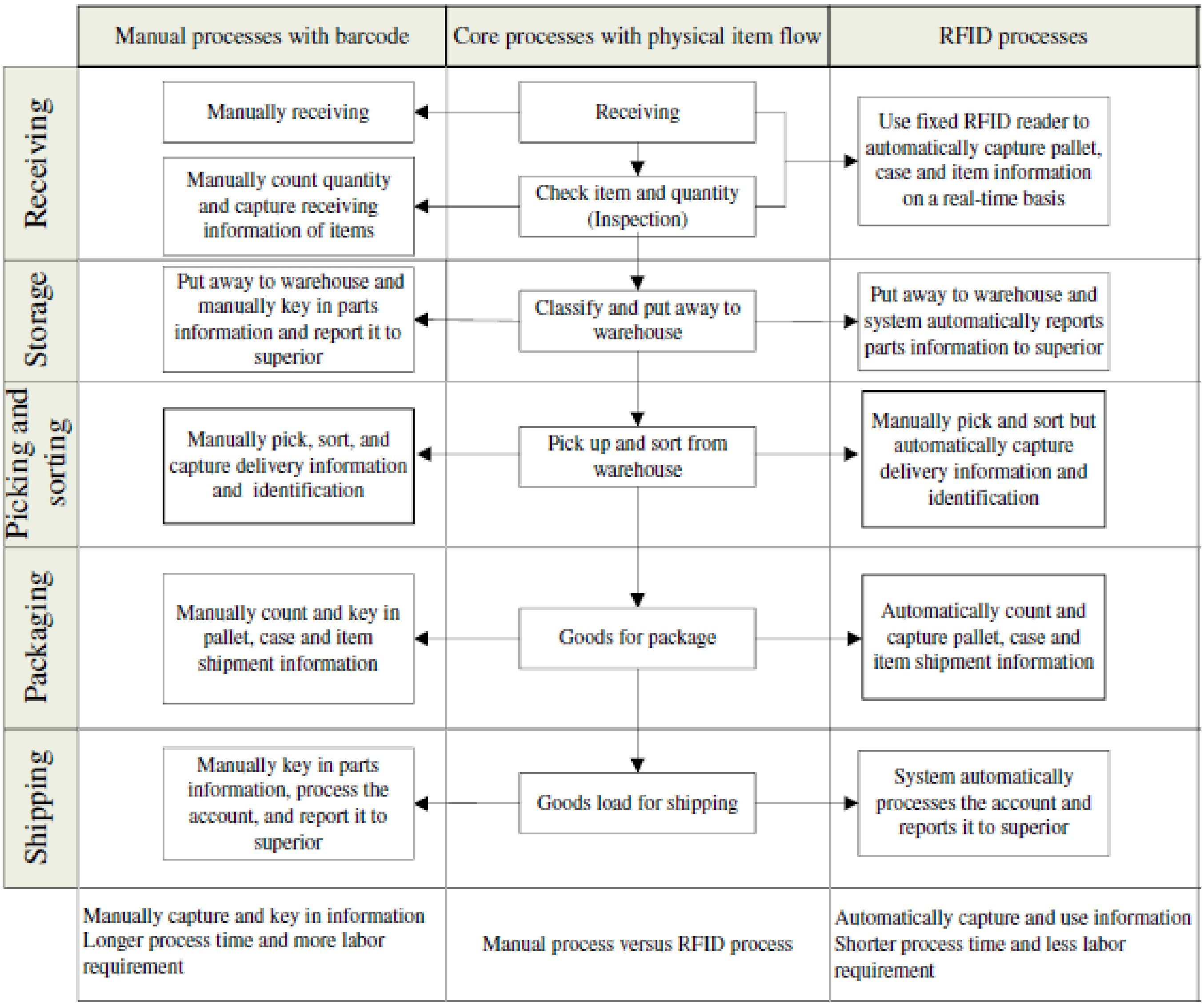

Figure 20: The operation process comparison between manual process with barcode and RFID-based [20]

2.4.3 IOT based warehouse automation

Internet of things (IOT) is a net-based technology that generate different kind of sensor devices such as infrared light sensor, GPS, radio frequency identification device (RFID) which creates connection to each other. IOT is a network that targets real time things' data. It is a system structure which includes PML information system, information collecting system, application management system and object name service (ONS) [25].

- Information collecting system: it is created via electronics tags, reader and writer and managerial computer with data collecting software. It helps to recognize the products and receive electronic product codes (EPC). EPC codes can be obtained via reader and writer once relevant electronic tags enters the defined zone.

- PML (Physical markup language) information server: PML data service is created and administrated by manufacturers. The goods can be coded regarding the predefined rules.

- Object Name Service (ONS): it creates connections between data collecting nodes and PML information servers and understands the mapping from EPC to their PML data.

- Application management system: it receives EPC data from the interface via data collecting software, comprehends PML data server for products by ONS.

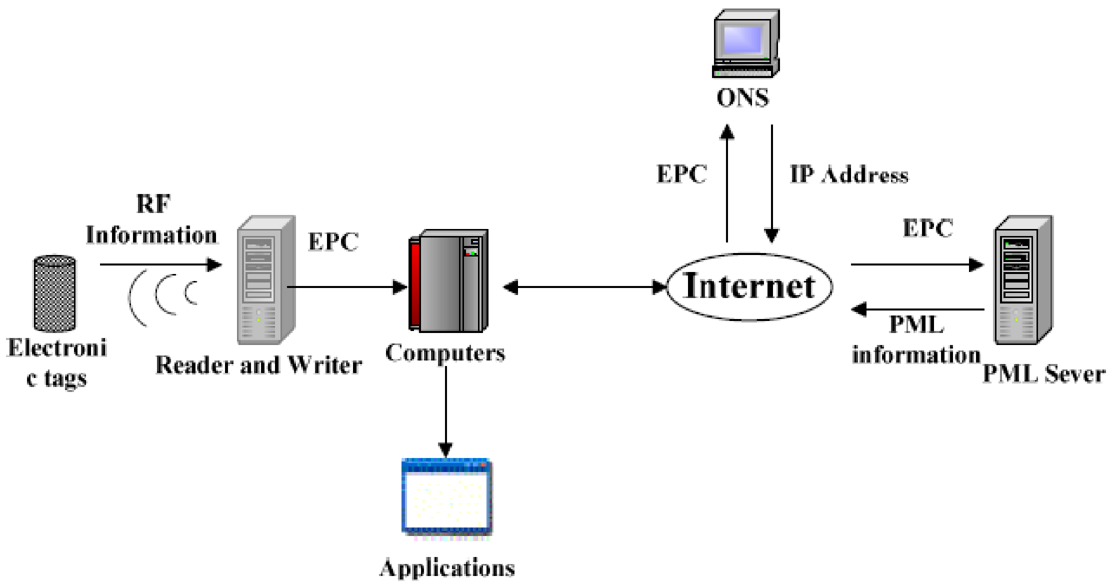

Figure 21: IOT structure [25]

The main principle of the automated warehouse management system via IOT is to obtain product detail data by using RFID where its reader and writer and electronic tags will be used. We can set RFID reader and writer to the entry of the warehouse and it can detect the products' data automatically by reading their electronic tags which are attached to the goods. Meanwhile the data which is collected by IOT can create the inbound list automatically [25].

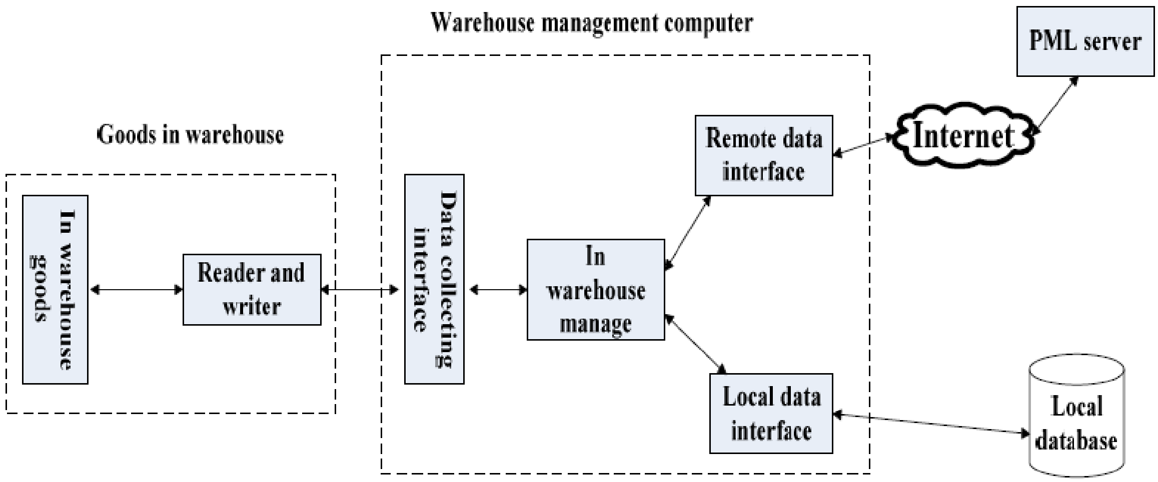

Figure 22: Automated warehouse management system structure [25]

IOT infrastructure links RFID with wireless sensor network (WSN), connecting object paradigm and multi-agent system (MAS). IOT and cloud computing targets to succeed automated product identification and real-time data access. Automated logistics monitoring platform consists of EPC, RFID, GPS, GSM and WSN. It can have three layers; information receiving, data transfer and background data analysis. Data receiving part is responsible of getting information about products through EPC and GPS tools. Every shipment can have a unique EPC number. Data transfer is the communication between components by GPS and the background data analysis is to receive and process the shipment data [26].

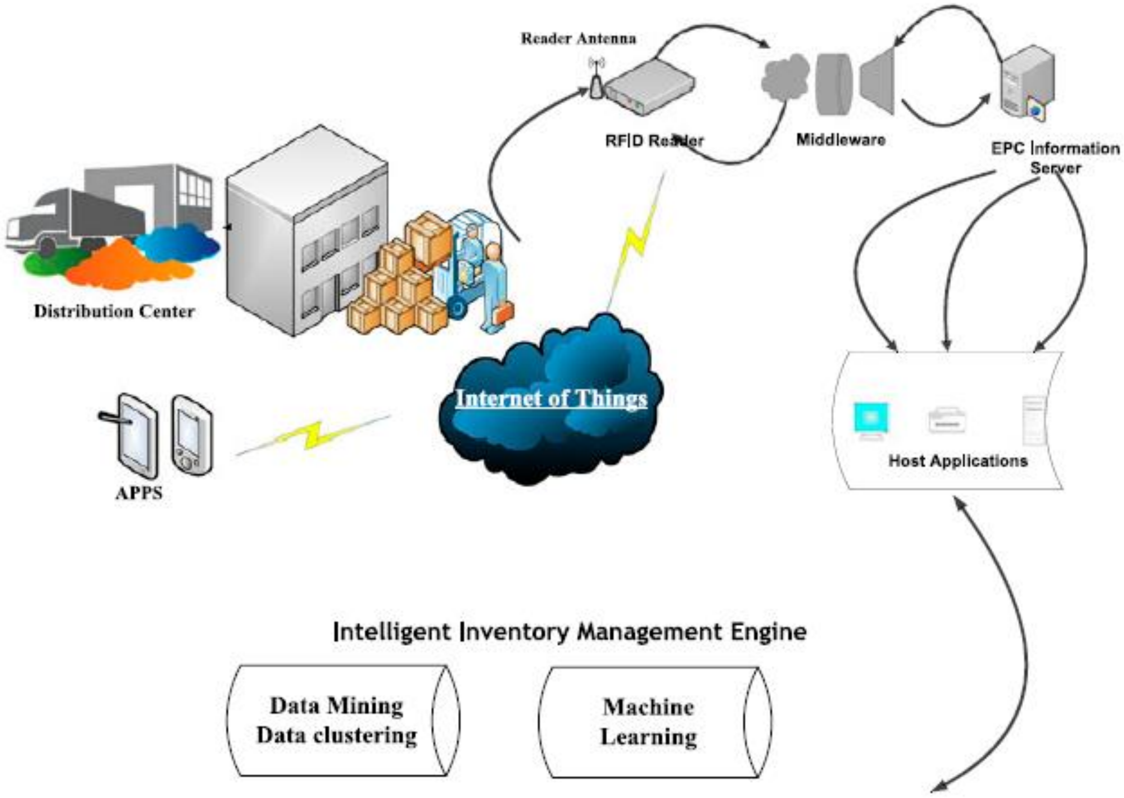

Figure 23: The framework of IOT-based warehouse management system [27]

3. SUPPLY DISTRIBUTION HUB ANALYSIS

3.1 Information about the Supply HUB

A prominent telecommunication equipment manufacturer opened a Europe Supply HUB in Germany and it has approximately 32,000 square metres of storage space. The main aim is to reduce customer delivery lead times by strategically having this HUB in Germany and offer specific customized solutions for the customers. There is a third-party logistics (TPL) partner who is responsible to operate the HUB on behalf of the manufacturer.

Analysis of the Supply HUB has three main phases; firstly author defines the current warehouse layout and its operations and secondly author analyses, detects and prioritizes the wastes and improvement needed steps by the evaluation of value stream mapping and Genba-Shikumi method and thirdly author improves and recommends solutions by VSM and RFID based techniques for the detected and improvement needed operations.

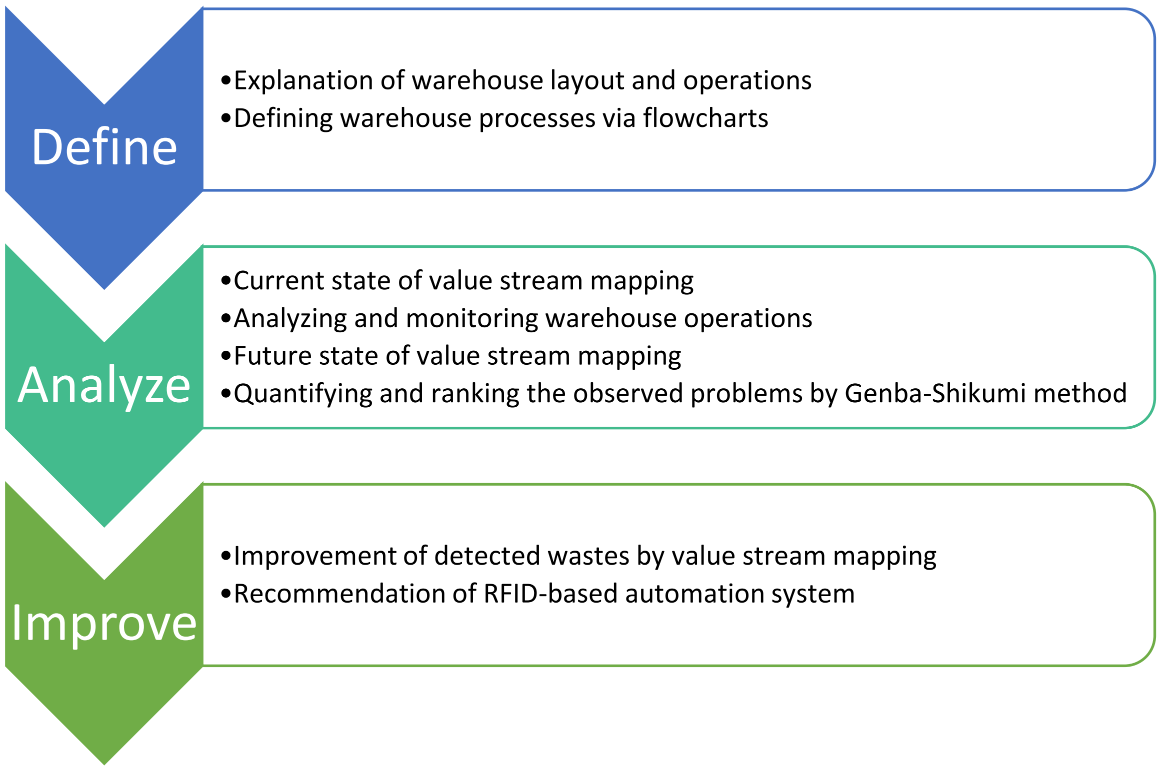

Figure 24: Roadmap of the Supply HUB analysis

3.2 Warehouse layout and operations

3.2.1 Warehouse layout

Supply HUB's warehouse layout has three main halls and their operational usage is described as below;

- Hall 1:
  - Customized specific solution (CSS) order assembly
  - CSS material storage
  - Repacking of the damaged goods upon arrival

- Hall 2:
  - Inbound zone (3-4 gates), goods arrival
  - Inbound quality, product data and amount check
  - Pick & pack operations
  - TPL control tower unit
  - High runner, light and small material storage

- Hall 3:
  - Outbound zone (3-4 gates), goods departure
  - Low runner, heavy and bulky material storage
  - Stored packed goods (SPG) area
  - Damaged goods storage

3.2.2 Warehouse operations

Warehouse has its own WMS by using barcode system to track all the goods. Suppliers manufacture the products with relevant purchase order (PO) from the warehouse. There are five operators in the receiving zone and they unload and check the product information, quantity and quality. If there is any issue with product data, goods are rejected and moved to special area for further inspections by superiors. After all the controls, goods which are accepted, are put away into related storage zone by two operators. These operators need to scan all the barcodes of the goods in order to approve the quantity and enter their data into the local WMS. Warehouse control tower unit double checks the product data and updates the inventory level. The time period of receiving and putting away processes depend on time for barcode scanning, quality and quantity of the order, transferring data to WMS, moving and storing goods to related warehouse racks.

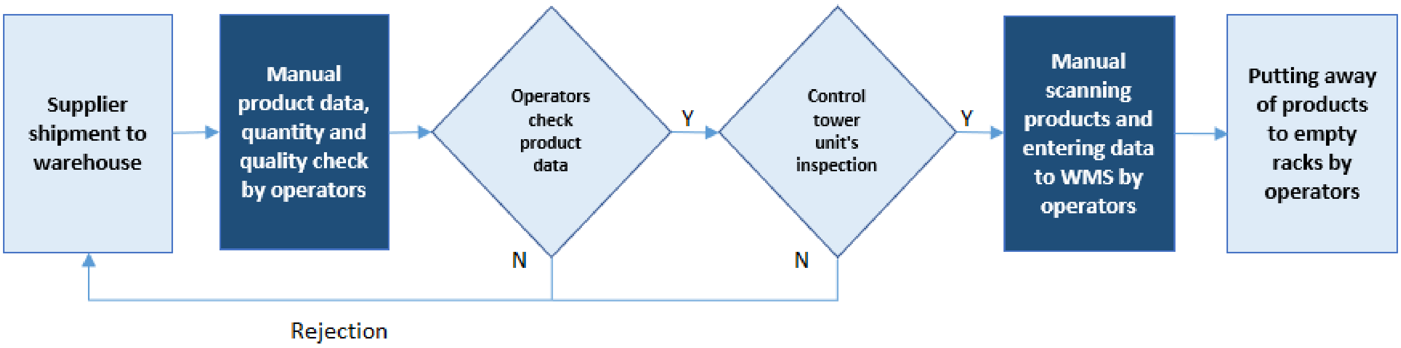

Figure 25: Warehouse receiving and storage process

Storage of newly accepted units are done based on chaotic inventory management. Operators store the goods to the closest random empty racks. It can cause a problem for high-demand and priority goods in case of storing them at farther location to the entrance or departure area of the warehouse. Therefore, it creates longer transportation distance and extra cost in picking operations which leads to inefficiency.

Every storage part has five rack levels, WMS system only shows and monitors the ground floor stock levels and offers replenishment for it and up to three operators are responsible for this process.

Order picking, packing and shipment operations of the warehouse is labour intensive and there are twenty pickers, twenty packers and six shipment operators are assigned for it. Pickers collect the goods according to the pick list which is created from WMS. Operators travel to the physical location of the goods, confirm the product and its quantity and collect and deliver it to packing zone. After the picking and sorting process, every operator must approve the completion of the order picking via barcoding to the WMS system in order to update the stock on hand. Afterwards, operators place goods into pallets and finalize the packing process and move it to the stored and packed goods (SPG) area. The last step is the shipment of the goods from SPG area via dedicated trucks.

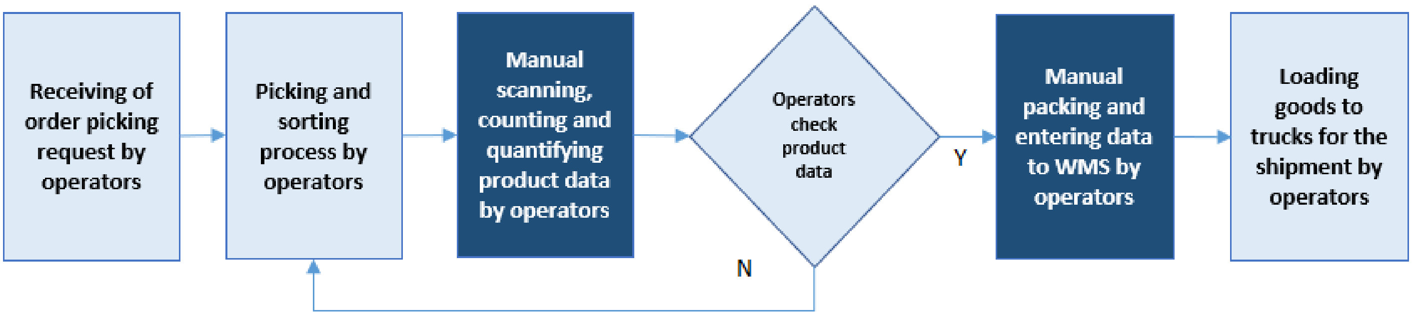

Figure 26: Warehouse picking, packaging and shipping process

3.3 Current and future state of value stream mapping

In the current state of value stream mapping, author focuses on one specific product group from a specific supplier with agreed truck delivery option in order to stabilize the external variables. Hence, author can monitor and analyse the whole internal warehouse operations and underline low-efficient activities and recommend needed improvements by usage of VSM tool and later via RFID application.

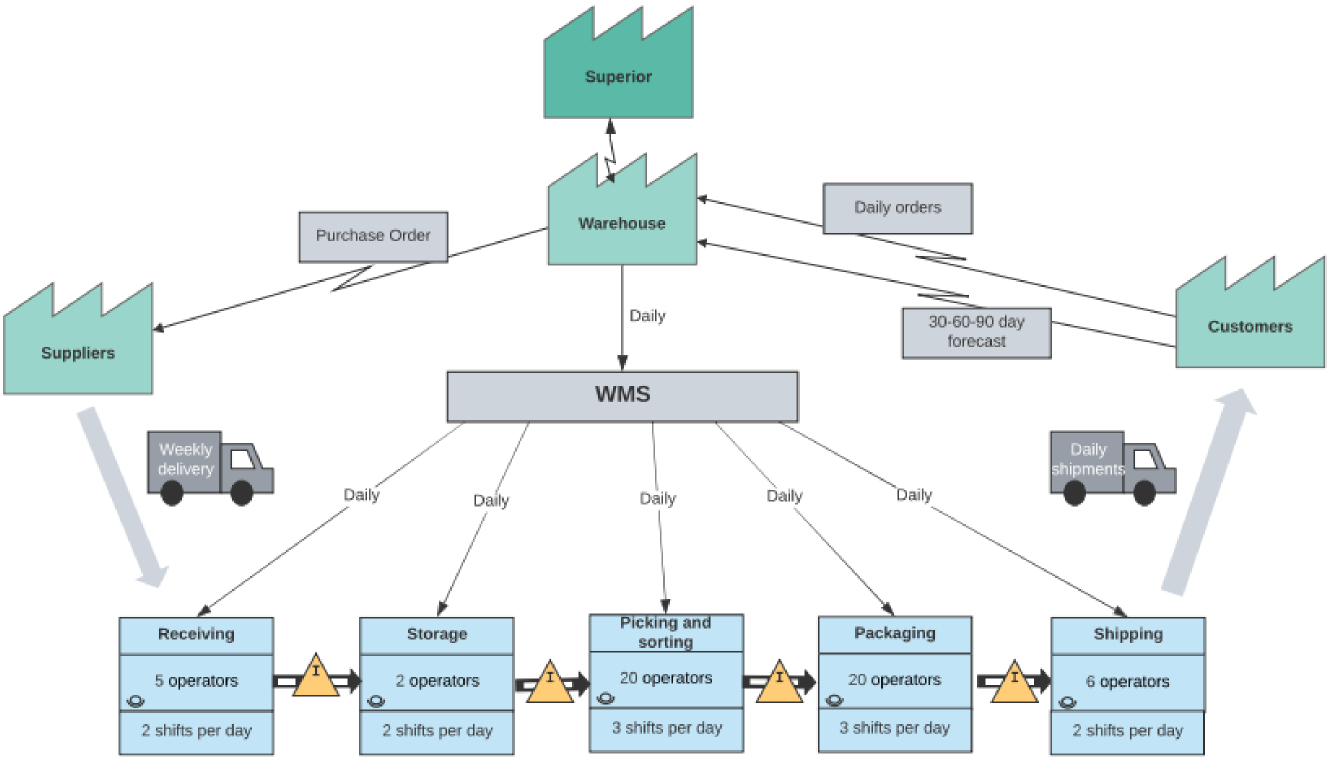

Figure 27: Current state of value stream mapping

In the future state of value stream mapping, author detected three type of wastes; waiting, transportation and motion. There is no change in the activity flow, but there are inefficiencies through the receiving, storage and picking operations.

1) Waste of waiting in the receiving process: there is lack of communication between the supplier and warehouse management, receiving schedule of the goods could be agreed beforehand by the advanced shipping note (ASN) in order to reduce labour waiting time, optimize operator’s daily workload and pre-plan the goods acceptance inspection period.

2) Waste of transportation in the storage process: it is related with chaotic (random) storage management policy of the warehouse. After unloading the trucks, operators try to locate a random empty rack for the newly accepted goods, but it can easily create waste of transportation by randomly searching free place in the warehouse. Warehouse storage policy can be changed from random to fixed location hence operator will avoid searching random location and focus on the limited area for the selected goods.

3) Waste of motion in the picking process: this process creates the main cost since picking operations occupy majority of the overall warehouse costs. Therefore, it should be priority to remove the waste of unnecessary motion which is taken by picking operators. High runner and priority goods should be stored close to the entrance and departure zone of the warehouse in order to avoid longer travel times and higher labour costs. It will optimize the picking, packing and shipping activities and provide lower costs to the warehouse.

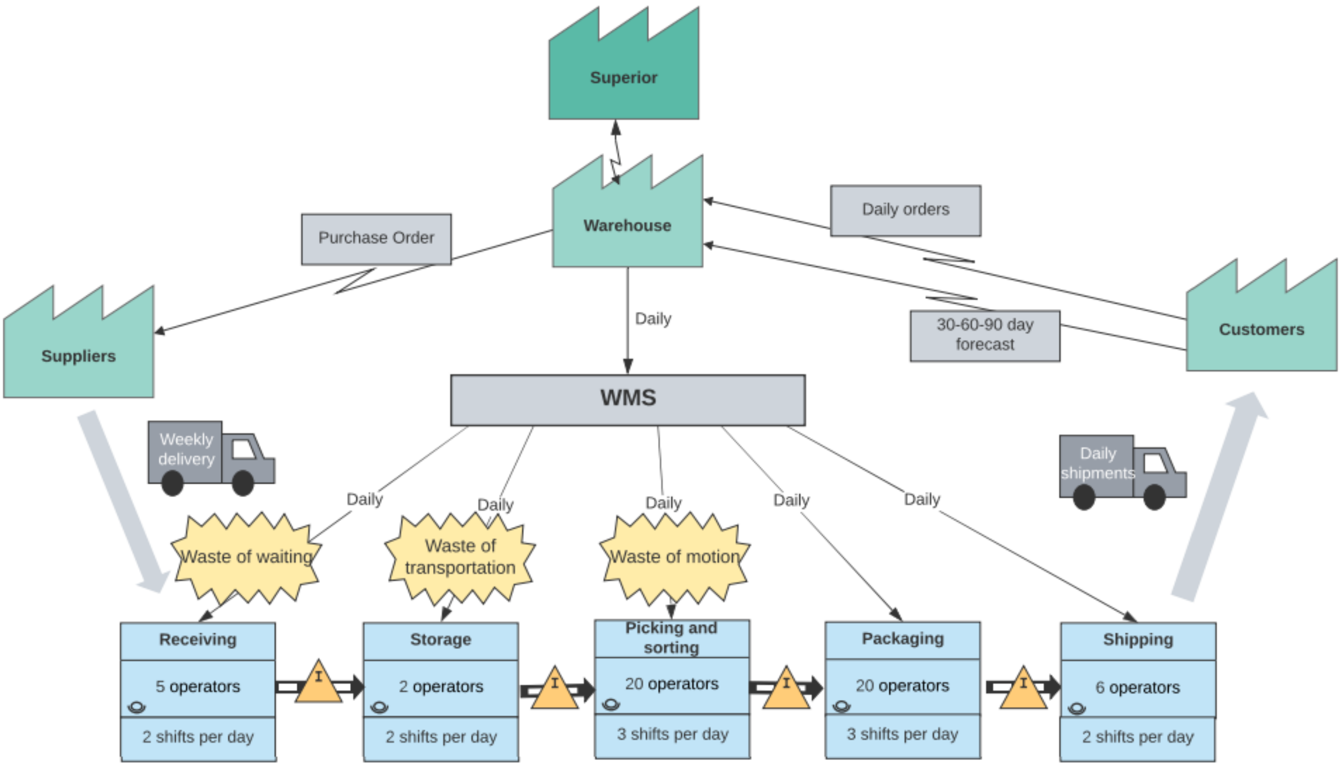

Figure 28: Future state of value stream mapping

3.4 Genba-Shikumi technique

Genba-Shikumi is a technique for quantifying and ranking the anomalies in the organization. The main aim of Genba is to detect the visible issues by going on the shop floor to check for wastes and improvement opportunities. Thus, in case of any issue, superiors should go to shop floor and observe and understand the problem by collecting data from all available resources [21].

In the previous VSM step, author detected three main wastes which are waste of waiting, transportation and motion in the receiving, storage and picking operations. In the Genba method author starts with muda matrix and muda vector (MV) which indicates detected waste for each problem.

In the muda matrix;

- if the selected problem is indicated as "1", then it has effect on the chosen waste,
- if the selected problem is indicated as "0", then it has no effect on the chosen waste.

Table 10: Muda matrix and vector

#	Observed problems	Overproduction	Waiting	Transportation	Extra processing	Inventory	Motion	Defects	MV
1	Product receiving schedule		1				1		2
2	Product acceptance inspection process		1						1
3	Chaotic warehouse storage policy			1			1		2
4	Product picking process						1		1
5	Manual barcoding process		1				1		2
			3	1			4		

In the muda matrix above, author can see lack of standardized policy, optimization and automation in receiving, storage and picking operations which lead three type of wastes. Hence, author creates correlation matrix and vector (CV) to assess each problem's degree of correlation.

In the correlation matrix;

- if the selected problem is correlated as "1", then it has correlation with another problem,
- if the selected problem is correlated as "0", then it has no correlation with another problem.

Table 11: Correlation matrix and vector

#	Observed problems	Product receiving schedule	Product acceptance inspection process	Chaotic warehouse storage policy	Product picking process	Manual barcoding process	CV
1	Product receiving schedule		1			1	2
2	Product acceptance inspection process	1					1
3	Chaotic warehouse storage policy				1	1	2
4	Product picking process			1		1	2
5	Manual barcoding process	1		1	1		3

In the correlation matrix above, author can monitor the manual barcoding process's degree which is linked three other specified problems. Subsequently, the priority matrix and vector (PV) is created in order to define each detected problem's effect on three selected key performance indicators (KPIs) which are receiving efficiency, inventory accuracy and order picking/packing.

In the priority matrix;

- if the selected problem is indicated as "2", it has high impact on the chosen indicator,
- if the selected problem is indicated as "1", it has low impact on the chosen indicator,
- if the selected problem is indicated as "0", it has no impact on the chosen indicator.

Table 12: Priority matrix and vector

#	Observed problems	Receiving efficiency	Inventory accuracy	Order picking/packing	PV
1	Product receiving schedule	2	1		3
2	Product acceptance inspection process	2	1		3
3	Chaotic warehouse storage policy		2	2	4
4	Product picking process		1	2	3
5	Manual barcoding process		2	2	4

In the priority matrix above, author can observe that chaotic warehouse storage policy and manual barcoding process have strong weight in the warehouse operations.

The next step is to create absolute importance matrix and vector in order to quantify the severity of the evaluated problems.

Table 13: Absolute importance matrix and vector

#	Observed problems	MV	CV	PV	AIV
1	Product receiving schedule	2	2	3	7
2	Product acceptance inspection process	1	1	3	5
3	Chaotic warehouse storage policy	2	2	4	8
4	Product picking process	1	2	3	6
5	Manual barcoding process	2	3	4	9

$$AIV = MV + CV + PV$$

Genba-Shukimi technique is used to quantify and prioritize five observed problems which create three main wastes. These observed problems were product receiving schedule, product acceptance inspection process, chaotic warehouse storage policy, product picking process and manual barcoding process. Genba analysis is conducted by creating muda, correlation, priority and finally absolute importance matrix. According the calculated AIV above; we quantified and ranked these five observed problems as below;

1) Manual barcoding process (AIV=9)
2) Chaotic warehouse storage policy (AIV=8)
3) Product receiving schedule (AIV=7)
4) Product picking process (AIV=6)
5) Product acceptance inspection process (AIV=5)

Manual barcoding process, which is highly prioritized, is automated via RFID-based warehouse optimization technique and the suggested process is described in the next section.

3.5 RFID-based optimization

RFID implementation process is used to optimize manual barcoding process which was observed and ranked as number one problem in the warehouse. It could be effective and efficient tool together with lean management. In the RFID implementation, RFID readers can be installed to receiving and shipping gates in order to obtain the data from RFID tags which are attached to either boxes or pallets. In the figure 29 below, we can see RFID automation effect in receiving, picking, sorting and shipping processes. It has significant improvement in figure 25 and 26's dark blue coloured manual barcoding steps.

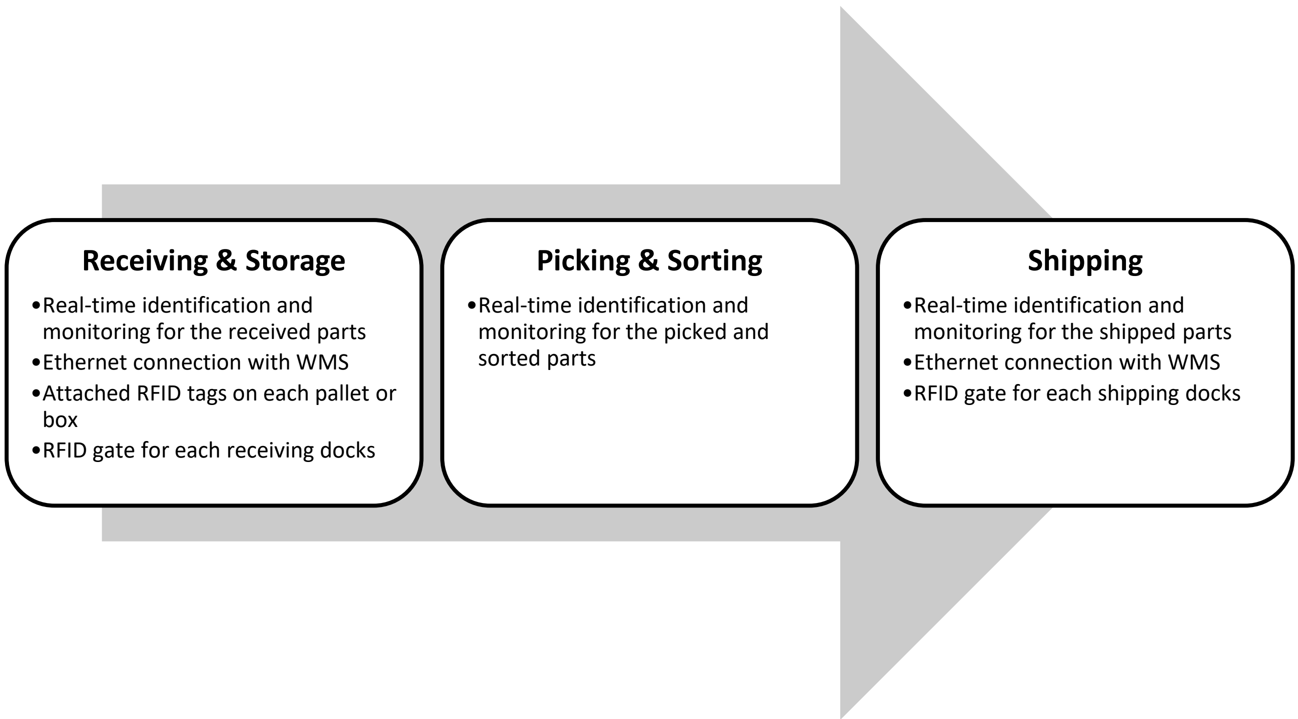

Figure 29: RFID implementation effect in warehouse operations

Ultra-high frequency (UHF) RFID is suitable for warehouse operations due to its long-range reading capacity. Good installation location for RFID readers and antennas should be chosen at inbound and outbound gates and passive RFID tags can be used on either on each of the boxes or pallets. These RFID tags can provide information regarding the id number, model and quantity of the product.

High runner and priority goods can be selected in RFID implementation due to its big impact on warehouse costs. Warehouse RFID process is described below;

1. Manufacturers dispatch the goods to the warehouse with attached RFID tag pallets.

2. Inbound operator uses forklift to unload the pallets and pass through the inbound gates. RFID reader will obtain the information on RFID tags and sent it to WMS system on real-time basis.

3. During the shipping process; operator uses forklift to load the pallets to shipping zone. While passing from outbound gates to the trucks, RFID reader will receive and record the data from each RFID tags.

4. After reading RFID tags' data, WMS will obtain the entire data from the readers and complete the shipment process.

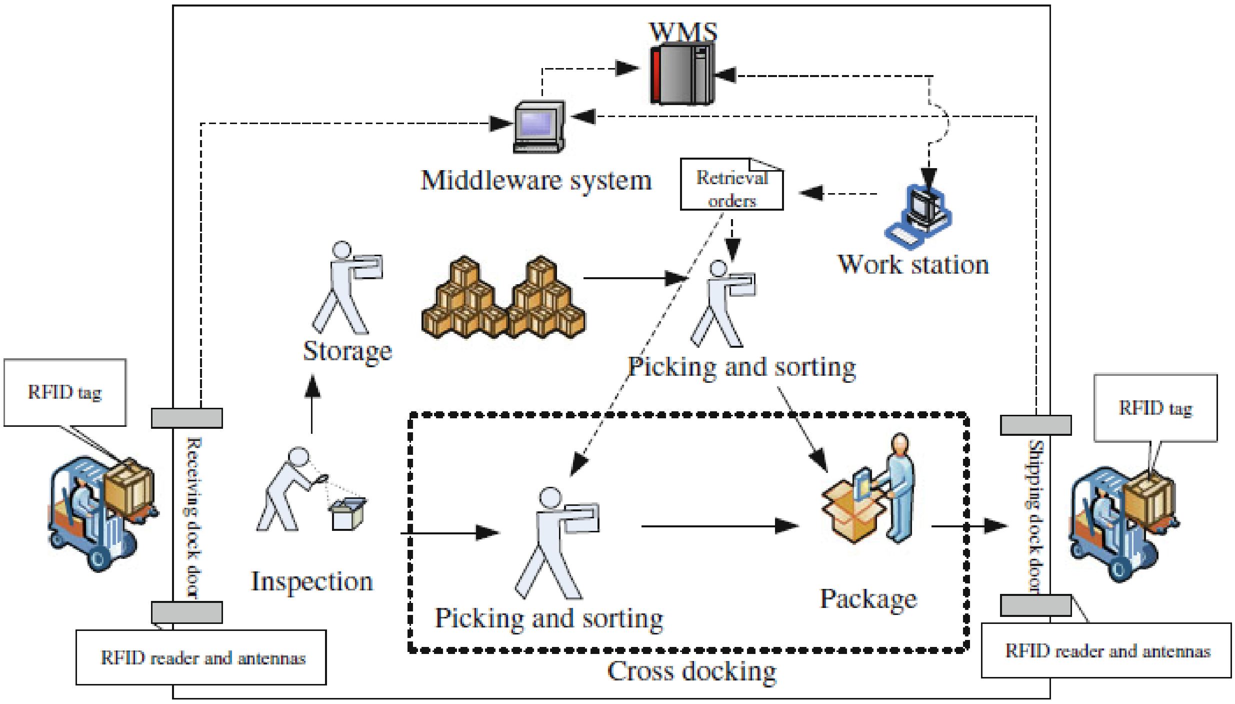

Figure 30: RFID technology implementation in warehouse operations [20]

In the figure 30 above, changing the processes from manual barcoding to RFID based optimization, data flow efficiency is improved significantly and superiors have real-time data and advanced visibility and tracking in each steps. RFID automation provides minimum human touch flow and manual processing hence less labour usage, less operation period and cost are needed.

4. FINDINGS AND RECOMMENDATIONS

Supply distribution hub analysis had three main steps; first of all, author explained and defined the distribution hub's layout and operations and used flowcharts to show its receiving, storage, picking, packaging and shipping processes. It is seen that warehouse operations are based on traditional manual barcoding system and there can be significant time wasting in each step. Secondly, current state of value stream map is drawn in order to monitor and analyse all the supply hub operations. There are three main wastes are detected such as; waste of waiting in the receiving, waste of transportation in the storage and waste of motion in the picking process and highlighted in the future state of value stream map. Afterwards Genba-Shikumi method quantified and prioritized five observed problems for these three detected main wastes. Lastly, author recommended improvement and stabilization solutions for the observed problems.

Genba-Shukimi technique's absolute importance matrix showed that chaotic warehouse storage policy and manual barcoding process have greater importance and priority over the other problems. Therefore, these problems are prioritized and solved before the other remaining issues. Absolute importance matrix is an effective tool to rank the observed problems.

It was seen that manual barcoding process has the highest weight among the five observed problems. Product data and quantity check in the receiving, entering data to WMS in the storage and packing and counting the goods in the picking process via manual barcode scanning creates the main waste in the daily warehouse operations. Author checked the best feasible automation solution for it and found RFID-based optimization solution for these manual steps. As it is described in the last part of the supply hub analysis; RFID implementation in all warehouse operations can easily improve the data input to WMS system, eliminate unnecessary manual barcode scanning steps, decrease labour cost and motion and provide real-time data and advanced visibility and tracking system.

Chaotic warehouse storage policy is the second prioritized problem and it mainly causes waste of transportation in the storage process. Operators strive to locate random empty warehouse racks for the newly arrived goods. Author recommends changing storage policy from chaotic to fixed location in order to eliminate unnecessary motion and transportation which is created by operators. This problem is directly connected with product picking process. If warehouse has fixed location storage policy for all goods then management can manage to optimize the storage of high runner and priority goods to the entrance and departure zone of the warehouse in order to avoid longer travelling times and higher labour costs.

There is lack of communication between the supplier and the warehouse management and it decreases productivity of labour's daily work and increases waiting time in the product receiving and acceptance inspection process. Author recommends using advanced shipping note procedure via WMS system which is connected to supplier's system in order to plan the receiving and inspection schedule beforehand. It will provide full visibility of the upcoming goods and eliminate the waste of waiting.

SUMMARY

The aim of the thesis is to describe and analyse which lean and automation-based techniques could be implemented on traditional warehouse operations management and how to use them in order to improve the current activity flow and eliminate the wastes in warehouse operations. It is essential for global supply chain companies to stay competitive and innovative with low operation costs and high productivity and profitability.

In the literature review, lean ideology, techniques and tools, warehouse operations management and optimization solutions are explained and analysed from various resources. Afterwards, supply distribution HUB analysis is conducted and it is found that the best feasible lean techniques for warehouse operations are value stream mapping and Genba-Shikumi and the automation solution is based on RFID technology.

During the supply distribution hub analysis, firstly current warehouse layout and operations are defined and then value stream map is created to monitor and detect the wastes in the daily warehouse operations. Afterwards, Genba-Shikumi method is used to quantify, rank and prioritize the observed problems under the detected three main wastes. In the recommendation part, according to the priority, improvement solutions are recommended for five observed problems by the efficient and effective usage of lean ideology and RFID automation technique.

Optimization of the warehouse operations could be achieved with a professional approach via dedicated top management. Supply chain companies should analyse and invest in their warehouse operations for continuous improvement in order to be competitive and strong in the constantly changing global market.

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