

Benchmarking of IT Solutions to support Warehousing Operation and Management

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To my family,

Abstract

The current competitiveness of the marketplace and the complexity of modern logistics force organizations to differentiate themselves. Warehouses are increasingly considered as strategic points along the Supply Chain that enable to rapidly satisfy customer orders and reduce logistics costs.

Therefore, the information systems which support the operation and management of warehouses are crucial to increase the automation, accuracy, coordination and efficiency of their processes. These solutions provide increased real-time visibility of locations, movements and stock levels, improved management of resources as equipment and manpower, and an efficient use of storage space.

Considering the multiplicity of these solutions on the market and the diversity of sectors in which the Industrial Engineering and Management team operates, INEGI identified the necessity for an information support tool to compare warehouse management systems. This deliverable compiles the main functionalities, strengths and limitations of each system provider, enabling the recommendation of the most suitable solutions for each warehouse operation level and business sector.

Furthermore, the reference customers and sectors, the pricing and deployment models and the contact details of each supplier are also presented on the document.

Throughout the development of the deliverable, distinct sources of information were used such as direct contact with the providers, interviews, demonstrations carried out by users of the systems, case studies, catalogues and visits to partner companies.

The key performance indicators that these systems should assess were also identified, as well as their main requirements, namely: basic and extended functionalities, usability, analytical capabilities, handling equipment integration, implementation and technology support, adaptability and simplicity. This has enabled a framework to be developed to guide the selection of a warehouse management system.

Finally, a case study was conducted, based on the recommendation of a warehouse management system for a company in the distribution sector through the prioritization of requirements and adequacy to the warehouse's current situation, in accordance with the framework designed.

The present dissertation highlights the importance of evaluating and prioritizing all criteria when choosing an information system, from the investment willing to be made, the key requirements to be fulfilled to the implementation and pricing models to be adopted, since there is no ideal warehouse management system solution. It is of utmost importance to parameterize all the requirements and attributes.

These systems should be appraised within the specific context of a warehouse, as needs and workflows can vary significantly between them. Hence, only an individualized analysis considering the size of the warehouse, type and turnover of stored products, inbound and outbound flows, automation capabilities, and customer expectations enables an understanding of the needs of each operation and the choice of the most suitable solution to ensure operational efficiency.

Benchmarking de soluções informáticas de suporte à Operação e à Gestão de Armazéns

Resumo

A atual competitividade dos mercados e a complexidade da logística moderna conduzem à necessidade de diferenciação por parte das organizações. Os armazéns são cada vez mais considerados como pontos estratégicos ao longo da cadeia de abastecimento que permitem satisfazer rapidamente as encomendas de clientes e reduzir custos logísticos.

Neste sentido, os sistemas de informação que suportam a operação e gestão de armazéns são fundamentais para o aumento da automação, precisão, coordenação e eficiência dos seus processos. Estes proporcionam um aumento da visibilidade em tempo real de localizações, movimentos e níveis de stock, uma melhor gestão de recursos como equipamentos e mão de obra e um aproveitamento eficiente do espaço de armazenagem.

Face à multiplicidade das soluções existentes no mercado e à diversidade de setores de atuação da equipa de Gestão e Engenharia Industrial do INEGI, foi identificada a necessidade de um suporte de informação para a comparação de sistemas de gestão de armazém. Este reúne as principais funcionalidades, os pontos fortes e limitações de cada sistema, possibilitando a recomendação das soluções mais adequadas a cada nível de operação e setor de negócio.

Adicionalmente, são ainda apresentados no documento os clientes e setores de referência, os modelos de preços e implementação e os contactos de cada fornecedor.

No decorrer do desenvolvimento do documento, foram utilizadas distintas fontes de informação como contacto direto com os fornecedores, entrevistas, demonstrações realizadas por utilizadores dos sistemas, casos de estudo, catálogos e visitas a empresas parceiras.

Foram ainda identificados os indicadores de desempenho que os sistemas devem permitir calcular e os requisitos principais pelos quais estes foram avaliados, designadamente: funcionalidades básicas e alargadas, usabilidade, capacidade analítica e de integração de equipamentos de movimentação, suporte de implementação e de tecnologias, adaptabilidade e simplicidade. Isto permitiu o desenvolvimento de um modelo para orientar a escolha de um sistema de gestão de armazém.

Finalmente, foi conduzido um caso de estudo que assenta na recomendação de um sistema de gestão de armazém para uma empresa do setor de distribuição através da hierarquização de requisitos e adequação à situação atual do armazém, de acordo com o modelo desenvolvido.

A presente dissertação salienta a importância de avaliar e hierarquizar todos os critérios na escolha de um sistema de informação, desde o investimento que se pretende fazer, os principais requisitos a satisfazer até aos modelos de implementação e preço a adotar, uma vez que não existe uma solução ideal de sistema de gestão de armazém. É de extrema importância parametrizar todos os requisitos e atributos.

Estes sistemas devem ser avaliados no contexto específico de cada armazém, uma vez que as necessidades e os fluxos de trabalho podem variar significativamente entre eles. Assim, só uma análise individualizada, considerando a dimensão do armazém, o tipo e a rotatividade dos produtos armazenados, os fluxos de entrada e saída, as capacidades de automação e as expectativas dos clientes, permite compreender as necessidades de cada operação e escolher a solução mais apropriada para garantir eficiência operacional.

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Glossary

3PL - Third-Party Logistics
AGV - Automatically Guided Vehicles
AHP - Analytic Hierarchy Process
AI - Artificial Intelligence
API - Application Programming Interface
APS - Advanced Planning and Scheduling
AR - Augmented Reality
ASN - Advanced Shipping Note
ASRS - Automated Storage and Retrieval Systems
B2B - Business-to-Business
BI - Business Intelligence
BOM - Bill Of Materials
CI - Consistency Index
CR - Consistency Ratio
CRM - Customer Relationship Management
CTI - Technology and Innovation Centre
EDI - Electronic Data Interchange
ERP - Enterprise Resource Planning
FEFO - First Expired First Out
FIFO - First In First Out
FMCG - Fast Moving Consumer Goods
IoT - Internet of Things
IS - Information Systems
IT - Information Technologies
KPI - Key Performance Indicator
LED - Light-Emitting Diode
LIFO - Last In First Out
MES - Manufacturing Execution System
MHE - Material Handling Integration
ML - Machine Learning
OMS - Order Management System
PDA - Personal Digital Assistant
PIM - Production Information Management
PLC - Programmable Logic Controller
RFID - Radio Frequency Identification
RGV - Rail Guided Vehicle
SC - Supply Chain
SCE - Supply Chain Execution
SCM - Supply Chain Management
SKD - Software Development Kit
SKU - Stock-Keeping Unit
SMB - Small and Medium-sized Business
TCO - Total Cost of Ownership
TMS - Transport Management System
UX - User Experience
WCS - Warehouse Control System
WIP - Work In Progress
WMS - Warehouse Management System

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1 Introduction

1.1 Project framework and motivation

The present dissertation was developed within the scope of the Master's degree in Mechanical Engineering at the Faculty of Engineering of the University of Porto. This project had the duration of five months and it was carried out in a corporate environment, in the Industrial Engineering and Management department of INEGI, with the purpose of establishing a benchmark of distinct warehouse management information systems.

The INEGI institution, designated as Institute for Science and Innovation in Mechanical and Industrial Engineering, is a Technology and Innovation Centre (CTI), which was founded in 1986. This organisation is oriented towards the progress of industry and the economy, focusing on technology-based research and innovation activities and the provision of services.

INEGI has more than 270 employees and 582 clients, 232 of whom are international. Its values focus on customer orientation, responsibility, cooperation, ambition, and passion for innovation (INEGI, 2023).

The organisational structure of this institution is based on three pillars of activity specialization: research and development; innovation and technology transfer; and lastly consulting, laboratory, and advanced training services. These are dedicated to different market segments such as manufacturing, infrastructures, equipment assets, aeronautics, space, and defence, automotive and transport, renewable energies, circular economy, health and sports.

The heterogeneity of sectors and customers leads to the necessity of satisfying many and diverse requirements specific to each operation.

As part of the consulting services in Industrial Engineering and Management, this project aims to systematize and organize information regarding warehouse management systems of different providers in order to support the recommendation of informatic solutions to INEGI's customers.

Warehouses are increasingly perceived as strategic points in the supply chain of an organization. As a result, the systems that support their operation are fundamental to improve the disposition, traceability, and visibility of warehouse assets, from products to information.

The use of a warehouse management system (WMS) leads to streamlined operations and reduced logistics costs, by promoting process automation. It conduces to greater safety within the warehouse, fewer errors and consequently, an increased customer service level.

1.2 Benchmarking project at INEGI

INEGI's consulting services cover a wide range of areas, including energy, circular economy, industrial engineering and management, production technologies, industrial safety, and environmental studies.

The Industrial Engineering and Management department provides consulting projects in the fields of logistics and supply chain management, operations management, quality and process engineering, benchmarking and performance management, sector studies, quantitative marketing, customer management, and lastly, public transport and urban logistics (INEGI, 2023).

The need to develop this project was identified by INEGI, since currently, warehousing operations are often supported by information systems. However, companies do not always use all the available functionalities of information systems, thus not taking maximum advantage of their capabilities.

Bearing this in consideration, it became necessary to create a documentation support that allows a comparative analysis of the various IT solutions available to promptly propose those that meet the needs and requirements of INEGI's potential customers.

Therefore, the benchmarking project for WMS solutions aims to compile and provide the necessary information to respond quickly and effectively to clients' requirements.

This benchmarking process consists of a method for measuring and comparing the performance and requirements fulfilment of systems from different providers, which enables a deeper and broader understanding of the market offers for these systems. This demands defining key requirements and performance indicators, the state of the art and future prospects for improvement and integration of these systems.

Thus, it is possible to structure an analysis on how each provider stands out from the competition and which are the most appropriate systems for different sectors and levels of warehouse operation in order to find the best solution for each specific warehouse.

1.3 Project goals

This project's main purpose relies on the comparison of warehouse management system software solutions from different providers through a benchmarking process.

According to the specific goals of the dissertation, the following main outcomes are expected:

- Identification of the main providers of warehouse management software solutions and the corresponding systems.
- Assessment of the usability and applicability of each solution.
- Establishment of a comparative matrix of the system providers evaluated according to the criteria defined and a framework to guide the selection of a system.

Afterwards, a case study is presented containing an information system suggestion to support the warehousing operation of a client company through the developed framework.

1.4 Method used throughout the project

In order to guarantee the achievement of the goals outlined for the project, a work methodology (Figure 1) was developed detailing its distinct phases and respective tasks, as well as a project execution chronogram (Figure 2).

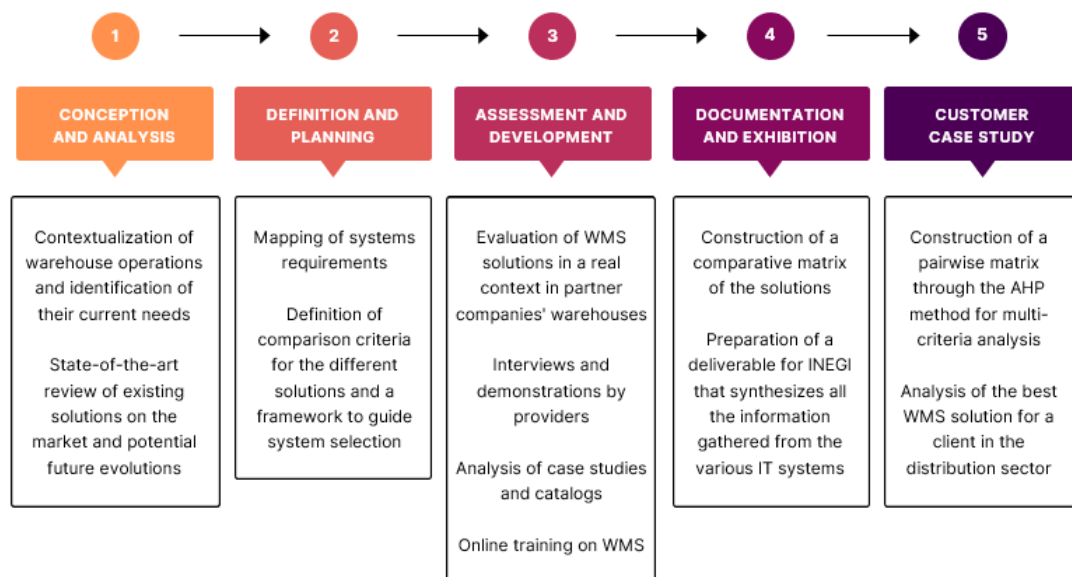


Figure 1 - Project methodology

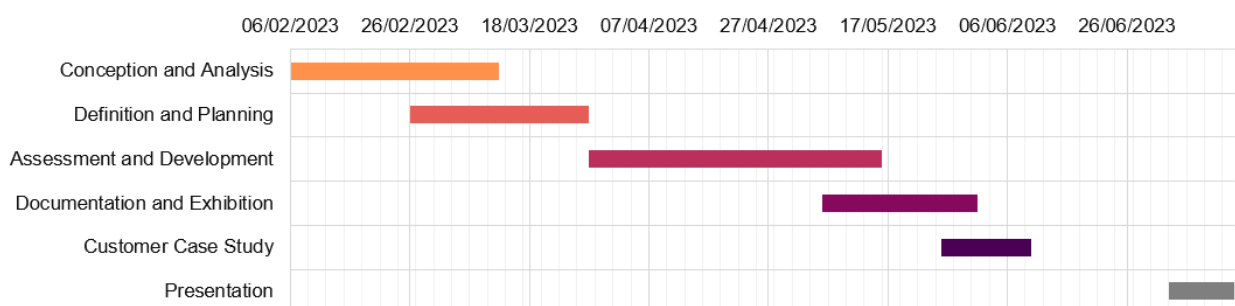


Figure 2 - Project timeline

1.5 Structure of the dissertation

The present dissertation is structured into six different chapters. Initially, the project is presented, as well as its motivation, purpose, and methodology.

Chapter 2 addresses the literature review on the main themes presented throughout the project. The operations, costs and common structure of warehouses are contextualised, as well as the technologies and systems used and their respective functionalities. Furthermore, the analytical method for multi-criteria decision-making applied in the case study is detailed, allowing the relative weighting of each of the key system requirements.

Chapter 3 describes the evaluation parameters used to evaluate the solutions and the KPIs they should calculate in order to develop a framework to guide system selection. Whereas Chapter 4, effectively focuses on the comparison of the IT providers and proposed solutions.

Chapter 5 presents a case study consisting of a recommendation of a WMS solution for a company in the distribution sector according to the analysis previously developed and the application of the analytic hierarchy process method.

The final conclusions are described in chapter 6, which summarises the final considerations when choosing a solution for the management of warehouses and explores perspectives for future work. Finally, the bibliographical references are presented, followed by the attachments which are referred to along the whole dissertation.

2 State of the Art

2.1 Information Systems in Supply Chain Management

Supply Chain Management (SCM) consists of a strategic planning process based on cooperation, collaboration, and coordination of its integral parts, from suppliers, intermediaries, third-party providers to customers. It encompasses all activities involved in procurement, acquisition, conversion, development, and logistical operations such as warehousing and distribution of products or services (Carvalho, 2012).

The main purpose of Supply Chain Management is to increase companies' market share and profits as well as customer satisfaction. Within this scope, the emergence of the Internet and Information Systems has enhanced customer interaction, promoting the creation of trust-based relationships, which has been essential for the evolution of the SC towards multi-channel strategy.

Besides, SCM also enables the integration of functions and processes within and across organizations leading to more consistent business models by using Information Systems which allow real-time information sharing. When analysed within a specific framework, information is a valuable resource that can be seen as a factor of strategic differentiation.

Information Systems (IS) bridge business and computer science by linking systems, people and processes to generate, store, process, assess, and deliver information. Frequently, these comprehensive systems integrate supporting Information Technologies (IT) to increase the efficiency and flexibility of operations.

These systems represent a fundamental role in supporting decision-making processes given the emerging operational complexity that defines modern logistics. Such complexity relies on different factors, such as market globalization, increased product heterogeneity and customization, more frequent and fragmented orders, higher client expectations and greater technology innovation leading to reduced time-to-market and lead time.

According to Porter (1998), the logistical strategy of a corporation must reduce transaction costs and maximize customer service. Customer service can be measured in terms of the availability of materials, operational performance, and reliability, especially in terms of deadline compliance (Bowersox and Closs, 2002).

Information systems, not only improve the agility of the SC, but also lead to business growth due to the analysis of data, the identification of opportunities for improvement and the exchange of information between different departments of a company. For instance, production requires information about the demand provided by sales and marketing and distribution areas rely on customer-related data (Frazelle, 2016).

The assessment of satisfaction parameters and the coordination of the information flow throughout the SC is assured by IT systems which present four functional levels - Table 1. These systems can be based on satellite systems, wireless networks, or fibre optic connections (Dehgani and Navimipour, 2019).

Table 1 - Functional levels of Information Technologies (Carujo, 2021)

Strategic Planning	Strategic alliance formulation
	Costumer service analysis
	Development and enhancement of expertise and opportunities
Decision Analysis	Route planning
	Stock management
	Vertical integration against outsourcing
Management Control	Financial costs and asset management
	Productivity, quality, and customer service management
Transactional Systems	Order management
	Invoicing
	Order picking and dispatch
	Customer information
	Stock

In a long-term perspective, Strategic Planning provides a clear understanding of the company's objectives and future directions. In a medium-term one, the proper use of information is indispensable for Decision Analysis since it consists of a systematic, visual, and quantitative approach to decision-making that enables the assessment and comparison of logistics strategies and tactics. Finally, at the operational level, Management Control is responsible for recurrent performance evaluation and reporting, and the Transactional Systems record the daily input and output activities.

According to Data Management, software applications can also be divided into transactional or analytical systems. While transactional systems are responsible for acquiring, processing, and communicating raw data related to past and current operations, analytical systems develop and evaluate decision models. The first ones include sales reports and e-commerce systems, whereas the second ones include the production scheduling, forecasting, and optimization systems (Helo and Szekely, 2005).

There is an incremental convergence in the functionalities of Information Systems. However, it is essential that all of them provide and process large amounts of data in real-time, while being flexible and easily interconnected and integrated. This enables continuous adaptation to the future needs of corporations and their goals.

Software systems employed in Supply Chain Management should enable supplier, production, warehouse and transport management, order processing, demand forecasting and operation planning, while presenting financial, logistic and security tools. In most cases, the solution implemented by companies is a result of the integration of different system modules and functionalities, presented in Table 2 (Nettsträter et al., 2015).

The integration of these modules produces value to the supply chain, namely economic, market and relevance value. The economic value concerns the efficiency of the economies of scale, characterised by the creation of products or services at the lowest total cost. Market value is related to product and sector diversification and relevance value refers to product positioning and value proposition (Bowersox and Closs, 2002).

Table 2 - Information systems modules in SCM

Software	Function
ERP Enterprise Resource Planning	ERP is a comprehensive software solution that provides tools for nearly every function of a company such as finance, human resources, sales, production scheduling, material planning, logistics and marketing. It connects all the information flows and allows the creation of balance sheets and profit and loss statements.
WMS Warehouse Management System	WMS is focused on the control, coordination, and optimization of operations within a warehouse. This type of system allows the management of inventory, regarding its quantity, location, handling, and movement. Besides controlling all the inflows and outflows, it also supports the technologies commonly used such as voice picking, pick and put to light and radio frequency identification (RFID).
MES Manufacturing Execution System	MES is an automated control system software which allows the collection and analysis of data regarding the production process directly from the shop floor, through robots, sensors, machine monitors and employees. It manages bills of materials (BOM), consumables, work orders, and production routes.
TMS Transport Management System	TMS is a management tool responsible for planning and optimizing the movement of goods through the assignment of means of transport and vehicles, yard management, dock allocation, route optimization and document control.
APS Advanced Planning and Scheduling	APS refers to an advanced production planning system capable of controlling the actual capacity of production resources and their operational requirements. It outlines the forward planning and scheduling of processes within production and logistics.
OMS Order Management System	OMS provides digital tools to manage the entire lifecycle of an order, simplifying purchasing processes for companies and customers by centralising information from different sales channels. These systems support the omnichannel strategy by tracking processes from order entry, inventory management, fulfilment and after sales service as well as facilitating the ordering and traceability of products and services.
PIM Production Information Management	PIM software permits the creation of product catalogues and the continuous revision and updating of product information and availability. Recorded information covers designation titles, descriptions, categories, images, prices, and inventory levels of the various products.
CRM Customer Relationship Management	This technology manages relationships and interactions with customers and potential customers, by simplifying the contact between all. A CRM module stores contact information, identifies sales opportunities, and manages marketing campaigns so that customer information is accessible to everyone, enabling major improvements in customer service.

2.2 Warehouse Management

Currently, warehouses are seen as strategic points for the potential growth of organizations that enable reduced customer waiting time. These storage systems enable the holding of specific materials in the appropriate quantities, in a suitable environment and at a minimum cost.

Warehouses are facilities within the supply chain they are integrated into, in charge of the reception, storage, protection, control and expedition of goods. Their prevailing operations consist of receiving, inspection and quality control, repackaging, put away, storage, replenishment, order picking, sorting, packing, cross-docking, and shipping, further explained in Table 3.

Table 3 - Warehouse Operations (Riedel, 2011)

Receiving	Reception of all incoming materials and further quantitative and qualitative validation in accordance with the information from the suppliers or customers. It includes reverse logistics activities as returns.
Inspection and quality control	Product validation that can be simple as visual examination or advanced as tests carried out in laboratory.
Repackaging	Allocation of products into the most suitable loading unit for storage. For instance, many products are bought in bulk on pallets and then stored in boxes. This may include labelling products for easier identification.
Put away	Process of placing and handling material in storage. This considers the withdrawal principle, e.g., whether products should be picked according to FIFO, FEFO or LIFO. It comprises the distribution of material to other organizational departments that required it.
Storage	Physical confinement of goods pending a demand.
Replenishment	Primary picking locations are replenished from reserve storage locations.
Order picking	Process of removing certain products from the storage area in the right quantity to satisfy a set of customer orders.
Sorting	Process of selecting, organizing, and grouping individual items from inventory according to the specific requirements of a customer's order to streamline order fulfilment processes.
Packing	Preparation of selected items for shipment to customers. It includes the packaging of goods into an appropriate transport container and the application of labels, invoices, or other necessary documentation.
Cross-docking	Supply Chain strategy that involves the direct transfer of goods from inbound vehicles to outbound ones with little or no storage time in between.
Shipping	Process of delivering products to customers. It involves loading vehicles for dispatch in the reverse order of unloading.

It is generally in these facilities that the flow of material between the supplier and the client is consolidated, and customer orders are materialised. The consolidation process occurs when a customer orders several product lines and wants them to be delivered together.

The storage of products reduces procurement and transport costs, increases process efficiency, and shortens lead times. This enables organisations to adapt to the intrinsic changes of the market and to add value to the different processes of the supply chain in order to achieve economies of scale and better service levels.

The typical configuration of warehouses is moving towards greater horizontal operation, lower space utilization, less reserve storage volume and a greater number of doors and docks in order to increase and simplify in-and-out flows.

In a traditional warehouse process flow as illustrated in Figure 3, the receiving, inspection, repackaging and put away operations take place in the Inbound Staging area, whilst the order-picking, packing and shipping processes occur in the Outbound zone. While in the Case Picking area articles are picked per case from various storage mediums, in the Broken-Case Picking area these are separated into individual units for order fulfilment.

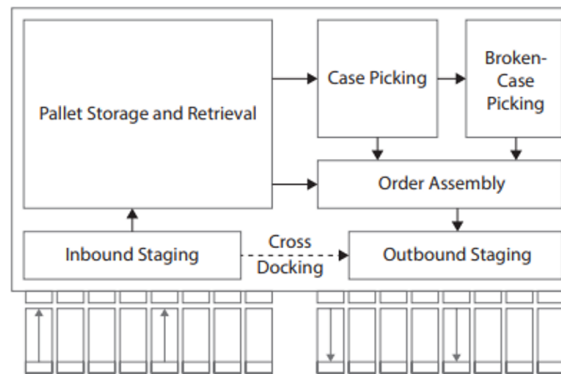


Figure 3 - Traditional warehouse process flow (Frazelle, 2016)

The basic principles of a storage system focus on maximizing the use of available space, minimizing movements, controlling material flows, and ensuring the safety and security of goods and personnel, at a minimum cost.

These require meeting operational and product constraints such as volume and weight compatibility, separating high-flow areas, segregating order picking stock from reserve stock, and defining the most suitable loading unit to streamline material handling. As such, it is crucial to establish location systems for products:

- **Fixed Location:** Items being stored have predetermined storage locations, depending on the product or family of products. The warehouse capacity needs to be established for maximum stock levels.
- **Dynamic Location:** There are no predefined storage positions for the allocation of a product or family of products since they can be stored in any free location within the racking or shelving. Storage space can be defined for average stock levels, including a safety margin. It requires an IT-supported warehouse management system.

Additionally, the flow of materials in a warehouse should also be specified for better control of product movements.

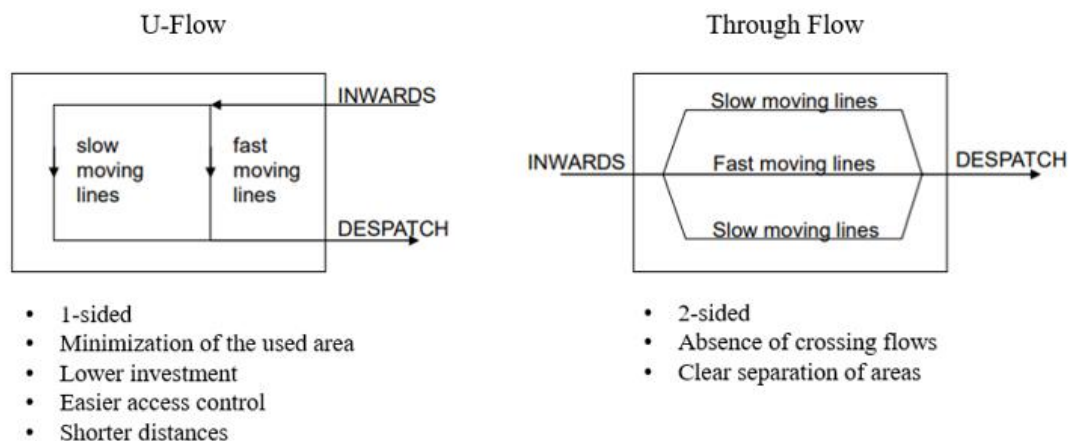


Figure 4 - Distinct types of warehouse flows, adapted from Carvalho (2012)

There are several types of warehouse designations according to the types of products stored and the functions performed: raw materials, work in progress (WIP), finished goods and distribution centers.

Stocking quantities must take into consideration the balance between the supply and demand in order to react to unforeseen events and to avoid lost sales while minimizing costs. The amount of products or parts stored should be in accordance with the level of service to be provided.

Stock can be defined as all purchased materials, spare parts and products that are not for immediate use or sale. Despite being able to add great value to a company, these assets are generally devalued as they do not represent profit margins. The value of these items depreciates over time since they present obsolescence and degradation risks.

There is a wide variety of stocks regarding their nature, such as raw material, components and WIP which are responsible for feeding production processes, finished products that are stored at the end of the production line, pipeline stocks held in the distribution chain for delivery to the end customer, and spare parts used for repair and maintenance (Rushton et al., 2022).

Beyond the aforementioned categories, it is possible to classify the stored goods into working, safety, speculative and seasonal stock according to their purpose.

Table 4 - Stock categories (Rushton et al., 2022)

Working stock	Stock of products in large quantities to cover small and frequent orders according to the expected demand.
Safety stock	Stock which covers unexpected fluctuations in demand - Figure 5.
Speculative stock	Raw materials and parts purchased in advance and finished products to meet expected future increases in demand.
Seasonal stock	Products that respond to seasonal peaks in demand.

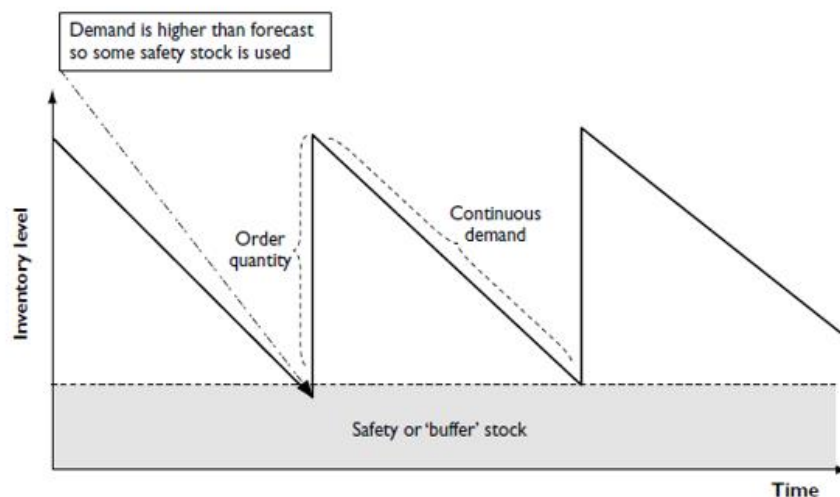


Figure 5 - Inventory levels with safety stock in place (Rushton et al., 2022)

Stock must be stored in strategic positions along the logistics network as hubs or contact points between suppliers and customers. By holding stock, it is possible to improve service levels, reduce production, transport, and buying costs, accommodate seasonal variations in demand, cover delays in Supply Chain lead times and benefit from quantity discounts (Richards, 2011).

While holding low stock levels precludes the immediate fulfilment of customer orders, high stock levels require large capital investment and present risks.

Inventory replenishment systems are essential to balance the aforementioned disadvantages. They can be based on periodic reviews, in which stock is reviewed at regular intervals and the quantity replenished varies, or on fixed point reorders, in which the same quantity of product is ordered (Economic Order Quantity) when the reorder point of stock has been reached.

To conclude, warehouse management aims to plan and control operations to efficiently fulfil customer orders with the most appropriated resources and support systems - Figure 6.

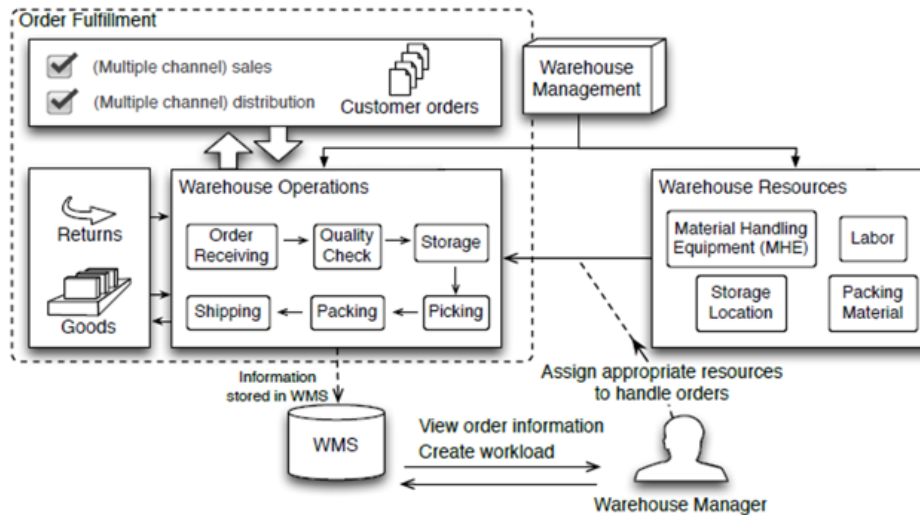


Figure 6 - Warehouse Management Integration (Linde and Akerblom, 2016)

Warehouse Costs

Inventory storage requires continuous investment since it entails facilities, workforce, equipment, information systems and maintenance costs. Consequently, the number, location, and storage systems of warehouses, as well as their technologies and equipment, must be considered when balancing costs and required customer service levels.

Warehouse costs can be segregated into distinct categories according to Barros (2005).

- **Fixed costs:** which include administrative expenses such as salaries, insurance, and accounting costs.
- **Variable costs related to stock movement and handling:** related to warehouse operations from the loading and unloading of vehicles to the order preparation.
- **Variable expenses associated with the warehouse facilities:** including rent, security, and maintenance.
- **Stock holding costs:** that comprise risk cost associated with deterioration, obsolescence, damage, and theft.
- **Out-of-stock costs:** which cover the cost of lost sales and delays.

Warehousing costs account for about 2 to 5% of sales (Frazelle, 2016) and for 22% of a company's logistics expenses (Richards, 2011). These costs are dependent on many factors such as industry sector, company size, geographical location, stock volume and process efficiency.

Despite the challenge of quantifying costs, it is generally accepted that the most preponderant ones are related to manpower and space rent - Figure 7.

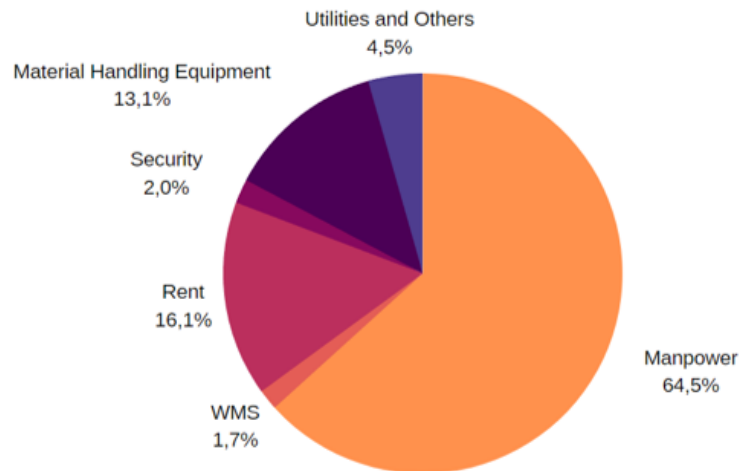


Figure 7 - Warehouse costs, adapted from Frazelle, (2016)

Thereby, the automation of a warehouse leads to significant cost savings while allowing the increase of throughput rates and inventory turnover. The growing use of information technologies leads to a decrease in the need for manpower and a better use of storage capacity, since it helps to allocate and organize stock in a more effective and efficient way according to product specifications (Frazelle, 2016).

Regarding operations, order picking is the activity that presents the highest cost, followed by sorting, dispatching, and packing as presented in Figure 8. Order preparation can be optimized when supported by technologies such as automated systems, WMS and RFID solutions.

WMS enables the visualization of inventory levels in real time and their exact location, which leads to a greater efficiency of these processes. Furthermore, they enable the optimization of space utilization and the reduction of inventory and labor costs, while improving the operators' quality of work.

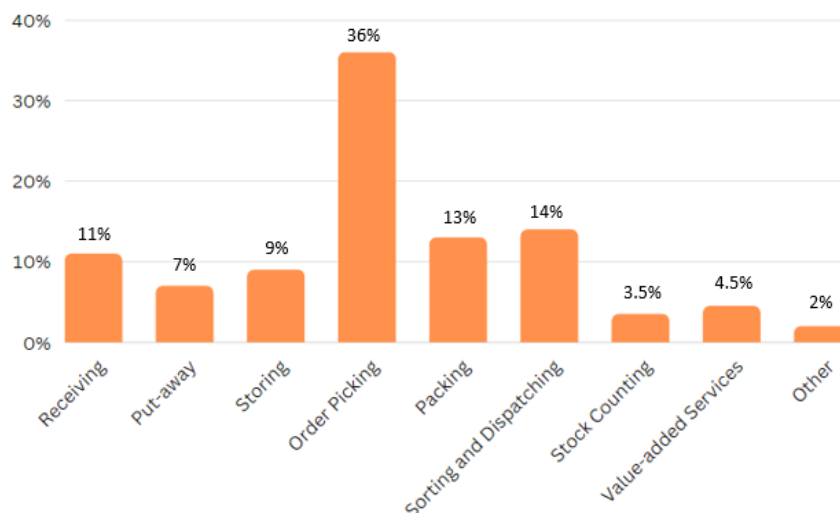


Figure 8 - Warehouse activities as a percentage of warehouse costs, adapted from Škerlić and Muha (2017)

Digital transformation is a rising tendency as the dematerialisation of documents and processes drives down costs and learning times of new collaborators rendering organisations more efficient, reliable, and sustainable. Several firms are currently investing in the application of artificial intelligence (AI) systems and in the implementation of robotic systems and intelligent sensors within warehouses (Frazelle, 2016).

2.3 Warehouse Management Systems and Technologies

The current competitiveness of the market forces organizations to differentiate themselves. A Warehouse Management System ensures to increase the levels of automation, accuracy, and productivity within organizations by combining Information and Communication technologies with Supply Chain processes, namely at the production and distribution level.

WMS is a database-driven software program which controls stock storage, movement, and its associated transactions. The main purpose of this module consists of optimizing how warehouse resources are allocated within the storage area, by facilitating their organization, management, and planning.

The major functionalities of these systems in a company's logistics activity are summarised in Tables 5 and 6 (Carujo, 2021).

Table 5 - Core functionalities of WMS

Order planning and allocation	Process of planning and assigning physical inventory items to shipping orders according to priority and order status. WMS enables a fast, accurate, and meticulous order reception at the warehouse, which improves the operating system's performance and service planning.
Resource planning and allocation	Automatic planning of workforce and material handling equipment assignment by task allocation on a daily basis.
Receiving	Support for receipt registration and confirmation, product and quantity validation, quality audits, label reading, repackaging and returned goods management providing stock levels visibility.
Put away and Stock Locating	Definition of storage groups and routes to place the received articles, suggestion of positions based on existing stock and articles/locations reading support. WMS provides a clear overview of the warehouse layout facilitating its adaptation.
Flow of goods	Management and optimization of the flow of products, namely the transfers between storage areas (e.g., reserve and picking locations) or warehouses that can either be owned or outsourced.
Replenishment	Support in the transfer of stock from reserve storage locations to picking positions according to maximum or minimum capacities and current orders, to maintain adequate inventory levels to meet customer demand.
Order picking	Selection of the most appropriate picking method, such as picking by piece, by case, by pallet, by batch, by zone, by wave and automatic picking systems support like voice picking or pick-to-light. The system anticipates packaging needs while minimising resources used.
Shipping	Selection of the optimal shipping mode, such as the means of transport and carriers. WMS provides automatic document creation (as manifests and advanced shipping notices), label printing and package tracking.
Packing control	Definition and control of quantities and cargo packing modes and creation of shipping containers: single or multiple waybills.
Inventory Management	Support of the cycle counting process whether it is user or system directed, by grouping or zone. It reports on the registration of inventories and stock differences identified.
Task Interleaving	Productivity strategy that consists of combining several tasks on a single run through the warehouse to reduce the total travelled distance.
Reports	Comprehensive monitoring of the warehouse's daily activity, creation of dashboards and management tools such as logistics performance reports.

Table 6 - Extended functionalities of WMS

Slotting	Allocation of optimal storage locations for products according to their availability, demand, size, weight, and turnover characteristics. It involves analysis of historical data and reorganization of the warehouse layout.
Yard Management	Management of resources, activities, and inventory in a warehouse yard which involves tracking trailer and container movements, scheduling dock activities, and dock allocation to vehicles. It reduces truck waiting times and costs associated with demurrage and detention.
Voice Picking	Support to order picking system where warehouse workers use voice recognition technology to receive instructions and confirm completed tasks, enabling a hands-free operation.
Parcel Manifesting	Communication and information sharing between the warehouse and the carriers, whether these are by rail, air, ocean. This functionality generates shipping labels, packing slips and other documentation necessary for the dispatch of orders, often integrated with carrier software.
Kitting	Support of the creation process of new products through the assembly of component items. The system suggests and predefines the component ratios by knowing the bill of materials (BOM).
3PL Billing	Invoicing process for services provided by third-party logistics (3PL) providers, including warehousing, transportation, and value-added services. It is often integrated with accounting software.

These systems emerge from the evolution of control systems (WCS) exclusively focused on controlling automated material handling equipment such as conveyors, sorters, automated storage and retrieval systems (ASRS) and automatically guided vehicles (AGV). This evolution has enabled the optimization of both operational (material flow) and administrative (information flow) activities through inventory and labor management, order processing, slotting optimization, and reporting.

WMSs improve the traceability, reliability, and flexibility of processes by presenting real-time information through dashboards and reports with self-verification systems which ensure the validation and control of the data collected and the information presented.

According to their functions, these solutions can be classified into three categories (Subramanya and Rangaswamy, 2012).

- **Basic:** if it is oriented towards recording information by focusing on throughputs and controlling the different stock disposals and locations.
- **Advanced:** if it is capable of analysing outputs, stocks, and capacity in order to plan resources and operations and synchronise the flow of products.
- **Complex:** if it is focused on optimizing and planning value-added functions for SC such as segmented product, dock information and transportation network.

Besides characterizing the current situation of the warehouse, warehouse management systems also provide recommendations for improvement. At the operational level, they prevent re-work by monitoring people, processes, and equipment.

This type of software usually features some hardware flexibility and can be integrated into an existing module of an ERP system or implemented on its own through local or cloud deployment. Cloud deployment refers to the hosting and use of software on remote servers accessed via the internet, while on-premises implementation involves the installation and operation of software on local infrastructure within the organisation's physical facilities.

The cloud deployment can be either dedicated/single or multi-tenant. In a dedicated deployment, the software is provisioned exclusively for a single organisation, providing them with stand-alone resources and customisation options, whereas in a multi-tenant one the WMS software is shared between multiple organisations using a single infrastructure, with each organisation having its data and settings isolated for security and privacy.

By centralizing information, these solutions enable an increase in storage density since they support the dynamic localization system in which there is no need to reserve the maximum storage space for each product.

All hierarchical levels must be involved in the implementation and application of these systems in order to establish a culture of continuous improvement inside the corporations. This process takes time, investment and requires a redesign and restructuring of processes, otherwise it will only solve human failures.

In order to achieve this cultural change and overcome the resistance presented by the workforce, it is crucial to assure a correct implementation of the WMS through a good IT support structure and by dedicating time to the parameterization of the system by codifying products, zones, and operations.

A quantitative and qualitative cost-benefit analysis should be performed before its implementation. Besides economic and financial studies, the return on non-financial drivers such as increased service level, customer satisfaction, brand recognition, innovation and improved working conditions for pickers should be assessed. Subsequently, it is necessary to invest in the management and control of the installed solutions as well as to audit them to analyse what can be improved (Whiting, 2021).

WMS applications often enable the digitalization and automation of warehouses since they support several IT solutions such as data capture and transmission devices and automated equipment. These technologies include hand-held terminals and personal digital assistants (PDAs), barcodes, RFID, voice picking, pick and put to light, cobots, AGVs and automated storage and retrieval systems (ASRS).

Put away, picking, replenishment and packing processes can be assisted by optical reading terminals or by voice picking solutions, the latter presenting productivity gains of 30% and error elimination of 20% as they allow hands-free operations (Škerlić and Muha, 2017).

Alternatively, put and pick to light can be used to guide the operator from where to pick and place items, although this is a more expensive solution since it requires LEDs for each location.

Regarding the reading terminals, these can read barcodes or RFID tags. While barcodes usually only contain the code of the product, pallet or location and are laser scanned in the visual field of the device, radio frequency tags are readable at distance in all three directions and can contain more information.

Table 7 - Comparison of IT solutions price

Solution	Price
Hand-held terminals / PDA	300 – 3.000 €
Voice Picking	2.500 - 3.000 € by user 50 €/month by user 10.000 € / implementation
Put and Pick to Light	100 - 200 € by location 10.000 € /implementation
Cobot	35.000 €
AGV	40.000 - 200.000 €
Automated storage systems	70.000 - 1.500.000 €

2.4 Analytic Hierarchy Process Method

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method which provides a comprehensive and rational procedure for structuring problems, representing, and comparing decision criteria and assessing alternative solutions through qualitative and quantitative analysis.

This method involves a hierarchical structuring of criteria and alternatives with the objective of simplifying the decision problem. Thus, relative weights or priorities are assigned to each evaluation criteria based on their importance to the overall objective in order to obtain the best measure of performance (Wolff, 2008).

These weights are defined through a scale of priorities in pairwise comparisons, represented in Figure 9.

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favour one over the other.
5	Much more important	Experience and judgement strongly favour one over the other.
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice.
9	Absolutely more important.	The evidence favouring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

Figure 9 - The Saaty Rating Scale (Coyle, 2004)

AHP method usually entails several steps:

- Definition of the decision objective and significant criteria.
- Assignment of the relative importance to each pair of criteria using the Saaty scale.
- Construction of a pairwise comparison matrix in which the most important element is always used as an integer value of the scale, and the least important as the inverse of that unit.
- Calculation of priority weights, the consistency index (1) and the consistency ratio (2) where $\lambda_{\max}$ is the highest eigenvalue of the matrix, n corresponds to its size and RI is the average random index that depends on matrix order (Figure 10). If the consistency ratio is less than 0.1, then there is consistency to proceed with the analysis.

$$\text{Consistency Index (CI)} = \frac{\lambda_{\max} - n}{n - 1} \quad (1)$$

$$\text{Consistency Ratio (CR)} = \frac{CI}{RI} \quad (2)$$

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Figure 10 - Saaty's random consistency index (Prasad and Kousalya, 2017)

3 Development of a System Selection Framework for Warehouse Management

The process of electing an information system adequate for the needs of a specific warehouse and company is guided by a step-by-step framework built upon certain evaluation parameters.

3.1 Evaluation Parameters

3.1.1 Requirements for Warehouse Information Systems

The definition of requirements is one of the most critical steps in the implementation of an information system in order to align the system functionalities with user needs, manage expectations, ensure quality and support, provide long-term maintenance assistance, balance costs and control development and deployment times. Therefore, key requirements were identified in order to compare WMSs according to their critical capabilities, in Table 8.

Table 8 - Key requirements for WMS, adapted from Tunstall and Klappich (2022)

Core WMS	Basic WMS functions such as receiving, quality control, put away and stock locating, inventory management, cycle counting, order picking, replenishment, packing, shipping, and cross-docking, as well as RFID and barcode technology support.
Extended WMS	Broader WMS capabilities such as additional modules for labor management, task planning and optimization, slotting, yard management, dock scheduling, value-added services as kitting, 3PL billing, parcel manifesting and order management.
User Experience (UX)	The user-friendliness and usability of the interface measured by its design, UX testing and feedback. It includes responsive UI design, workflow management tools, visualization capabilities, differentiated access, and interaction modes such as mobile, voice, and augmented reality (AR).
Analytics/BI	Reporting, descriptive, and predictive analyses, AI capabilities (machine learning), modelling and simulation (Digital Twins) features.
Implementation Tools	WMS implementation and configuration tools, such as wizards, partner network, software development kits (SDKs), APIs, and documentation.
Adaptability	The ability to be responsive and configurable with tools such as rule engines, no-/low-code development and scripting languages.
Supporting Technologies	Technologies supported by the WMS, such as mobile devices, RFID and voice technologies, wearables, smart glasses, conversational agents, robots, smart carts, put walls regarding the maturity of the integration.
Material Handling Integration	Integration of material handling equipment such as forklifts, order pickers, conveyors, trolleys, AGVs via a native Warehouse Control System for further automation.
Simplicity	Easy of understanding, using, configuring, and maintaining the WMS with no unnecessary complexity.

The pricing model, deployment mode, major sectors and levels of warehouse operation, product types being managed, and integrations should also be evaluated when comparing and evaluating warehouse management systems.

Successful and effective information systems can only be selected and developed by understanding customer needs and priorities. This is the only way for systems to add value to controlled operations and adapt to the intrinsic changes of business environments.

3.1.2 Key Performance Indicators

Warehouse management systems are able to assess and optimize the performance of warehouse operations due to their analytical capabilities for calculating Key Performance Indicators (KPIs). These indicators can also be estimated externally, automatically extracted into databases and monitored via dashboards.

KPIs consist of quantitative or qualitative metrics that enable the measurement and monitoring of customer service and process efficiency, accuracy, and productivity in order to identify bottlenecks and opportunities for improvement. These support data-driven decision-making and the definition of benchmarks which promote continuous improvement and alignment of operations with strategic objectives.

It is extremely important that the information system that supports the warehousing operations is capable of obtaining some of the following KPIs (Rushton et al., 2022).

Cost Efficiency

- Cost per unit of cargo (e.g., carton or pallet) or weight;
- Cost per stock position;
- Cost of reception per supplier order line;
- Cost of put away per line stowed;
- Cost of picking per order line;
- Cost of shipping per order;
- Cost per order processed;
- Budget compliance for costs of personnel, maintenance, equipment, and packaging materials.

Service Levels

- Order lead time (time between the moment of the customers' order and the arrival of the product to them);
- Accuracy of order fill (number of order preparation/picking errors);
- Orders fully satisfied i.e., all order lines supplied (%);
- Orders supplied on first request (%);
- Orders delivered within the specified time (%);
- Number of stock-outs;
- Damaged or lost items (%);
- Number of returns and customer complaints.

Productivity

- Number of loads and unloads per hour;
- Volume received per man-hour;
- Number of received lines/cases/pallets put away per man-hour;
- Number of order lines/cases/pallets picked per man-hour;
- Number of consolidated/shipped orders per man-hour;
- Equipment uptime (hours of equipment availability without breakdowns or routine maintenance).

Resource Utilization

- Warehouse/rack/pallet storage capacity used (%);
- Utilization of labor and equipment for picking (%);
- Utilization of labor and equipment for put away (%);
- Dock utilization (%);
- Number of working hours of the personnel and material handling equipment;
- Absenteeism and sickness rates (%).

Stock integrity

- Positions with correct stock (%);
- Obsolete stock over sales (%);
- Stock turnover (cost of goods sold/average inventory level);
- Stock coverage (stock volume/ average demand);
- Maximum and minimum stock levels for each article.

Cycle Times

- Reception/put away/shipping process time;
- Picking time per order;
- Average number of hours between customer order receipt and dispatch of goods;
- Average number of hours between the arrival of goods on site and their put away to storage location (i.e., available for replenishment or picking).

Safety

- Number of days without an accident;
- Number and seriousness of accidents;
- Number of days of safety training.

3.1.3 Warehouse Operation Levels

Five levels of warehouse operation were defined regarding the critical capabilities of its operating systems - Table 9. For each level, a relative weight of importance was assigned to each WMS key requirement, as presented in a reference table - Table 10. This was an analysis performed by Gartner based on internal metrics to assess typical warehousing operations.

Table 9 - Levels of warehouse operations, adapted from Tunstall and Klappich (2022)

Level 1	Level 1 warehouses are generally characterized by manual operations and fixed location systems, mainly requiring the core functions of a WMS, such as receiving, storage, picking and shipping. They often consist of stockrooms, service depots or small retail shops that do not need major IT support, only stock localization.
Level 2	Level 2 warehouses are paper based but aiming at further digitalization. Besides supporting basic warehouse operations, their systems provide multi-site stock warehousing functionalities and direct put away activities, with a focus on simplicity and usability.
Level 3	At this level, systems are more complex and optimize resources in a more automated and integrated way focusing on process improvement. Their functionalities are deeper as they coordinate operations of cross-docking, task interleaving, wave planning, multiple picking, batch control, packing and cycle counting. Level 3 requires more flexibility and customization such as the introduction of advanced locators and scripting languages.
Level 4	At level 4, the emphasis is on the automation, agility, and adaptation of processes by adding value-added decision support capabilities. These include task, workforce, slotting, carrier, 3PLS and dock management based on business intelligence and information transparency and traceability. Level 4 covers more sophisticated operations such as wave or waveless planning, light assembly, and kitting.
Level 5	Level 5 operations focus on the extensive use of material handling automation systems (WCS). Sometimes entire facilities are designed to support highly automated technologies as conveyors, AGVs, and ASRS systems.

Table 10 - Weighting of key requirements at the various warehouse levels (Tunstall and Klappich, 2022a)

Key Requirements	Level 1	Level 2	Level 3	Level 4	Level 5
Core WMS	10%	15%	40%	25%	5%
Extended WMS	0%	0%	15%	30%	5%
User Experience	10%	15%	10%	10%	5%
Analytics/BI	0%	5%	10%	10%	15%
Implementation Tools	5%	10%	10%	0%	5%
Adaptability	5%	10%	10%	10%	10%
Supporting Technologies	0%	0%	5%	10%	10%
Material Handling Integration	0%	0%	0%	5%	45%
Simplicity	70%	45%	0%	0%	0%

Selecting a WMS that is appropriate to the level of warehouse operation is extremely important. As such, the most common levels supported by each system will later be analysed.

3.2 Conceptualization of the System Selection Framework

This framework serves to facilitate and organize the selection of a provider and warehouse management system, since these systems are complex and there is a diversity of alternatives on the market.

Initially, the factors and criteria that must be considered when choosing a system were identified. These were organized in order to guide a consistent and efficient selection in different contexts that enables organizations to choose the most suitable system for their needs. Finally, this framework was proposed and discussed with system experts and then applied to a case study.

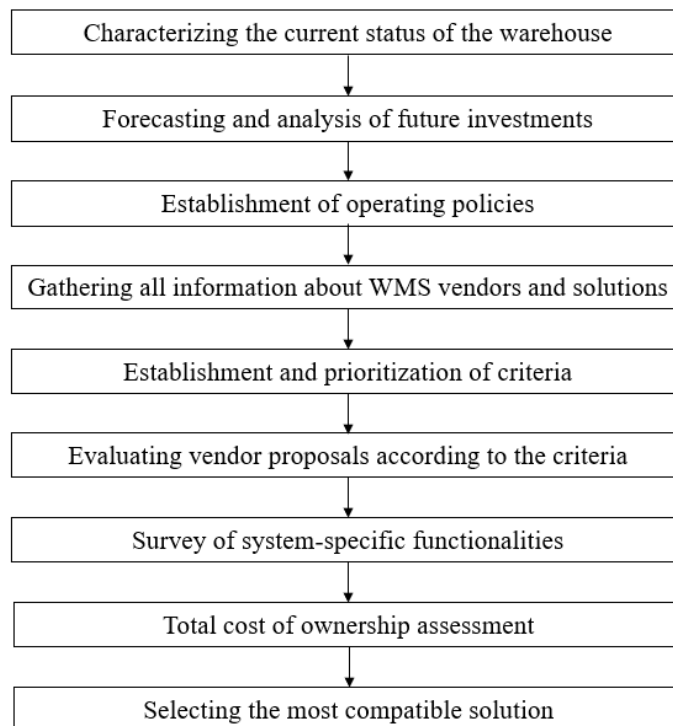


Figure 11 - System selection framework

Characterizing the current status of the warehouse

Initially, it is fundamental to specify the type and purpose of the warehouse by characterising the current situation. The complexity of the operation must be defined, namely the storage capacity and area, the diversity and type of products, the number of picking lines processed, the inbound and outbound flows such as the number of pallets received and dispatched, and the number of docks.

It is also important to assess requirements and needs for integration of handling equipment as well as storage systems. Thus, the level of the warehouse operation can be defined according to Table 9.

Forecasting and analysis of future investments

All upcoming technological investments in the warehouse must be considered as well as the growth perspectives of the operation, so that the chosen selection not only meets the present needs but is capable of covering future ones. It is essential to precisely map out the warehouse digitalization plan in order to ensure the best suitability of the system.

Establishment of operating policies

Prior to the choice and implementation of any information system, the processes and their sequence must be well established by means of flowcharts. It is imperative to parameterise all item-related attributes and to identify all storage systems, zones, and locations.

This step is one of the most important for the future use of the system, since without solid and accurate data the support from the system is limited.

Gathering all information about WMS vendors and solutions

Collection of the widest possible range of information about suppliers and WMS solutions in professional magazines, catalogues, interviews, case studies and demonstrations.

This research should be comprehensive and include both established and emerging vendors to ascertain their characteristics in terms of sectors and sizes of operation, implementation modes, integration capabilities, and pricing models. Those suppliers that are clearly not qualified should be eliminated from the survey.

Establishment and prioritization of criteria

The main requirements of the WMS must be defined for each operation, based on Table 8. The analytic hierarchy process can be used to prioritize the criteria, requiring the assignment of importance to each evaluation parameter with a pairwise matrix by using the Saaty scale. It enables the calculation of the relative weight for each individual criteria.

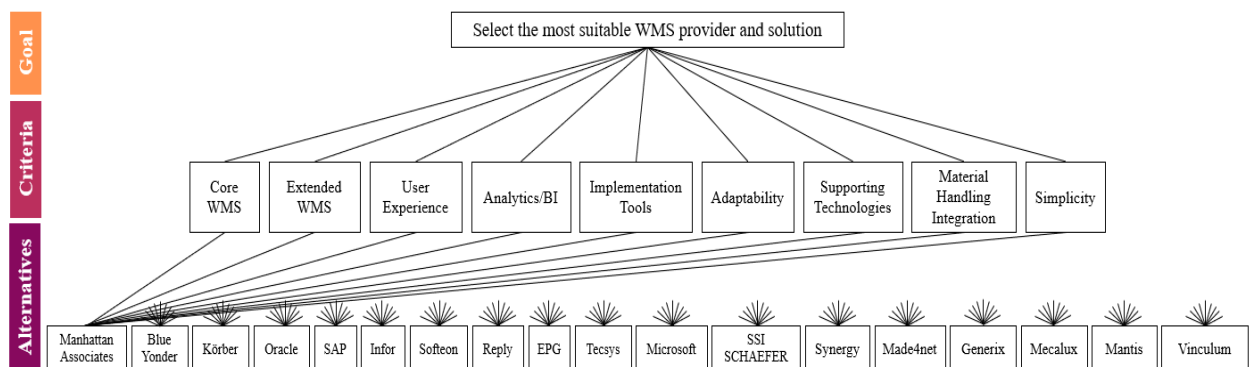


Figure 12 - Hierarchy for selecting a WMS provider and solution based on key requirements

It should be analysed which providers best meet key requirements such as features, usability, adaptability, and deployment and support tools, in order to select the most appropriate solution. Alternatives are evaluated based on criteria that contribute to the goal achievement as represented in Figure 12. All alternatives should be linked to all criteria, as Manhattan Associates.

Evaluating vendor proposals according to criteria

By combining the weighting of each criteria with the vendors' rating for each one, the top scoring suppliers should be chosen as they best meet the identified needs.

After evaluating providers based on requirements, further factors must be taken into account, such as sectors of activity, integration platforms, implementation modes, and the levels and dimensions of warehouse operations supported by them.

Survey of system-specific functionalities

For choosing the system that better addresses the identified needs, the basic and extended functionalities covered by the systems should be thoroughly evaluated as well as the sector-specific features.

Furthermore, the KPIs calculated by the systems should be analysed in order to provide relevant information for improvements.

Total cost of ownership assessment

The upfront and ongoing costs associated with the implementation and maintenance of the WMS should be considered, such as licensing or subscription fees, implementation costs, training expenses, and support costs charges. In addition, charges can be levied for consulting services, user training, and technical support for updates.

The cost of a WMS solution can vary significantly depending on the size of the company, operations complexity, required functionalities, number of users and transactions, and integrations with other systems.

Selecting the most compatible solution

After gathering all the information and feedback, the solution that best aligns with the business requirements, pricing, and integration needs has to be selected. An implementation plan must be elaborated with the chosen provider and the resources and timeline for the process must be defined. The implementation should be ensured through data migration, testing, and user training.

Finally, the selected system must be continuously monitored and optimized by identifying areas for improvement with user feedback.

4 Benchmarking of IT Providers

Information technologies which support warehousing operations ensure on-time compliance and customer satisfaction. However, with a multitude of IT vendors in the market, selecting a partner can be a daunting task.

It has become crucial to assess and compare providers and their offered solutions, in terms of capabilities, deployment and pricing models, strongest sectors and levels of operation, to identify the best solution for each business. Only by benchmarking the various providers against the standards and best practices in each sector can informed decisions be made.

The benchmarking process relies on the continuous measurement and comparison of the performance of systems and providers under evaluation, which includes the identification of key features, strengths and cautions, integration capabilities and customer support provided by each vendor - Appendix A. This enables the discovery of breakthrough solutions and emerging technologies, a comprehensive understanding of each provider's strategic objectives and improvement implementation.

In order to find the best IT solution for the warehouse management process, a market analysis was performed and around 100 solutions from various service providers were identified. After deep research of the different software characteristics, considering Gartner's and other companies' analysis and recommendations, it was possible to select 18 service providers whose solutions are at the forefront and stand out from the competition.



Figure 13 - IT providers under evaluation

According to Figure 14, in Gartner's analysis WMS vendors are evaluated according to their ability to execute and completeness of vision.

Regarding the ability to execute, criteria such as pricing, breadth and depth of product capabilities, technical cloud architectures, ability to provide support services for effective deployment and usage, viability and visibility, customer base, goal achievement and market responsiveness of each provider were considered.

As for completeness of vision, it relies on market, product, marketing, sales, geographic and verticalization strategies, considering market understanding, innovation, and soundness of business models.

In this analysis, the best WMS solutions providers identified in 2023 are allocated to four distinct quadrants characterised by specific features. In order to compare these solutions, the providers were addressed, interviews were conducted, demonstrations were attended, and case studies and catalogues were analysed – Appendix B.



Figure 14 - Magic Quadrant for Warehouse Management Systems (Tunstall et al., 2023)

4.1 Leaders Quadrant

The leading SCM WMS vendors stand out due to the sophistication and complexity of their systems when operations require in-depth and extended capabilities (Tunstall et al., 2023).

- Great proven success in medium to highly complex warehouses;
- Large customer base and strong new client's growth through consistent performance;
- Extensive market visibility and global scalability;
- Comprehensive WMS capabilities aligned with an SCE (Supply Chain Execution) convergence strategy.

4.1.1 Manhattan Associates

Manhattan Associates is a U.S.-headquartered provider with \$767 million of revenue that offers a broad suite of SCM solutions, including warehouse, transportation, distributed order and omnichannel management systems. These are deployed either on-premises or on its microservices multi-tenant cloud architecture which supports extensibility and continuous updates across its 1.600 customers (Tunstall et al., 2023).

This vendor offers three adaptable and seamlessly interconnectable solutions that combine demand, supply, labor, slotting and automation into reliable tools to measure the efficiency and fulfilment across warehouse facilities - Figure 15 (Associates, 2022).

- **Manhattan SCALE:** based on a Microsoft interface, usually serves small and medium-sized business (SMBs) and 3PLs whose warehouses are Level 2 and 3.
- **Manhattan Warehouse Management for IBMi (WMi):** most suitable for IBMi platform clients with Level 3 and 4 warehouse operations.
- **Manhattan Active Warehouse Management (WM):** versionless system that never needs upgrading or extending, often used in complex and highly automated warehouse environments (Level 4 and 5). It cannot be deployed on-premises.

Manhattan predominantly serves the retail, e-commerce, grocery, apparel/footwear, 3PL and wholesale distribution sectors, featuring modules for order processing, inventory, billing, labor, claims and yard management, slotting and picking optimization, cycle counting and carrier integration. It also embeds WCSs to support technologies as conveyors and retrieval systems (ASRS).

Some of its limitations include the inability to issue receipts prior to shipments and to customize put away rules.

Although Manhattan is renowned for translating customer requirements into quality products and it was the first provider to re-architect its WMS on a multi-tenant microservices cloud, its solutions require some investment and supporting effort. Its pricing model is license or subscription based, requiring a minimum commitment of 1 year (SelectHub, 2023a).

Further, Appendix C demonstrates the catalogue of this provider showing the capabilities of the system by industry.

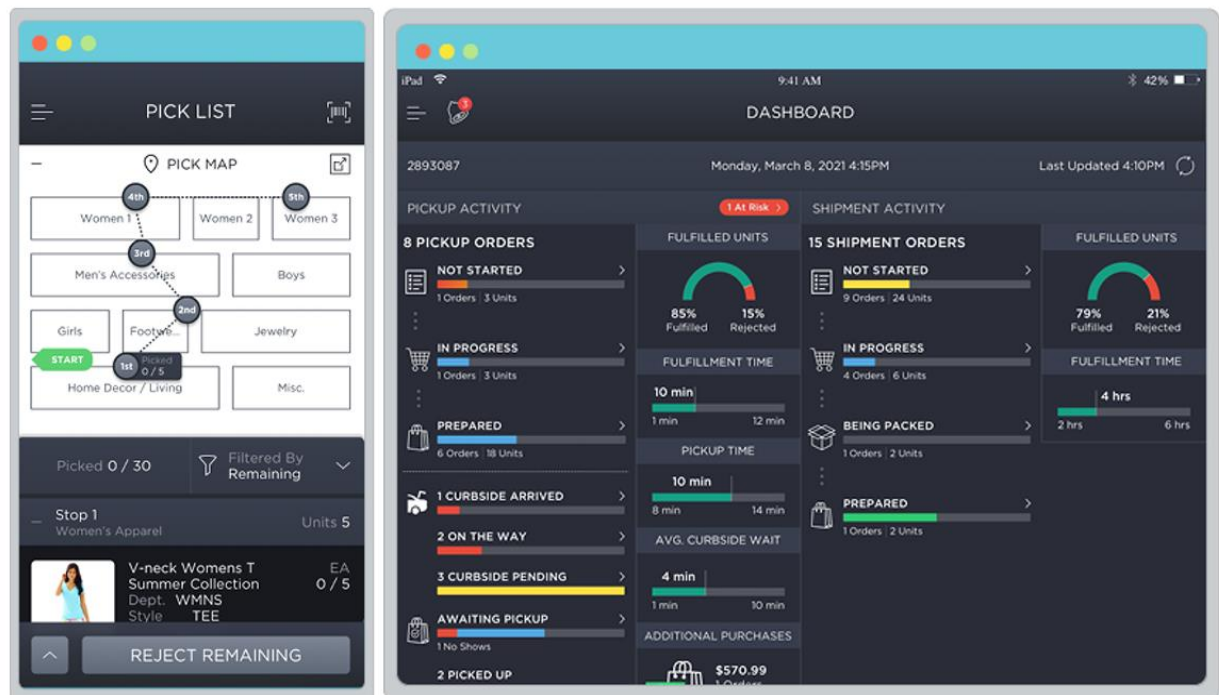


Figure 15 - Manhattan Active WMS order picking and performance dashboards (Associates, 2020)

4.1.2 Blue Yonder (JDA)

Blue Yonder, previously known as JDA, continues to be the largest independent SCM suite vendor with around \$1.25 billion in sales, 1,000 WMS clients and 88 global partners. It offers an SCM solution platform that includes supply chain planning and warehouse, transportation, and labor management systems in combination with advanced analytics and AI tools.

Blue Yonder provides two WMS applications most commonly used in sophisticated Level 3 and 4 operations but can be scaled up from Level 2 to 5 (Tunstall et al., 2023).

- **Luminate Logistics:** an intuitive cloud native SaaS mobile solution scalable with microservices/APIs.
- **JDA Dispatcher (Legacy):** a software application focused on optimizing internal warehouse operations such as resource orchestration, stock management and inbound/outbound processing.

Its WMSs cover a wide variety of industries, from manufacturing to distribution, yet the most relevant ones are 3PL, consumer goods, retail, and pharmaceuticals. In manufacturing, they support processes such as kitting, light manufacturing, multi-levels BOM and raw material control, including backflushing which consists in the automatic accounting of the materials consumed for production, i.e. automatic goods issue (JDA, 2014).

Although these systems guarantee 100% improved accuracy, they lack support for multiple languages, payment processing and supplier compliance management. Also, the dashboards and notifications are not user definable.

Despite optimizing yard operations (Figure 16) and being at the forefront of AI solutions such as robotics and task orchestration, Blue Yonder systems are an expensive undertaking with non-continuous upgrades that incur financial penalties.

The provider deploys its products on-premises or cloud via licenses starting at \$250,000 or monthly subscriptions starting at \$1,200. Its WMS solutions are not true multi-tenant cloud built using microservices which can lead to complex system migrations (SelectHub, 2023a).

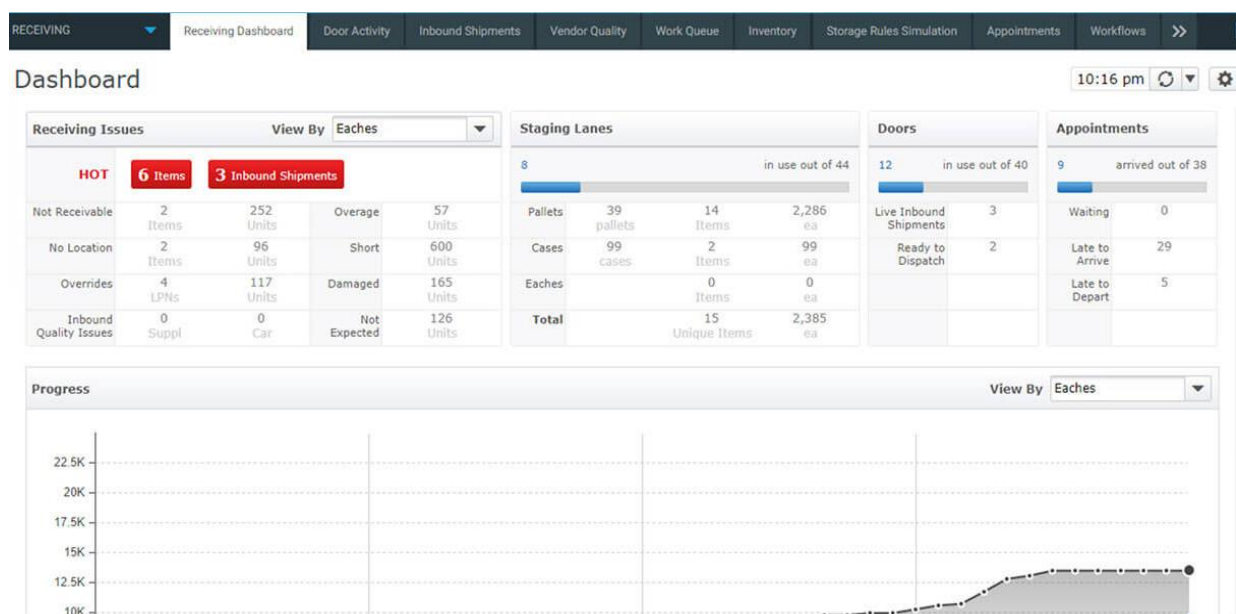


Figure 16 - Blue Yonder WMS control panel for real-time inbound processing (Yonder, 2021)

4.1.3 Körber

Körber, formerly known as HighJump and inconso, brings together twelve SC technology providers with international presence in areas such as warehousing, material handling, robotics and voice support technologies.

This vendor serves 1.600 customers with four WMS solutions whose main benefits are the fully mobile-compatible features, data capture capabilities, integration of technologies (IoT sensors, robotics and AR) and adaptable add-on modules. Its strongest sectors consist of retail, wholesale distribution, manufacturing, consumer goods, 3PLs and e-commerce (Tunstall et al., 2023).

- **K.Motion Warehouse Edge:** which mostly fits Level 2 and low Level 3 warehouses.
- **K.Motion Enterprise 3PL:** best suited to Level 3 and low Level 4 warehouses.
- **K.Motion Warehouse Advantage:** ideal for Levels 3 and 4, with some presence in Level 5 operations. This system is scalable and customizable, as it allows for specific changes at the business logic level without changing the source code of the software.
- **K.Motion WMS X:** used in France and Spain to support mainly Level 5 warehouse operation, but also capable of serving Levels 3 and 4 warehouses.

With a 99% customer retention rate, the provider complements these systems with its own WCS that enables modeling and integration of material handling equipment. It is recognized for the digitization, automation, and optimization of processes by predictive analytics through AI and machine learning and support of technologies such as conveyors, stacker cranes, shuttles, RGVs, sorters, mini loads and AGVs (Körber, 2020).

Even though Körber presents a robust partner network with more than 100 implementation affiliates, its WMSs have different logics, some complexity, high support costs and low customer relationship assistance. Currently, the provider deploys on a fully dedicated cloud but intends to move towards a multi-tenant microservices architecture.

4.1.4 Oracle

Oracle is a global software mega vendor presenting over \$41.5 billion in total revenue. It offers four systems to help reduce inventory and operating costs that can either be integrated with other Oracle's Cloud SCM solutions as Fusion Cloud SC & Manufacturing, NetSuite and Retail Merchandise Operations Management Cloud or with other non-Oracle applications.

- **Oracle Fusion Cloud WM:** a pure multi-tenant SaaS/cloud WMS for basic materials management and Level 1 operations.
- **Oracle JD Edwards EnterpriseOne WM:** which is a robust extended solution with a web-based architecture at significantly lower total cost of ownership (TCO). It uses open standards (REST APIs) to facilitate integration.
- **Oracle Retail WMS:** that streamlines the Supply Chain for multichannel retailers, including store, catalog, and e-commerce retailers.
- **Oracle Enterprise Business Suite (EBS) WM:** a comprehensive WMS that manages logistics, human resources, procurement, projects, finance, and assets lifecycle.

The provider serves mainly the retail, manufacturing, distribution, automotive and financial services sectors with support from 20 implementing partners. Its clients are well distributed across Level 2 to 5 warehouses, being more concentrated on Level 3 and requiring low material handling equipment (MHE) integration (Tunstall et al., 2023).

Oracle differentiates itself in User Experience through its Redwood platform, in application development with Visual Builder, and in technologies such as voice-enabled Digital Assistants but lacks in extended functionalities such as labor and yard management.

However, its systems are capable of monitoring task completion times, planning replenishment according to minimum and maximum stock levels, push and pull strategies and replenishment time periods and controlling inventories by batch and serial numbers, accepting two units of measure for revision control (Oracle, 2018).

Its pricing model can be based on licenses starting at \$10.000 per person for a minimum of 20 users with updates at \$2.110 or on monthly subscriptions starting at \$50 per 1000 warehouse transactions (SelectHub, 2023a).

4.1.5 SAP

SAP is a global application mega vendor with a software revenue of \$25 billion, best known as a leading ERP provider. It presents over 30 years of warehousing experience and serves 7.000 clients with three WMS solutions in the consumer goods, retail (including e-commerce, grocery and food service), automotive, industrial and construction machinery areas (AppsRunTheWorld, 2023).

- **SAP Extended WM:** frequently employed throughout Europe in Level 2 and 3 warehouses but capable of scaling up to Level 5. Since this is an advanced system with extended functionalities, it is too complex for Level 1 operations. It is estimated that 84% of its 2.300 customers hold EWM on-premises, 13% hosted in dedicated cloud, and 3% in multi-tenant.

In spite of having one of the strongest customer bases, it is best suited for SAP exclusive businesses (ECC or S/4HANA), presenting a high total cost of ownership and requiring the SAP Material Flow System option for material handling integration.

- **SAP ERP WM (Legacy):** the former version, suitable for simpler and less complex warehouse environments. It shares logic and integrates with SAP ERP Central Component.

This system features some inflexibility and low capacity to support automated warehouses, as well as lack of labor management, invoicing (integrated with the SAP Hybris billing tool) and BI functionalities (integrated with the SAP Business Objects BI platform).

- **Stock Room Management:** a component of SAP ERP that focuses on inventory management in specific areas, such as production or maintenance. Designed to serve small and manual warehouses, this solution supports the migration from SAP ECC to S4/HANA.

SAP WMS applications support the automation of distinct warehouse processes through inventory management, detailed mapping of physical article locations and the integration of external control modules such as forklift control and stock removal solutions. These integrate with ERP systems to streamline order fulfillment and financial activities.

SAP systems provide an effective management of hazardous materials and storage bin, improving planning activities and optimising warehouse operations through AR, RF mobile terminals and voice picking support technologies (SAP, 2022).

The provider generally favours a subscription-based pricing model (SelectHub, 2023a).

4.1.6 Infor

Infor, owned by Koch Industries, is one of the largest business application providers with approximately \$3.1 billion of global revenue. It offers several SCM applications embedded in its ERP solutions for warehouse, labor, 3PL billing and transport planning and management.

Infor presents a WMS solution, designated as **Infor WMS**, that supports 1,500 users in the 3PL, retail, wholesale distribution, pharma, fashion, automotive and industrial areas. This is a cloud-based application that provides real-time visibility into logistics operations and service levels through 3D virtual analytics, while enabling task prioritization, inventory cost reduction and bottleneck mitigation (Infor, 2020).

This system generally serves Level 3 operations but can support more complex Levels 4 and 5 warehouses. In its ERP systems, Infor provides the Factory Track solution suitable for low complexity warehouses (Level 1 and 2) (Tunstall et al., 2023).

Infor WMS is versionless, improves warehouse processes visualization through travel path analysis with color heat indicators (Figure 17) and enhances resource management by workload planning and equipment allocation, but it does not support material requirements planning nor integrates with FedEx or UPS.

This vendor leverages developed innovations as Birst for analytics, Coleman for AI, ION for integration between Infor and external applications, Mongoose's Object Data Modeling (ODM) library for code-free customizations, and its own Infor OS for predictive analytics.

Infor lacks experience across multiple sectors such as healthcare and has limited extended features compared to other leading providers. In addition, many of its customers present outdated systems whose upgrade is complex.

Although the vendor prefers a multi-tenant deployment in the cloud and a subscription-based pricing model, it also installs on-premises and supports perpetual licenses (SelectHub, 2023a).



Figure 17 - Infor WMS Manager Dashboard

4.2 Visionaries Quadrant

This quadrant is characterized by thought-leading providers as they offer innovative and differentiated solutions with a unique position in a specific vertical market or with distinctive go-to market strategies. These solutions are more oriented towards customer service but still have to solidify their market position (Tunstall et al., 2023).

- Coherent and innovating strategies that are at the forefront of emerging concepts;
- Lack of management capacity to handle multiple and complex requirements;
- Execution flaws at the viability and global scaling level;
- No compelling SCE (Supply Chain Execution) convergence plan or capabilities.

4.2.1 Softeon

Softeon is a modest SCE solutions provider with total revenues of \$45 million, based in North America where its 165-member customer base is centred. Although Softeon has expertise in warehousing, it is converging its SCE strategy with distributed order and transport management and planning.

Softeon WMS is this vendor's offering to optimise warehouse operations, from core activities such as receiving, put away, inventory management, barcode support, order picking, packing, loading and dispatching to value-added services as assembly, kitting support and 3PL billing.

This is a highly functional and configurable solution that is predominantly used in Level 3 and 4 operations, but it can be adapted from Level 2 to fully automated Level 5 warehouse environments. It guarantees a 100% implementation success rate, having been considered the second best for Level 5 warehouses by Gartner (Tunstall and Klappich, 2022b).

Softeon WMS controls material flow through advanced shipment notes (ASN) and blind receiving, dock activities programming and carrier system integration, simplifies integrations and simulations through Enterprise Integration Workbench (EIW) toolset and increases resource utilization by its LUCA solution which offers end-to-end work orchestration and supports voice, put walls and robotic pick to cart technologies - Figure 18. However, this system lacks sufficient support for invoicing and payment (Softeon, 2023).

Its strongest market segment is 3PL, but Softeon is expanding to other sectors such as retail, consumer goods, electronics, apparel, and healthcare where it provides added functions.

Softeon provides its WMS in three distinct ways: on-premises, dedicated cloud (the most common) and multi-tenant cloud, preferring a subscription-based pricing model. Its deployments are generally less expensive and fixed price although its network of implementation and consulting partners is not expressive (SelectHub, 2023a).

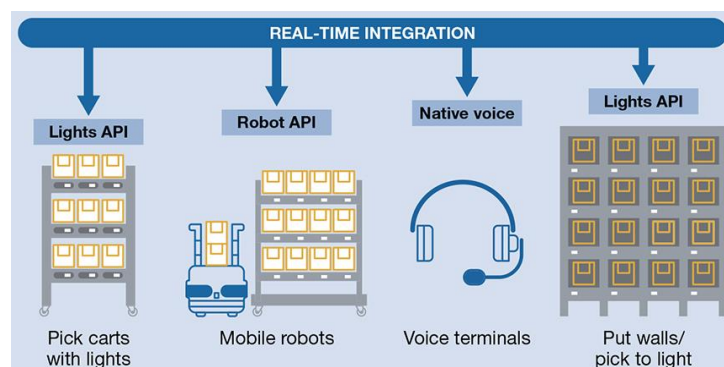


Figure 18 - Softeon's warehouse technologies (Michel, 2019)

4.2.2 Reply

Reply is a visionary IT services vendor with \$1.5 billion in total revenue and a strong focus on consulting, system integration, digital services, and cybersecurity. It offers two WMS to ensure continuous management and control of inventory (finished goods, semi-finished or spare parts), improve task monitoring, and optimize space allocation (Tunstall et al., 2023).

- **Click Reply:** its legacy system with 146 clients mainly from the automotive, industrial, service, high tech and 3PL sectors. Click Reply serves Level 3 and 4 (up to 5) warehouses globally, often using material handling automation. It can be hosted as a dedicated cloud solution (ClickReply, 2021).

Some of its limitations include no integration support for CRM, billing, and labor management features (integrated with the Click Reply Labor module).

- **(LEA Reply):** a multi-tenant cloud-based system built on a contemporary microservices architecture with 143 customers predominantly from the areas of retail, e-commerce, food and beverage, fashion, and luxury. It is most suitable for Level 2 and 3 operations, but it can support Level 4 and 5 warehouses.

Reply has pioneered the extensibility of building in microservices and presents the LEA EDGE solution that integrates the cloud-implemented WMS with other MHE applications software as well as other supporting technologies such as robots.

Despite having differences in maturity, adaptability, and architecture, these two offers present overlapping functionalities. While LEA Reply is recent and offers advanced features such as drop shipping support, supplier portal and parcel management, Click Reply still lacks a comprehensive SCE convergence strategy.

These systems can be integrated with all major ERPs and are compatible with highly automated warehouses, automated guided vehicles (AGVs), automated storage and retrieval systems (ASRS), and the latest supporting technologies: RFID, smart tags, pick-to-Light, voice solutions and wearables.

This provider's pricing model can be based on licenses or subscriptions requiring at least 1 year of commitment (SelectHub, 2023a).

4.3 Challengers Quadrant

Providers within this quadrant demonstrate a high degree of maturity, being functionally solid and well-proven, with strong records of customer adoption and successful deployments. Their solutions can scale to support Level 3 or higher warehouse operations. Despite having core and comprehensive warehouse system capabilities, they do not stand out in terms of innovation to be market leaders (Tunstall et al., 2023).

- Solid customer base thanks to successful and mature business models;
- Solutions capable of managing large and complex warehouses but with features not as broad as the leaders;
- Weaknesses in the SCE convergence and innovation strategy.

4.3.1 Ehrhardt Partner Group (EPG)

EPG is a German logistics solutions provider with revenues of \$122 million and 832 WMS customers, focused on software and hardware technologies.

Besides having a WMS application designated as **EPG LFS**, the vendor also offers several SCE solutions, a native WCS and a voice tool named Lydia Voice. It further supports consulting, cloud, and hosting services in various regions.

With a strong presence in Europe, these solutions cater for sectors as consumer products, 3PL, retail/e-commerce, automotive/parts, and industrial and construction machinery with specific functionalities for food/beverage, pharma/healthcare and textiles.

EPG WMS offering is best suited to Level 4 and 5 warehouses, although it extends from Level 3 to the most sophisticated ones. Most deployments of this system occur in a dedicated cloud environment using EPG's private cloud services, usually under perpetual licenses. However, it is also possible to install the system on-premises (Tunstall et al., 2023).

The main features of this WMS include support for packaging, picking (multi-order, multi-stage, paper-based, pick-by-voice, pick-by-light, RFID-supported, pick-to-belt and pick-to-carton), storage systems (automated high-bays, shuttle systems, AGVs, wireless pickers and forklifts) and transport operations (route mapping, loading space planning and dock scheduling - Figure 19). Also, it allows a better visualization through intuitive interfaces and 3D simulations (Digital Twins - Figure 20) and provides extended capabilities for labor, contract and billing management (EPG, 2022).

Excelling in terms of price and TCO, the EPG LFS is best suited for very complex and automated warehouses, rather than simpler operations.

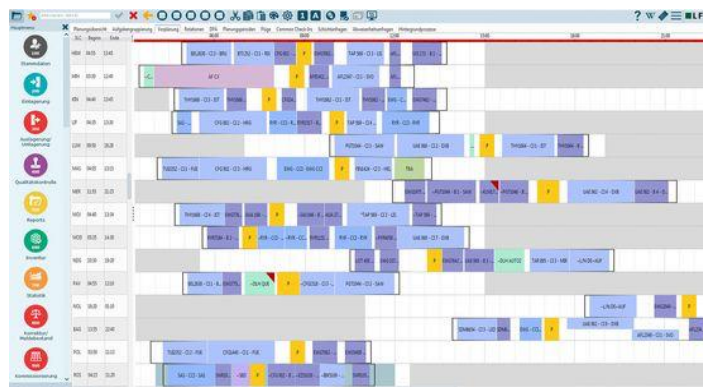


Figure 19 - Dock scheduling panel in EPG LFS (EPG, 2022)

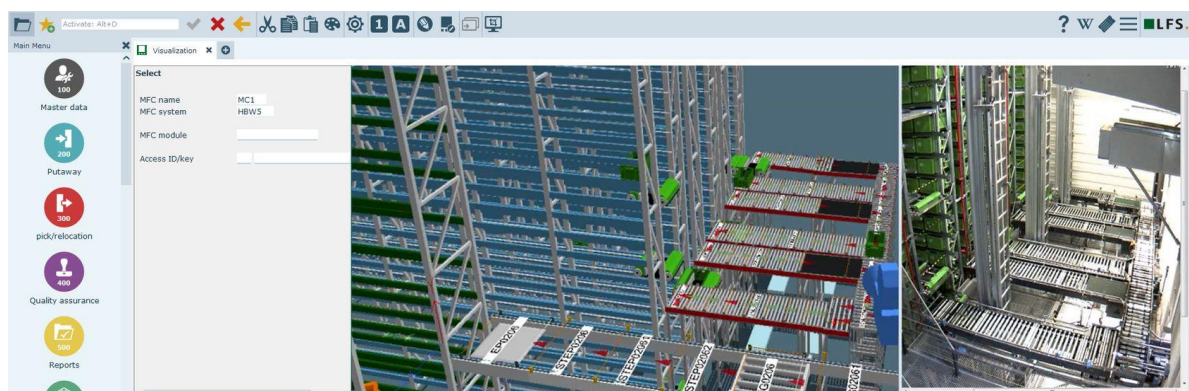


Figure 20 - 3D simulation (Digital Twin) in EPG LFS (EPG, 2022)

4.3.2 Tecsyst

Tecsyst is a vendor of SCE solutions including warehouse management services with over 40 years of experience and \$105 million in software and services revenue. It currently features 214 WMS customers and a strong position in the healthcare and life sciences markets.

In the healthcare sector, Tecsyst offers partnerships and compliance with industry directives (e.g., new Drug Supply Chain Security Act [DSCSA] guidelines), supporting automated hospital replenishment and assisting pharmacies and perioperative areas (Tecsyst, 2021). Meanwhile, in the industrial equipment and spare parts areas, it offers customized functionalities for controlled substances and non-traditional units of measurement.

With no presence in Portugal, the provider offers two WMSs whose most deployments have been on-premises with software licenses. In the future, the preferred implementation option will be on dedicated cloud/SaaS.

Also, the vendor provides modules such as Elite TMS, Elite Analytics, Elite Distribution ERP and Elite Billing to complement its warehouse solutions.

- **Tecsyst WMS:** mainly deployed in Level 3 and low 4 environments even though it can support less complex environments. It has a specialized version in the healthcare sector (Tunstall et al., 2023).
- **Omni WMS:** new system focused on low complexity omni-channel environments.

Besides supporting core WMS functionalities such as picking methods (wave, waveless, zone, batch, cluster, and user-defined), these systems also cover broader features as dynamic slotting, kitting, manifesting, labelling, 3PL billing and multi-carrier routing. Nevertheless, some of its limitations consist of incapacities for advanced analytics and connection to major e-commerce portals (Tecsyst, 2022).

Tecsyst systems are flexible and scalable with little need for code through the integration of APIs and its Itopia solution. Notwithstanding, they lack functionalities for manufacturing and multimodal transport sectors.

4.3.3 Microsoft

Microsoft offers a cloud ERP solution called Microsoft Dynamics 365 Finance and Supply Chain Management which includes WMS capabilities - Figure 21. The WMS module is rarely installed independently and directly by Microsoft, having a greater presence in medium-sized companies.

Microsoft Dynamic 365 offers a portfolio of intelligent business applications that support different areas such as financial, supply chain, human resources and project management, sales, marketing and customer service. With a global network of partners and a robust community of users, it caters to businesses of all sizes.

This solution aims to streamline and optimize warehouse and manufacturing processes by providing real-time information and predictive analytics using AI and IoT. It predominantly serves Level 3 warehouse operations, being present at over 850 customers (Tunstall et al., 2023).

The provider presents a mature cloud architecture and extensibility framework with a dedicated cloud solution that benefits from the Microsoft Azure infrastructure. Plus, this system is seamlessly integrated with Power Platform for analytical capabilities.

It predicts demand through machine learning, performs analysis using Power BI, maps routes with Zebra ZPL and supports procurement through supplier performance management tools and centralization of information on contracts, communications, and transactions.

However, this application requires extensive training to be mastered, presents time-consuming loading of stored information, and is not suitable for complex environments, since it lacks extended functionalities such as multi-site inventory and 3PL billing (Microsoft, 2023b).

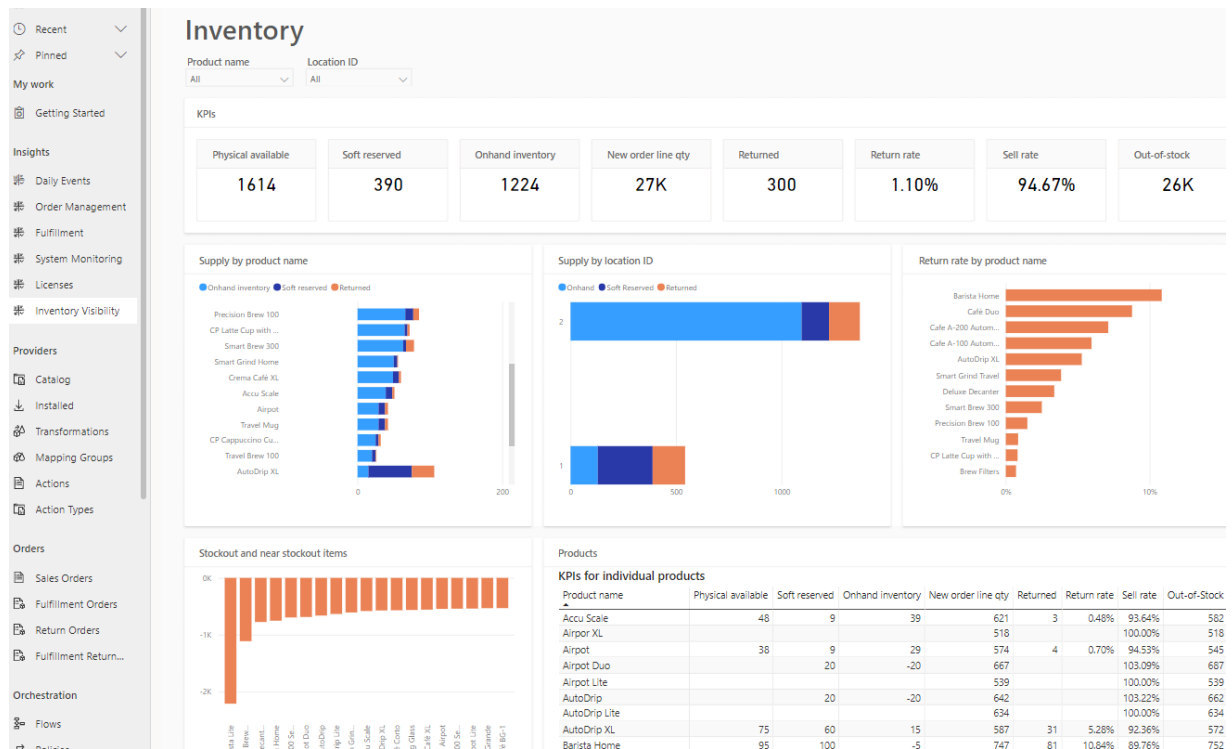


Figure 21 - Microsoft dashboard for managing inventory and returns (Microsoft, 2023a)

4.3.4 SSI SCHAEFER

SSI SCHAEFER is an IT provider, headquartered in Austria and Germany, that emerges from a group specialized in manufacturing and warehousing materials, equipment, and material handling automation. It offers independent WMS, WCS and MHE solutions and IT consulting services for SAP EWM (SCHAEFER, 2020a).

Its own WMS, entitled **WAMAS**, can be implemented in entirely manually operated warehouses independent of material handling systems or in highly automated warehouses (Level 5) which corresponds to 40% of its deployments (SCHAEFER, 2020b).

This system lacks in-depth capabilities for high Level 4 warehouses with people-driven environments, presenting limitations for medium complexity operations (Tunstall et al., 2023).

WAMAS relies on ABC analysis and 3D modelling to optimize warehouse layout, supports quality control, calculates productivity KPIs and supports technologies such as PLCs, forklifts, conveyors, and ASRS.

With a strong presence in Europe, SSI SCHAEFER counts 418 WMS clients whose implementations have been carried out by local subsidiaries along with engineering companies. Currently all of them are on-premises with perpetual licenses, while the cloud solution, although it has passed internal testing, is not commercially available.

The acquisition of DS Automotion increased SSI SCHAEFER's material handling integration capabilities.

4.4 Niche Players Quadrant

The solutions presented by this quadrant are often sufficient from a functional point of view, although they are the weakest in terms of vision and execution. These generally low maturity providers can offer ideal solutions for low levels of warehouse operation or specific applications (Tunstall et al., 2023).

- Focus on a particular market sector or geographic location;
- Limited WMS capabilities, visibility and viability, although the vendors might be growing in their target market;
- Low differentiated systems with no SCE convergence.

4.4.1 Sinergy Logistics

Synergy Logistics, headquartered in the UK, is a small software company with offices in Spain and the US focusing on e-commerce, 3PL, wholesale distribution and consumer goods.

Focused exclusively on WMS and related products such as mobile robots, Synergy offers the **SnapFulfil** solution for managing inventory and warehousing processes. Having a strong presence in Europe and the US, SnapFulfil serves Level 2 and 3 operations, being able to support from 1 to 4 with few extended capabilities (Tunstall et al., 2023).

This system enables the assessment of workers performance such as the number of orders/lines fulfilled per day, premium hosting in high security data centres, quality management by serial number, lot code, country of origin and expiration date and develop custom integrations by APIs with most ERP systems, shopping carts, marketplaces, storefronts and carriers.

SnapFulfil enables improved warehouse management through planning and monitoring of order processing via dashboards, support of multiple picking methods (wave, multi-zone, pick and pass), RF-driven put away, task interleaving based on priorities, permissions and proximity and suggesting replenishment according to demand - Figure 22.

Also, it features two modules including SnapControl for prioritization and work assignment for optimized resource management and SnapBuddy that provides instructive and interactive guidance to platform users through real-time instructions and feedback (SnapFulfil, 2021).

However, some of its limitations include additional costs for customer service, insufficient multi-shipper support and limited mobile printing solutions and implementation tools.

This solution supports 260 customers, primarily SMBs, but also enterprises worldwide. SnapFulfil is available as a subscription service, based on the number of users, offering two payment methods: perpetual or funded license. It offers the flexibility to withstand seasonal peaks in demand, enabling the number of licenses to be increased as needed.

Synergy's historical cloud-dedicated deployment model (SaaS) is recognized for its speed and reliability.

Customer Shipment Summary

● Due Out ● Released ● Closed

#	Shipment #	Stage	Tasks	Progress %	Name	Customer	Class	Reference	Priority	Region
●	2782399	Allocated	0		Svetlana Sagan	110890	6 Pack Order	14PM_0103	Low	
●	2787808	Allocated	0		Brad Sharkey	376648	12 Pack Order	15AM_1093	Low	
●	2807451	Pick	1		Nancy Castellanos	1836312	Multi Pack Order	16PM_0090	Low	
●	2815626	Pick	1		Carissa Ruud	1840865	Multi Pack Order	16PM_0031	Low	
●	2819388	Allocated	0		Robert Morrissey...	1610568	6 Pack Order	14PM_0125	Low	

Figure 22 - Order processing status according to priorities in Snapfulfil WMS (SnapFulfil, 2021)

4.4.2 Made4net

Made4net is a small WMS vendor which offers convergent cloud-based SCE solutions for over 800 customers, mainly SMBs. In 2022, Made4net acquired another provider, Zethcon, along with its cold-chain-focused Synapse WMS (Tunstall et al., 2023).

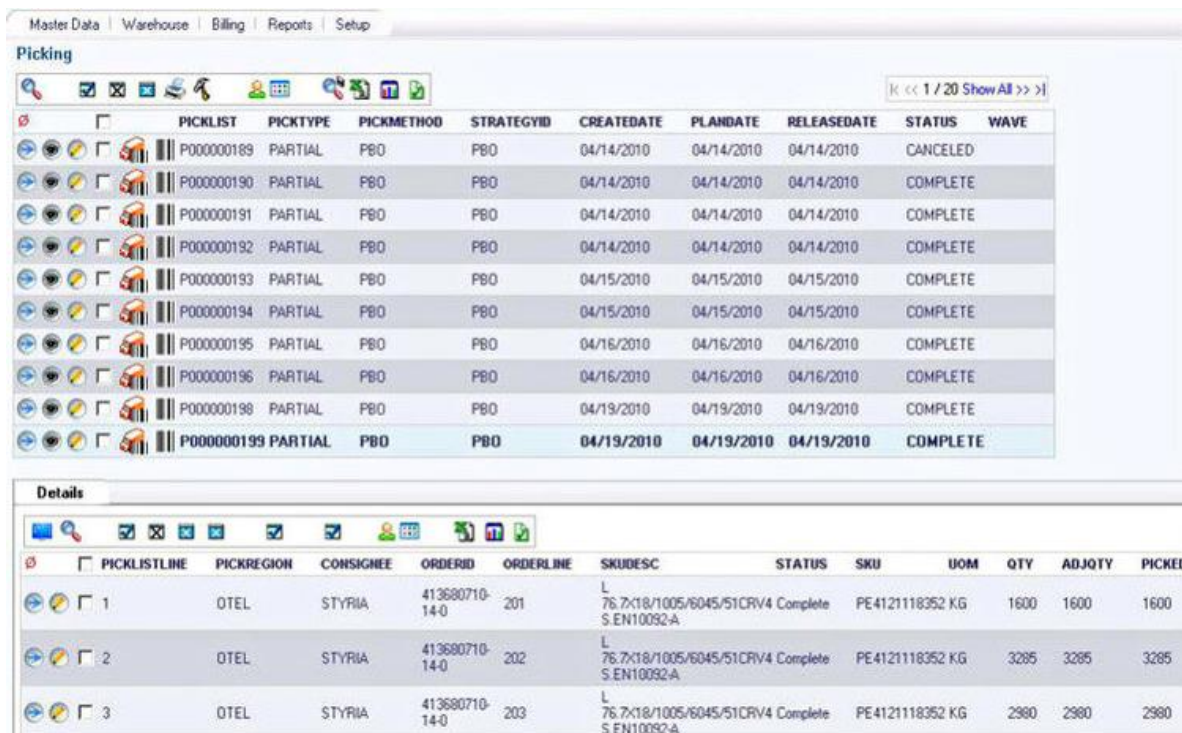
Therefore, the vendor presents two scalable and multi-language WMS solutions whose implementations can be either on-premises or cloud dedicated.

- **SCExpert Platform:** its legacy system, built on Microsoft technology, that features modules to manage deliveries, yard and workforce. It mostly serves Level 2 and 3 warehouses but has some presence in Level 4 and beyond.
- **Synapse WMS:** Zethcon's system geared towards the mid-market 3PL and cold chain segments, whose 111 customers are all located in the US.

These systems allow picking methods selection, dock scheduling, route planning by using advanced algorithms that consider delivery time windows and a more accurate delivery management through item traceability and estimated delivery time calculation. In addition, they enable seamless integration with systems such as Microsoft Dynamics and Oracle's NetSuite through a service-based integration layer, with MHE like shuttles, Automated Guided Vehicles (AGVs) and Automated Storage and Retrieval Systems (ASRS) and finally, with instrumentation technologies as sensors and controllers (Made4net, 2007).

The provider presents fast (6 weeks) and cost-effective implementations due to a substantial network of global partners, but it lacks experience in highly automated warehouses with complex operations and its cloud proposition is not as mature and differentiated.

Made4net's core target industries are 3PL, retail distribution, consumer goods, e-commerce, food services and apparel.



The screenshot displays the Made4net control panel interface. The top navigation bar includes 'Master Data', 'Warehouse', 'Billing', 'Reports', and 'Setup'. The main window is titled 'Picking' and contains a table of picking tasks. Below this, there is a 'Details' section showing a detailed view of a specific picking task.

PICKLIST	PICKTYPE	PICKMETHOD	STRATEGYID	CREATEDATE	PLANDATE	RELEASEDATE	STATUS	WAVE
P000000189	PARTIAL	P80	P80	04/14/2010	04/14/2010	04/14/2010	CANCELED	
P000000190	PARTIAL	P80	P80	04/14/2010	04/14/2010	04/14/2010	COMPLETE	
P000000191	PARTIAL	P80	P80	04/14/2010	04/14/2010	04/14/2010	COMPLETE	
P000000192	PARTIAL	P80	P80	04/14/2010	04/14/2010	04/14/2010	COMPLETE	
P000000193	PARTIAL	P80	P80	04/15/2010	04/15/2010	04/15/2010	COMPLETE	
P000000194	PARTIAL	P80	P80	04/15/2010	04/15/2010	04/15/2010	COMPLETE	
P000000195	PARTIAL	P80	P80	04/16/2010	04/16/2010	04/16/2010	COMPLETE	
P000000196	PARTIAL	P80	P80	04/16/2010	04/16/2010	04/16/2010	COMPLETE	
P000000198	PARTIAL	P80	P80	04/19/2010	04/19/2010	04/19/2010	COMPLETE	
P000000199	PARTIAL	P80	P80	04/19/2010	04/19/2010	04/19/2010	COMPLETE	

PICKLISTLINE	PICKREGION	CONSIGNEE	ORDERID	ORDERLINE	SKUDESC	STATUS	SKU	UOM	QTY	ADJQTY	PICKET
1	OTEL	STYRIA	413680710-140	201	L 76.7X18/1005/6045/51CRV4 Complete S.EN10092-A	Complete	PE4121118352 KG		1600	1600	1600
2	OTEL	STYRIA	413680710-140	202	L 76.7X18/1005/6045/51CRV4 Complete S.EN10092-A	Complete	PE4121118352 KG		3285	3285	3285
3	OTEL	STYRIA	413680710-140	203	L 76.7X18/1005/6045/51CRV4 Complete S.EN10092-A	Complete	PE4121118352 KG		2980	2980	2980

Figure 23 - Made4net control panel to support picking (Made4net, 2007)

4.4.3 Generix Group

Generix provides a suite of SCM solutions including warehouse, transportation, yard, order and replenishment management systems and electronic data interchange (EDI) technologies. In the areas of 3PL, retail, e-commerce and consumer products manufacturers, it serves 465 WMS customers, 150 of which are located in France (Group, 2021).

This provider offers two flexible WMS solutions most often used in Level 2 through 4 warehouses (Tunstall et al., 2023).

- **Generix Group WMS:** stronger in Europe and deeper in features, implemented in 375 customers and 1.960 warehouses. It can scale for Level 4 and 5 warehouse operations.
- **SOLOCHAIN WMS:** stronger in the US with a model-driven differentiated architecture and back-office capabilities. It is a WMS and MES solution with 90 customers.

This solution provides strong visual features for easy implementations and documentation of customer interaction. Also, it is well suited for combined manufacturing and warehouse operations as it offers a seamlessly integrated WMS and MES. However, SOLOCHAIN lacks the depth and completeness of WMS functions compared to Generix WMS.

Some of their constraints include overlapping functions, limited reporting capabilities and time consuming installations and configurations thanks to slow support (Group, 2022).

However, these systems improve asset, yard, and transportation management while taking environmental responsibilities into account. They also support multiple order delivery formats and channels, monitor item availability, and set delivery times based on picking and packing planning activities to facilitate e-logistics - Figure 24.

Although it does not feature a WCS for highly automated Level 5 environments, Generix does connect to some automation systems.

Currently, it prefers dedicated cloud deployment with subscription pricing model.



Figure 24 - Generix WMS task management (Group, 2023)

4.4.4 Mecalux Software Solutions

Mecalux Software Solutions, based in Spain, stems from the parent company Mecalux Group which provides services and products for warehouses, from shelving and racking manufacturing, automated MHE to WCS and WMS consultancy and development.

It offers a versatile WMS solution named **Mecalux Easy WMS** that predominantly serves midmarket businesses with automated facilities and manual warehouse operations via handheld RF devices. Its advantages consist of eliminating errors, reducing logistics costs, achieving a fast return on investment (ROI) in 12-18 months, and adapting to the needs of e-commerce (Mecalux, 2022).

It features a low total cost of ownership (TCO) and three ranges: Lite for educational purposes, Enterprise for manual operations and Robotics for automated ones. These support manufacturing through material requirements planning and kitting, advanced monitoring with alerts and notifications, technologies such as barcoding and RFID and seamless integration with major digital sales interfaces and marketplaces such as Amazon, eBay and PrestaShop.

Starting from \$70.000, this WMS usually caters for Warehouse Levels 2 and 3 but when supported by Mecalux native WCS can scale up to Level 5. It is accessible from a limited number of platforms as Windows and Linux devices (Tunstall et al., 2023).

Mecalux serves 1.000 WMS customers mainly from Europe with direct deployment resources and a strong partner network. It uses Microsoft Azure for cloud deployments, although the strategy is not as evolved (27% of customers).

Recently, new customers with complex operations are installing Mecalux Easy WMS in single-dedicated cloud and smaller companies are opting for multi-tenant solutions.

4.4.5 Mantis

Mantis is a WMS suite vendor, based in Greece, that was acquired by a logistics software and hardware company named Ecovium, in January 2022. With its WMS solution, **Logistics Vision Suite (LVS)**, Mantis serves 711 clients mainly present in Europe and Middle East that range from SMBs with single-site deployments to large multinationals with multisite and multicountry deployments.

LVS is mostly implemented in Level 3 and 4 warehouses, although it can scale from 2 to 5 and it has been successfully integrated with most major ERPs as SAP, Oracle, Microsoft Dynamics and Infor (Tunstall et al., 2023).

Key features of this system include increased adaptability through customised interfaces, document support for XML, CSV, ASCII and databases, software development with APIs, SQL and Microsoft DOT NET, rule creation and layout simulation. Moreover, it assigns and schedules dock and vehicle activities, supports billing, slotting, data analytics, cycle counting, kitting, backflushing, labelling and technologies such as voice picking, pick-to-light, put walls/sort-to-light, smart pick carts, smart glasses, RFID and mobile robots (shuttles, carousels, mobile shelves and AGVs). It also supports human resources management as shown in Figure 25 (SelectHub, 2023b).

Its strongest market segments are 3PL, distribution and multichannel retail (e-commerce). Most implementations of this WMS are on-premises, although some are in a dedicated public cloud on Microsoft Azure. Its cloud deployment strategy is overdue as is its multi-tenant architecture.

Mantis accepts both perpetual license and subscription pricing model. Its WMS easily meets the needs of even the most demanding large enterprises and assists them in achieving a fast return on investment with low total cost of ownership (TCO).

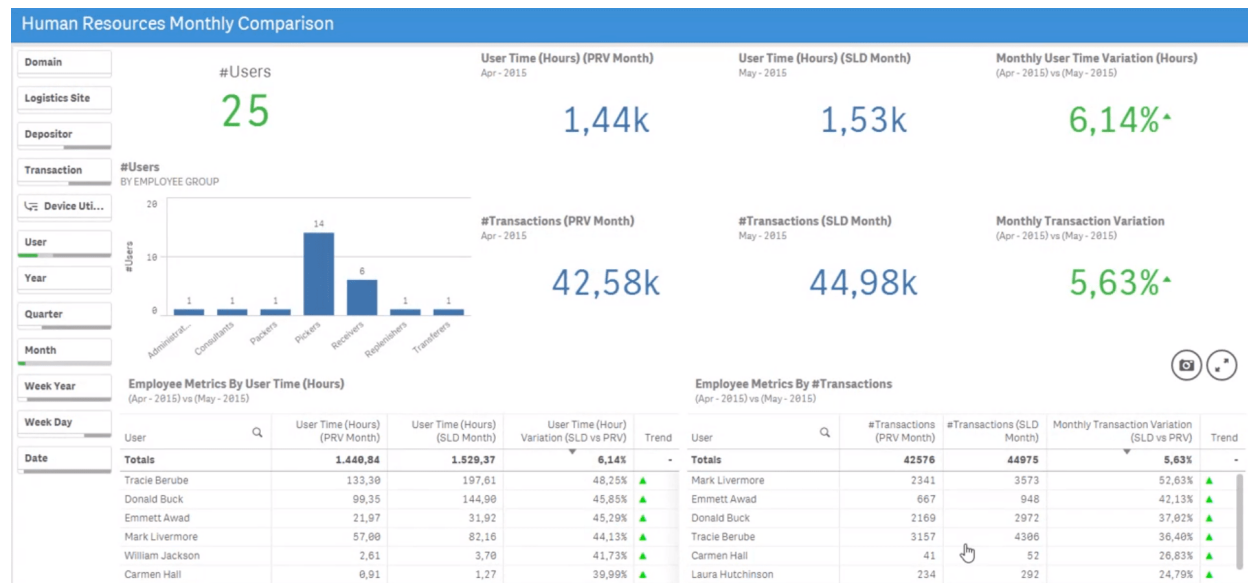


Figure 25 - Mantis dashboard for HR management (SelectHub, 2023b)

4.4.6 Vinculum

Vinculum is an Indian supplier of cloud/SaaS-based solutions that provides multichannel collaboration for its 685 WMS users (vendors, brands, retailers, 3PLs, e-retailers, consumer goods companies).

Besides its SaaS-based WMS solution, **Vin eRetail WMS**, Vinculum offers an OMS and PIM to manage product information, orders, returns, payments and merchandising in multiple channels. In India, its WMS is offered as part of Amazon Digital Suite.

Vin eRetail is best suited to emerging and midsize e-commerce and multichannel retailers, namely paper or mobile based Level 2 and 3 warehouses. Most of its customers are on multi-tenant cloud and the remainder on dedicated (Tunstall et al., 2023).

This system is primarily geared towards e-commerce and omnichannel retail, as well as dark store fulfillment and retail-focused 3PLs. However, its focus sectors include fashion and apparel, health and beauty, fast moving consumer goods (FMCG), home appliances, jewellery, electronics, fitness and industrial B2B (Vinculum, 2021).

It promises to improve order management through ERP integration and order status tracking, catalogue management via cross-platform product listing and marketplace presence through dashboards for live updates of orders. Some of its limitations include long feedback time and inability to support large amounts of information at a time.

Vinculum stands out through its WMS great usability, fast implementations, and attractive pricing model with customized subscriptions for startups with low volume of orders but lacks deployment resources in Europe. Then, it is highly oriented towards multi-channel retail and e-commerce, presenting potential challenges in other industries and few extended capabilities.

4.5 Comparative Analysis

The following section conducts a comparative analysis of the different providers based on the systems presented to assess and summarize their main characteristics, reference sectors, supported operational dimensions, pricing, implementation modes, and integration platforms. By evaluating various WMS solutions, this benchmarking aims to identify their respective strengths, limitations, and suitability for specific warehouse operation requirements and to substantiate decision-making.

Within the selected vendors, several present more than one warehouse management systems. In Table 11, the most comprehensive and complex system of each provider was considered, although it may not always be the most suitable solution for each warehouse.

Table 11 - IT providers rating based on key requirements (Tunstall and Klappich, 2022a)

Providers	Manhattan Associates	Blue Yonder	Körber	Oracle	SAP	Infor	Softeon	Reply	EPG
Key Requirements									
Core WMS	4.5	4.3	4.0	4.3	4.3	3.5	4.3	3.8	4.0
Extended WMS	4.5	3.8	4.0	3.5	3.8	3.3	4.3	3.3	3.8
User Experience (UX)	4.5	3.5	3.5	3.8	2.5	4.5	2.8	3.8	4.0
Analytics/BI	4.0	3.8	3.5	3.0	2.8	3.8	3.0	3.8	3.0
Implementation Tools	3.8	3.8	3.0	3.3	2.8	3.5	3.8	3.3	2.4
Adaptability	3.8	3.8	4.5	3.5	2.5	4.0	3.8	4.0	2.0
Supporting Technologies	3.5	3.5	3.5	4.0	3.5	3.5	4.0	4.3	4.0
Material Handling	3.8	3.5	3.8	3.0	3.5	2.8	3.8	2.8	4.0
Simplicity	1.3	1.3	1.5	2.0	1.5	1.8	1.8	2.5	1.3
Average Score	3.7	3.5	3.5	3.4	3.0	3.4	3.5	3.5	3.2

Providers	Tecsys	Microsoft	SSI SCHAEFER	Synergy Logistics	Made4net	Generix	Mecalux	Mantis	Vinculum
Key Requirements									
Core WMS	3.5	3.5	3.5	3.0	4.0	3.5	3.0	3.8	2.3
Extended WMS	3.5	3.0	2.3	3.0	3.5	3.5	2.5	3.0	1.5
User Experience (UX)	3.5	2.8	2.3	3.5	3.8	3.0	3.5	2.8	3.5
Analytics/BI	3.0	3.0	3.0	3.0	3.3	2.8	2.5	3.0	2.3
Implementation Tools	3.3	3.5	3.5	3.8	3.0	3.0	3.0	3.0	2.3
Adaptability	4.0	3.0	2.5	3.8	4.0	2.3	2.0	4.0	2.5
Supporting Technologies	2.8	2.5	2.3	3.3	2.3	2.5	3.0	2.5	2.5
Material Handling	1.3	2.5	4.0	1.0	3.0	3.3	4.0	2.3	1.3
Simplicity	2.0	1.7	1.5	3.0	2.8	2.0	3.0	1.5	3.5
Average Score	3.0	2.8	2.8	3.0	3.3	2.9	2.9	2.9	2.4

Outstanding	Excellent	Good	Fair	Poor

From the analysis of Table 11, it can be concluded that the more in-depth are the basic and extended functionalities of the WMS, the lower is its simplicity. The most fulfilled requirements by the systems consist of functionalities and usability (UX) while the least ones include analytical capabilities, material handling integration and simplicity - Table 12.

Table 12 - Fulfilment of the requirements by the systems

Key Requirements	Average	Standard Deviation
Core WMS	3.73	0.55
Extended WMS	3.34	0.71
User Experience (UX)	3.42	0.60
Analytics/BI	3.14	0.45
Implementation Tools	3.23	0.44
Adaptability	3.33	0.79
Supporting Technologies	3.19	0.64
Material Handling	2.98	0.95
Simplicity	2.00	0.66

Among the Leaders Quadrant, systems ratings are the highest, with the most noteworthy being Manhattan Associates, Blue Yonder and Körber. All systems present good basic features and support technologies. It is important to note that Körber, Oracle and SAP present limitations in implementation tools since their core business covers a broad spectrum of solutions, not focusing exclusively on WMSs.

Regarding the Visionaries Quadrant, Softeon and Reply score the same, with Softeon excelling in features and Reply outstanding in supporting technologies. Meanwhile, the systems in the Challengers Quadrant all exhibit sufficient WMS functionalities but some gaps in terms of analytical capabilities.

Finally, the Niche Players Quadrant shows the worst results overall not strongly supporting technologies, lacking consistent implementation tools and analytical capabilities.

Although this classification may help to understand the completeness of the capabilities offered by the systems, it should not be seen as an absolute measure. It is fundamental to recognise that assessing the suitability of WMS solutions extends beyond their overall performance, so other factors such as price and the extent to which they meet sector-specific requirements and levels of operation should also be considered. For instance, Appendix D shows the most suitable systems for each level of warehouse operation.

Therefore, Table 13 systematises the main sectors, the sizes of the operations served, the integration platforms, the installation methods and the relative price of each provider.

Table 13 - Systematized comparison of IT providers

Provider	Rating	Price	Company Size	Main Sectors	Deployment	Platforms
 Manhattan Associates	WMS Leader Gartner 2023	\$\$\$\$	S M L	Retail, distribution, grocery, 3PL, e-commerce and apparel	 	    
 BlueYonder	WMS Leader Gartner 2023	\$\$\$\$	M L	Retail, consumer goods, 3PL, manufacturing and pharma	 	    
 KÖRBER	WMS Leader Gartner 2023	\$\$\$	S M L	Retail, distribution, manufacturing consumer goods and e-commerce		    
 ORACLE	WMS Leader Gartner 2023	\$\$	S M L	Retail, manufacturing, distribution automotive and financial services		    
 SAP	WMS Leader Gartner 2023	\$\$\$\$	M L	Manufacturing, retail, consumer goods, automotive and industrial	 	    
 infor	WMS Leader Gartner 2023	\$\$\$	S M L	Retail, distribution, 3PL, pharma, fashion, automotive and industrial	 	    
 Softeon	WMS Visionary Gartner 2023	\$\$	M L	3PL (retail, consumer goods, media, electronics and healthcare)	 	    
 REPLY	WMS Visionary Gartner 2023	\$\$\$	S M L	Automotive, industrial, high tech 3PL, retail, e-commerce, food and beverage, fashion and luxury	 	    
 EPG	WMS Challenger Gartner 2023	\$\$\$	M L	3PL, retail, automotive, industrial, pharma, textile and food/beverage	 	    
 tecsys	WMS Challenger Gartner 2023	\$\$\$	S M	Healthcare, life sciences, retail, distribution, industrial and parts	 	    
 Microsoft Dynamics 365	WMS Challenger Gartner 2023	\$\$\$	M L	Professional services, real estate, manufacturing and distribution	 	    
 SCHAFER	WMS Challenger Gartner 2023	\$\$\$	S M L	Fashion, industrial, food retail, health and cosmetics		—
 SYNERGY	WMS Niche Player Gartner 2023	\$\$	S M	E-commerce, 3PL, wholesale distribution and consumer goods	 	    
 MADE4NET	WMS Niche Player Gartner 2023	\$\$	S M	3PL, distribution, retail, consumer goods, food services and apparel		    
 generix	WMS Niche Player Gartner 2023	\$\$\$	S M	3PL, retail, e-commerce and consumer products manufacture	 	—
 MECALUX	WMS Niche Player Gartner 2023	\$\$\$	S M L	3PL, automotive and industrial	 	    
 mantis	WMS Niche Player Gartner 2023	\$\$	S M L	3PL/4PL, distribution, multichannel retail (e-commerce)	 	    
 Vinculum	WMS Niche Player Gartner 2023	\$	S M	Fashion, health and cosmetics, jewelry, electronics, fitness, FMCG		    

5 Case Study: Recommendation of a WMS solution for a company from the distribution sector

5.1 Company's warehouse

The present case study consists in a recommendation of the most suitable information system for the warehouse of an INEGI's client company. This company counts with more than fifty years in the sector of distribution of consumer goods, being a national market leader.

The company owns a 12.000 m² warehouse which is supplied by several national and international suppliers, its own factory, and other companies of its group. The warehouse supports the processes of receiving, put away, picking and preparation, cross-docking, and shipping of finished products using the SAP WM solution.

During the receiving process, each pallet is properly identified by a Serial Shipping Container Code (SSCC) that identifies parameters such as item, batch, and quantity. The operator scans this code using a Personal Digital Assistant (PDA) that indicates the storage location through the WMS.

However, there are produced items which are not automatically palletized, so the operator is responsible for generating, printing, and attaching the corresponding label. It is important to note that there is a typology of articles which is received in the form of a container on American pallets that must then be reconditioned on Europallets.

Approximately 12.300 pallets are received each month and there is a queue in the receiving area exclusively for customer returns.

In the put away process, each storage bin is identified with an alphanumeric code that designates the aisle, level, and specific position of each location. In the information system, the weight and unit of measure for each type of product and the storage depot codes are also specified.

The WMS automatically suggests put away locations considering the article turnover, the reserve or picking zone, and the following criteria:

- **First In First Out (FIFO):** when the references do not expire;
- **First Expired First Out (FEFO):** when the references have a defined expiration date.

All warehouse handling operations are set off by Work Orders, from SAP WM, which are received in the operators' PDA according to established priorities. The WMS indicates the origin position to the operator and after digitally reading the pallet, information about the destination position is displayed. At the destination, the pallet is placed, and the new location is scanned.

The picking and preparation processes are prompted by Work Orders that may be associated with a picking movement of a full pallet or the construction of a multi-product pallet. By following the route and location instructions indicated by the PDA, the operator picks the ordered quantities and scans the SSCC codes of the products. On average, more than 23.000 picking lines are processed monthly.

This defined picking route is not mandatory since the operator can simply consult the articles to be picked and execute the route in the most convenient sequence.

Meanwhile, if the pallet is multi-product, the operator registers on the PDA the quantities that remain on the pallet of the current picking location after withdrawing the quantity ordered. In this way, a permanent inventory is carried out since the system forces inconsistencies to be resolved immediately. Additionally, each stock position is checked three times a year.

On multi-product pallets, the distribution of the load on the pallet is left to the judgement of the operator and his expertise. When their preparation is complete, another code is generated and a destination position is assigned, which can be either a dispatch area or a buffer where they are temporarily stored until dispatch.

There are 25 queues in the dispatch area that consider the delivery route and distribution of the load on the truck, including its maximum cargo (30 pallets). The WMS supports this activity by aggregating customer orders by date and location according to established distribution routes.

Around 15.000 pallets are handled monthly for shipping (50% of which are multi-product and 50% mono-product) and 3.000 for cross-docking. The ABC analysis of the shipped articles reveals that around 20% of the products account for 80% of the total shipping movements, in accordance with the Pareto Principle.

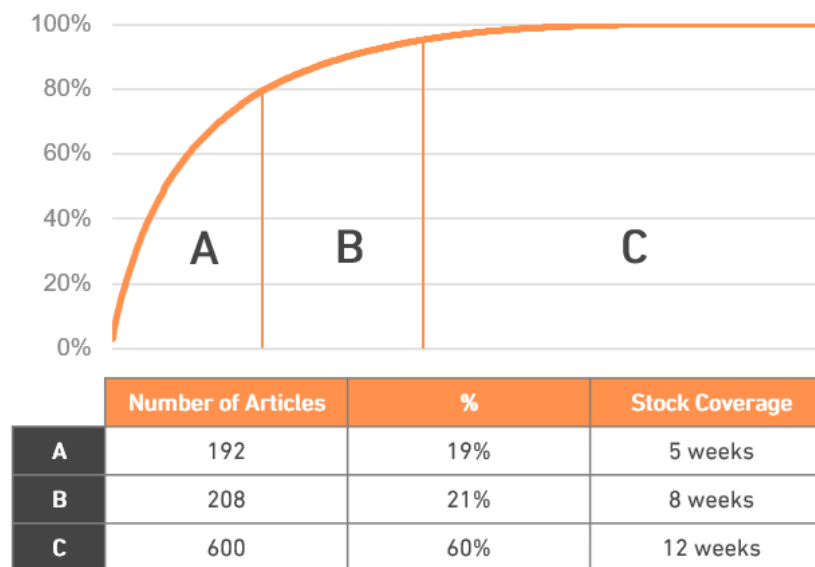


Figure 26 - ABC Analysis

The entry of pallets into trucks is recorded by scanning the SSCC code of the pallets and the dispatch dock where the vehicle is located, with the PDA. The billing functionality is only released after this process in order to minimize the possibility of billing unshipped items.

In the information system, the possibility of overlapping pallets is parameterised and the truck schedule and loading rate can be queried. The vehicle license plate number is associated with the corresponding dock manually, as well as the number of pallets loaded. Currently, there are 13 receiving and shipping docks.

It should be mentioned that it is the Order Centre that registers the orders in the computer system, but there is only stock reservation when the delivery notes are generated. Afterwards, the responsible for expedition forms work groups with the various consignments and only after the Transport Planning team concludes the definition of the distribution routes can the preparation and allocation of the pallets to the queues in the expedition area begin.

The company owns a range of products that is strongly affected by seasonality as its consumption peaks in the summer months.

This facility presents a storage capacity of over 12.000 pallets with 1.000 distinct articles in stock. Its handling equipment and storage systems are represented in Figures 27 and 28, respectively.



Figure 27 - Warehouse handling equipment

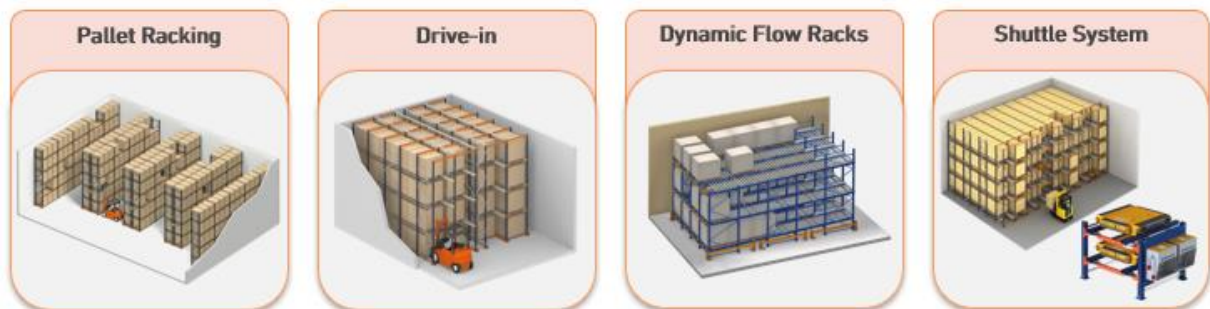


Figure 28 - Warehouse storage systems

The company currently employs 50 warehouse operators, with administrative, handling, picking, invoicing, and forklift operation functions. It values the labor force and does not intend to automate the processes much further. However, in the future, the client company is considering adopting voice picking systems due to the volume of this operation and more handling equipment such as reach trucks - Figure 29.



Figure 29 - Reach truck

5.2 Criteria assessment and solution proposal

As previously mentioned, the WMS solution adopted by the company is SAP WM. In this sub-chapter, the comparison conducted in chapter 4 will be used to verify which system best fits the company's needs as well as the AHP method.

It must be emphasized that the optimal system is not just the one with the best score, but the one that best meets the company's priorities regarding features, specifications, and price.

Initially, the decision objective of the case study was defined, which consists of finding the best WMS solution, and the significant criteria were analysed, namely the main requirements of each system. Then, a pairwise comparison matrix of the main requirements of WMS solutions was created. This matrix was developed together with an element of the IT department who is well aware of the IT needs of the company in order to ascertain the importance of each criteria for the client business (Table 14).

Built using the Saaty scale, this matrix can be interpreted as the ratio of column data entries to row data entries, highlighting the relative impact that different criteria have on the company, e.g., the Core WMS requirement is somewhat more important (3 in the scale) than Extended WMS and slightly less important than the User Experience (1/2), according to the company.

Table 14 - Pairwise comparison matrix of key requirements

	Core WMS	Extended WMS	User Experience (UX)	Analytics/BI	Implementation Tools	Adaptability	Supporting Technologies	Material Handling Integration	Simplicity
Core WMS	1	3	1/2	5	4	5	4	3	7
Extended WMS	1/3	1	1/4	4	3	5	3	1/2	6
User Experience (UX)	2	4	1	6	4	7	5	3	7
Analytics/BI	1/5	1/4	1/6	1	1/3	4	1/2	1/4	6
Implementation Tools	1/4	1/3	1/4	3	1	4	2	1/4	5
Adaptability	1/5	1/5	1/7	1/4	1/4	1	1/4	1/5	2
Supporting Technologies	1/4	1/3	1/5	2	1/2	4	1	1/3	5
Material Handling Integration	1/3	2	1/3	4	4	5	3	1	6
Simplicity	1/7	1/6	1/7	1/6	1/5	1/2	1/5	1/6	1

Table 15 - Normalized matrix and criteria weights

	Core WMS	Extended WMS	User Experience (UX)	Analytics/BI	Implementation Tools	Adaptability	Supporting Technologies	Material Handling Integration	Simplicity	Criteria Weights
Core WMS	0.21	0.27	0.17	0.20	0.23	0.14	0.21	0.34	0.16	0.21
Extended WMS	0.07	0.09	0.08	0.16	0.17	0.14	0.16	0.06	0.13	0.12
User Experience (UX)	0.42	0.35	0.33	0.24	0.23	0.20	0.26	0.34	0.16	0.28
Analytics/BI	0.04	0.02	0.06	0.04	0.02	0.11	0.03	0.03	0.13	0.05
Implementation Tools	0.05	0.03	0.08	0.12	0.06	0.11	0.11	0.03	0.11	0.08
Adaptability	0.04	0.02	0.05	0.01	0.01	0.03	0.01	0.02	0.04	0.03
Supporting Technologies	0.05	0.03	0.07	0.08	0.03	0.11	0.05	0.04	0.11	0.06
Material Handling Integration	0.07	0.18	0.11	0.16	0.23	0.14	0.16	0.11	0.13	0.14
Simplicity	0.03	0.01	0.05	0.01	0.01	0.01	0.01	0.02	0.02	0.02

Thus, it was possible to calculate the relative weights of each criteria in the customer's opinion through the normalized matrix presented in Table 15. In descending order, the most important requirements for the company are user experience, core WMS, material handling integration, extended WMS, implementation tools, supporting technologies, analytics, adaptability and lastly simplicity.

The company states that it is of utmost relevance that the system is perceivable and usable by all users so that the functionalities can be taken full advantage of. Since it has a lot of dock activity and handling equipment, it also favoured requirements such as extended WMS and equipment integration. On the other hand, the client does not want the system to be highly user-configurable and simple.

In the AHP method, consistency index and ratio are applied to assess the validity of the analysis. The maximum eigenvalue of the matrix presented in Table 14 is equal to 9.851.

$$\text{Consistency Index (CI)} = \frac{9.851 - 9}{9 - 1} = 0.106 \quad (1)$$

$$\text{Consistency Ratio (CR)} = \frac{0.106}{1.45} = 0.073 < 0.1 \quad (2)$$

By using equations (1) and (2) from subchapter 2.4 of the state-of-the-art it can be seen that the consistency ratio is less than 0.1 so the analysis is valid. The random consistency index (RI) is equal to 1.45 since the dimension of the matrix is 9x9, in accordance with Figure 10.

When applying the criteria weighting to the ranking of IT providers by requirements, the Table 16 is obtained.

Table 16 – IT providers classification based on the company's preferences

Providers Key Requirements	Manhattan Associates	Blue Yonder	Körber	Oracle	SAP	Infor	Softion	Reply	EPG
Core WMS	0.96	0.92	0.86	0.92	0.92	0.75	0.92	0.81	0.86
Extended WMS	0.53	0.45	0.47	0.41	0.45	0.39	0.51	0.39	0.45
User Experience (UX)	1.27	0.99	0.99	1.07	0.71	1.27	0.79	1.07	1.13
Analytics/BI	0.21	0.2	0.19	0.16	0.15	0.2	0.16	0.2	0.16
Implementation Tools	0.3	0.3	0.23	0.26	0.22	0.27	0.3	0.26	0.19
Adaptability	0.1	0.1	0.12	0.09	0.07	0.11	0.1	0.11	0.05
Supporting Technologies	0.22	0.22	0.22	0.25	0.22	0.22	0.25	0.27	0.25
Material Handling Integration	0.55	0.5	0.55	0.43	0.5	0.4	0.55	0.4	0.58
Simplicity	0.03	0.03	0.03	0.04	0.03	0.04	0.04	0.05	0.03
Average Score	4.17	3.71	3.66	3.64	3.27	3.65	3.61	3.57	3.69

Providers Key Requirements	Tecsys	Microsoft	SSI SCHAEFER	Synergy Logistics	Made4net	Generix	Mecalux	Mantis	Vinculum
Core WMS	0.75	0.75	0.75	0.64	0.86	0.75	0.64	0.81	0.49
Extended WMS	0.41	0.35	0.27	0.35	0.41	0.41	0.3	0.35	0.18
User Experience (UX)	0.99	0.79	0.65	0.99	1.07	0.85	0.99	0.79	0.99
Analytics/BI	0.16	0.16	0.16	0.16	0.18	0.15	0.13	0.16	0.12
Implementation Tools	0.26	0.27	0.27	0.3	0.23	0.23	0.23	0.23	0.18
Adaptability	0.11	0.08	0.07	0.1	0.11	0.06	0.05	0.11	0.07
Supporting Technologies	0.18	0.16	0.15	0.21	0.15	0.16	0.19	0.16	0.16
Material Handling Integration	0.19	0.36	0.58	0.14	0.43	0.48	0.58	0.33	0.19
Simplicity	0.04	0.03	0.03	0.06	0.06	0.04	0.06	0.03	0.07
Average Score	3.08	2.96	2.92	2.96	3.49	3.13	3.17	2.98	2.44

The top six providers were selected for further assessment, namely Manhattan Associates, Blue Yonder, EPG, Körber, Infor, and Oracle. Consulting Table 13, it is verified that all systems encompass the company's sector and its size since the company's business volume is medium to large.

Bearing in mind the characterization of the current warehousing operation and according to the company's preferred requirements, it can be stated that the company lies between warehouse operation Levels 3 and 4.

This means that the warehouse aims to increase its automation and integration, supporting cross-docking, multiple picking, batch control and cycle counting processes as a Level 3 warehouse and that it optimises article positions with slotting and manages its workforce and dock activity as a Level 4 warehouse.

As a warehouse between Levels 3 and 4, the company places great value on core and extended WMS functionalities as well as usability and does not require much simplicity.

To further compare and differentiate the solutions, specific functionalities of these selected systems were compared - Table 17. Since all of the systems are intended for warehouse management, they all cover the basic functions required, however they differ in the extended ones.

Infor was excluded from the analysis for having the worst features among all the options, Oracle for having separate solutions for labor and yard management and Körber for not supporting labor management. The client company highly values its employers, so it is essential that the tool incorporates their administration with the calculation of productivity and safety KPIs.

According to the selection and the aforementioned systems for each warehouse level, the following ones have been selected:

- **Manhattan Active Warehouse Management (WM);**
- **Luminate Logistics;**
- **EPG LFS.**

The Luminate Logistics solution was disregarded as it neither stands out in terms of functionalities nor is it economically competitive. So, if the company is willing to make a large investment in structuring its IT, the system that best meets its needs is the Manhattan Active WM. On the other hand, if price is a constraint, the best solution would be the EPG LFS, which can be integrated with EPG's voice technology (Lydia Voice) to optimize picking activity.

Consequently, according to the evaluation conducted in this dissertation, the two solutions were proposed to the company. This recommendation considers factors such as system functionalities, integration capabilities and expertise of the vendors, and industry best practices aiming to optimize warehouse management operations and enhance overall efficiency.

Table 17 - WMS key features comparison

Provider	Product Type		Software Features									
	Perishable Products	Nonperishable Products	Cross Docking	Forecasting	Kitting	Order Management	Inventory Management	Receiving and Put away	Returns Management	Yard Management	Labor Management	Picking and Packing
 Manhattan Associates	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
 BlueYonder Multi-geo potential	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
 KÖRBER	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓
 ORACLE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✓
 SAP	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓
 infor	✗	✓	✓	✗	✓	✓	✓	✓	✗	✗	✓	✓
 EPG Enterprise Performance Group	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

6 Conclusions and future work perspectives

The benchmarking project of IT solutions for warehouse management and support successfully achieved its goals of identifying the main providers and their information systems, establishing evaluation criteria, and analysing the applicability and usability of each solution as well as its key features, strengths and cautions.

There were established two comparative matrices on the basis of defined criteria that consider not only the key capabilities of each system, but also the prices charged, the sectors and sizes of operations supported, and the implementation and integration approaches of each vendor.

Considering the complexity and multiplicity of alternatives of these solutions, a framework was developed to facilitate the process of selecting a warehouse management system providing a comprehensive guidance to organizations seeking for a solution that aligns with their specific needs, technological advancements, and industry trends.

During the course of the information gathering, the various providers were contacted, interviews and visits were conducted, demonstrations by users of the systems were attended, and catalogues and case studies were reviewed.

The main challenges faced during the collection of information consisted of the resistance of providers to disclose features such as prices, contradiction of information from different sources, and lack of differentiation between some systems. Thus, it was essential to hierarchize the sources of information by credibility and to solicit information from the users of the systems.

At first, the main warehouse processes and the functionalities of the systems that manage them were contextualized. The requirements that these systems must fulfil have been specified in terms of functionalities, usability, analytical capabilities, implementation and support tools, adaptability, supporting technologies, material handling integration, and simplicity.

The key performance indicators these systems should evaluate in order to provide accurate and relevant information about the warehouse's operational performance have been defined, allowing for effective analysis, identification of improvement areas, and data-driven decision-making. These metrics were classified into seven different categories, namely cost efficiency, service levels, productivity, resource utilization, stock integrity, cycle times, and safety.

Then, the different levels of warehouse operation were categorized as well as the importance of each requirement for each level.

The definition of these evaluation parameters, namely the system capabilities, KPIs and warehouse operation levels has enabled the development of the framework to facilitate and guide the selection of systems for warehouse management. This outlines the steps required to elect the most suitable system for each warehouse operation.

It states that the first step should be to characterise the current operation and level of the warehouse as well as foresee future technological investments. It is necessary to establish operating policies such as the definition of processes and parameterization of product-related attributes.

All information on vendors and systems shall then be gathered through a benchmarking process by using comparative matrices. It should be reflected that there is no ideal WMS solution for all warehouses and that these comparative tools are not absolute measures, being imperative to evaluate the systems within the specific context of each warehouse. Therefore, evaluation criteria must be defined and prioritized in order to opt for the solutions that best address the specific needs of each organization.

After a detailed analysis of functionalities, a feasibility study must be performed considering the costs of the best solutions in order to select the most suitable one.

In order to demonstrate the applicability of the concepts discussed, a case study was conducted based on the defined framework consisting of the recommendation of a WMS for a company in the distribution sector, according to the analytic hierarchy process method. Thus, the current position and the importance of each requirement for the company was surveyed in order to completely satisfy its needs. The systems were analysed according to the warehouse operation level, key requirements, integration and implementation capabilities, and vendors' expertise to propose two solutions according to the investment willing to be made.

For future work, it would be interesting to expand the project scope to a benchmark of all information system modules such as enterprise resource planning, transportation management systems, manufacturing execution systems, advanced planning and scheduling, order management systems, product information management and customer relationship management.

Considering the particular framework of this project, it would be advantageous to address software programs commonly used in Portugal such as Eye Peak PRIMAVERA WMS, WPMS - IsRetail and PHC's warehouse management module, which currently is still difficult to evaluate quantitatively.

Furthermore, it would have been a valuable addition to gather demonstrations of the systems from all providers and to create user manuals for each system, however this was not feasible due to the time constraint of the project. This would provide end users with detailed guidance on system features, operations, and troubleshooting, thus promoting an easier adoption and use of the WMS solution.

It is crucial to emphasise that after selecting a system there is still an ongoing investment and effort required, being necessary to allocate resources for the maintenance of the solutions and to assess return on investment.

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Appendix A: Deliverable for INEGI

4.

MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | MANHATTAN ASSOCIATES

Presentation



- Manhattan's WMS are flexible solutions that combine demand, supply, labour, slotting and automation into reliable tools to measure the efficiency across warehouse facilities, regardless of their physical size, speed or volume of business.
- Manhattan offers three distinct user-friendly, adaptable and seamlessly interconnectable WMSs solutions:
 - Manhattan SCALE:** based on a Microsoft technical interface, targets the SMB and 3PL market segments whose warehouse operations are at Level 2 and 3.
 - Manhattan Warehouse Management for IBMi (WMI):** most suitable for Levels 3 and 4 warehouse operations.
 - Manhattan Active Warehouse Management (WM):** a microservices-based multitenant cloud WMS, that replaces Manhattan Warehouse Management for Open Systems (WMOS), often used in sophisticated, complex and highly automated warehouse environments (Levels 4 and 5). It is versionless so it never needs upgrading or extending.
- These enable clients to meet customer expectations with greater convenience, reliability, visibility and fast deliveries. Their modules include order processing, slotting optimization, inventory, billing, labour and yard management, cycle counting, claims and carrier management.
- Its WMSs are used by a wide range of industries, including retail, e-commerce, food distribution and grocery, 3PL, footwear and apparel, to improve warehouse productivity, reduce costs, and enhance customer service. With its advanced features, scalability, and integration capabilities, the Manhattan Associates WMSs are leading solutions in their market.

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MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | MANHATTAN ASSOCIATES

Software Specifications



Key Features

- Improved Inventory Management:** Real-time tracking and visualization of inventory levels, stock locations and movements within the warehouse. The receiving process is streamlined with cross-docking, quality audit and vendor performance features and the costly physical counts are supported by cycle counting functionality.
- Distributed Order Management:** Efficient order processing and fulfilment across multiple channels and distribution centers through machine learning strategies to support wave or waveless planning. It enables accurate and streamlined order allocation by suggesting the most efficient picking routes, reducing the travel distance and combining picks regardless of pick or order type.
- Advanced Labor Management:** Personnel performance evaluation and feedback, task allocation, workload balancing, gamified challenges, achievements, points and rewards, and workforce forecasting and planning by day, shift, job and zone.
- Warehouse Control System Integration:** Management of automated equipment such as conveyors and retrieval systems (AS/RS).
- Optimized Yard Operations:** Enhanced visibility over the inbound and outbound flow of goods in and out of the warehouse and yard. The system includes yard management capabilities for effective management of trailer and dock scheduling, gate check-in/check-out processes, and yard resource allocation.
- Advanced Slotting Optimization:** Continuous defining and re-defining pick locations according to sales trends and customer expectations and gathering commercially associated products for rapid fulfilment.
- Some of its **limitations** include lack of BI support and the inability to print/issue receipts prior to a dispatch and to customize put away rules.

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MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | MANHATTAN ASSOCIATES

Software Specifications



Strengths	Cautions
- Manhattan is a leading systems vendor and innovator of SCE solutions, namely in warehousing and omnichannel management. It presents a consistent and organic financial growth (not through acquisition) with a well-established customer base and high market share. It is the only SCE platform provider, and its products reveal outstanding depth and breadth. - It is renowned for translating business requirements effectively into adaptable, reliable and high-quality products and it was the first provider to re-architect its WMS on a multi-tenant microservices cloud which supports composability capabilities, extensibility and zero upgrades. - Its WMSs are well-suited to the needs of retail, particularly grocery, whereby the goal is to integrate inbound and outbound movements. Manhattan continues to offer one of the most compelling SCE convergence visions. It is built on a unique and differentiated common SCE/logistics platform that includes WMS, YMS, TMS and DOM.	- Manhattan is recognized as a high-end offering which is complex, costly, and requires greater supporting effort than other systems. Although Manhattan Active WM is versionless, reducing upgrade costs, the total cost of ownership is often high. This is only available in the cloud, so those who wish to deploy on-premises are now only able to do it through the less featured systems (SCALE and WMi). - Even though the Manhattan ProActive tool reduces customers' need for support, Manhattan's service team is recognised as being less willing, available and reliable with consulting and systems integration partners. Its customer base is mainly made up of North America, making support in Portugal potentially compromised. - Beyond its WMS Manhattan SCALE, the provider lacks a clear midmarket strategy. Its DOM and TMS offer some sophistication and complexity and are available on a variety of platforms making them expensive for mid-market businesses.

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MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | MANHATTAN ASSOCIATES

Software Specifications



On-premise
Cloud-based/SaaS



License or Subscription-based
Minimum commitment of 1 year is required



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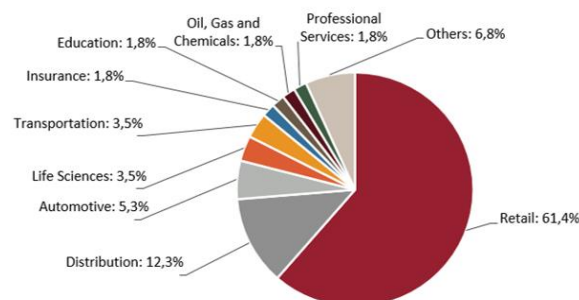
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MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | MANHATTAN ASSOCIATES

Reference Sectors



Reference Customers



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4. MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | BLUE YONDER (JDA)

Presentation

- Blue Yonder's WMSs are highly customizable solutions that offer in-depth visibility of all warehouse operations, providing real-time data on inventory levels, personnel and equipment performance across multiple channels and geographies, while being responsive to demand changes and other unforeseen events.
- These systems feature a user-centered approach providing dashboards to increase user engagement, motivation and productivity while continuously monitoring and controlling costs, productivity and service. They guarantee **100%** improved accuracy, **15%** increased productivity and **50%** cost reduction.
- Blue Yonder provides two WMS platforms most used in sophisticated Levels 3 and 4 warehouse operations, but can be scaled up from Level 2 to 5:
 - Luminate Logistics:** a cloud native SaaS mobile application scalable with microservices/APIs that is both intuitive and comprehensive.
 - JDA Dispatcher (Legacy):** a software program focused on optimizing internal warehouse operations such as resource orchestration, stock management and inbound/outbound processing.
- These solutions present a very broad scope and cover a variety of industries, from manufacturing to distribution, yet the most relevant ones are 3PL, food and beverage, consumer goods, retail, and pharmaceuticals.
- Blue Yonder's strategy is focusing on SaaS implementations with a fit-for-purpose approach in order to include services for less complex warehouses. Also, this provider offers an upfront self-assessment, which provides a tailored report comparing the client's supply chain operations with best practices.



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4. MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | BLUE YONDER (JDA)

Software Specifications

Key Features
- Improved Labor Management: Workforce planning and scheduling, task and schedule optimization, performance evaluation, regulatory compliance, online continuous training and impact analysis. - Streamlined Inbound Operations: Inbound shipment planning and scheduling, load consolidation and routing, carrier selection, vendor compliance, coordination with outbound shipments, yard and dock location assignments via wireless devices, receipt check-in by paper, RF or RFID, container optimization, task interleaving and returns processing (including disassembly/de-kitting). - Enhanced Inventory Management: Slotting that balances travel distances and resource constraints for optimal workload efficiency and safety considering replenishment activities to minimize disruptions and costs, cycle counting and monitoring of expiry dates and quality assurance. - Increased Manufacturing Support: Kit assembly, light manufacturing, multi-level bills of materials, raw material control (including backflushing) and assignment, sequencing and execution support of work orders. - Optimized Outbound Operations: System-directed packing, parcel manifesting for UPS, FedEx and USPS, pallet and load building, shipment documentation (BOL, manifests and HAZMAT), billing support and transport, fleet and global trade management. - Efficient Asset Management: Resource tracking of returnable containers, equipment, racks, parts and people through technologies such as barcodes, active and passive RFID, <u>mobile phones</u>, GPS and other AIDC devices. - Some of its limitations include lack of support for payment processing, ASN and supplier compliance management. Also, dashboards and notifications cannot be user-definable, and it does not support multiple languages.



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4. MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | BLUE YONDER (JDA)

Software Specifications

Strengths	Cautions
- Blue Yonder boasts an established and diverse customer base of the complex and scalable WMS solutions provided. It excels with a converged supply chain vision in areas such as labor management, workforce forecasting and scheduling, traceability and performance management. - The provider is exploring solutions in the artificial intelligence (AI) domain and improving its task orchestration and robotics capabilities, which may be emphasized by the acquisition by Panasonic. - Its streamlined implementation strategy for medium to low warehouse complexity levels is achieved thanks to improved automated testing and its robust partner network, which supports 50% of new WMS contracts.	- Migration strategies and upgrades for former Luminate WMS customers may be complicated by the new AFW solution, but Blue Yonder is moving new capabilities into the system. Plus, its software updates are not continuous and the lack of them incurs financial penalties. - Implementing BY's systems is an expensive undertaking and may have been slightly constrained due to the acquisition by Panasonic which has focused on a strategic level. Also, its vision for long-term supply chain modelling, as well as the financial impact analysis of scenarios, is below average compared to the market. - Blue Yonder adopts a hybrid methodology when changing installation to cloud since its WMS is not a truly multi-tenant cloud built with microservices, which entails difficulties while functionalities reside in different technologies.



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MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | BLUE YONDER (JDA)

Software Specifications



On-premise
Cloud-based/SaaS



License-based: starting price point: \$250,000 – \$500,000 all inclusive for a medium-sized facility implementation
Subscription-based: starting at \$1.200/month/site for unlimited users
Minimum investment of \$250,000 is required



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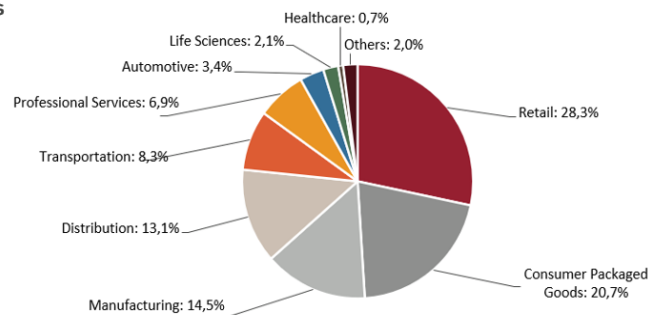
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MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | BLUE YONDER (JDA)

Reference Sectors



Reference Customers



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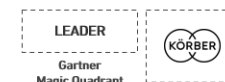
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MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | KÖRBER

Presentation



- Körber presents a wide portfolio of flexible WMSs solutions, demonstrating a deep understanding of supply chain processes and customer needs, given its extensive experience in deploying warehouse technologies globally.
- The vendor offers four systems whose main benefits are the fully mobile-compatible features, data capture capabilities, integration of technologies such as IoT sensors, robotics and AR, and the possibility of adaptable add-on modules:
 - K.Motion Warehouse Edge:** which mostly fits Level 2 and low Level 3 warehouse operations.
 - K.Motion Enterprise 3PL:** best suited to Level 3 and low Level 4 warehouses.
 - K.Motion Warehouse Advantage:** ideal for Levels 3 and 4, with some presence in Level 5 operations.
 - K.Motion WMS X:** used in France and Spain to support mainly Level 5, but also serving Levels 3 and 4 warehouses.
- The provider is dedicated to the cloud but intends to move towards a multi-tenant microservices architecture. Despite prioritizing cloud for new business, this cloud adoption varies by WMS - from 5% for WMS X to 80% for Enterprise 3PL.
- Körber integrates its systems with other supply chain solutions such as independent ERPs to optimize end-to-end processes. They serve a variety of distribution and manufacturing industries from 3PL operators, food and beverage, automotive, aerospace, pharmaceutical and apparel.
- With a **99%** customer retention rate, Körber's technologies can increase warehouse productivity by up to **50%**.

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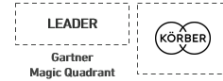
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MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | KÖRBER

Software Specifications



Key Features
- Process Digitization and Optimization: Increased performance and energy efficiency, improved industrial plants availability and reduced downtime by using predictive analytics and process optimization through machine learning, AI, deep tech and data science. - Streamlined Warehouse Operations: Management of advance shipping, staging, slotting, warehouse transfers, picking (by waves, clusters, zones or batches), packing and route optimization, supporting multi-client and multi-product operations. - Advanced Automation Capabilities: Management of all material handling and storage technologies, such as conveyors, stacker cranes, shuttles, RGVs, sorters, miniloader, AGVs. The system measures the equipment's performance by calculating the number of pallet movements per hour. - Enhanced User Experience: The intuitive user interface (UI), accessible on any device, reduces the learning curve while increasing overall productivity due to graphical panels and integrated visualization options to access data and provide actionable insights to continuously improve material flow. Controls can be multilingual and user-accessible. - Improved Inventory Count: Incorporation of a voice system in cycle counting to eliminate the risk of miscounting inventory and continuous update of inventory levels. - Improved Flow Control: Automation dock management support and suggestion of multimodal transport solutions. - KÖRBER has experience with the following VPNs: Microsoft, Cisco, FortiClient. - Some of its limitations may be related to integration at POS (Point of Sales) and with CRM (Customer Relationship Management) tools such as Salesforce.

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MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | KÖRBER

Software Specifications



Strengths	Cautions
- Körber not only has a robust business model in the fields of warehousing and materials handling, but also a strong international presence in the areas of intralogistics intelligent robotics and voice support technologies. It complements its WMS solutions through the possibility of adaptation, simulation, modelling and integration of materials handling by providing its own WCS. - The K.Motion Warehouse Advantage solution is known as scalable and customizable since customers claim to be able to make specific changes at the business logic level without having to change the source code of the software. - More than 100 specialized implementation partners, including cloud partners, work with Körber on a global scale.	- Currently, Körber is selling, developing and adapting four solutions and working on its next-generation platform. Although it has a large support network present in different countries and some functionalities are updated simultaneously in all solutions, its WMS present different logics, some complexity and high support costs. - Potential customers must have some maturity and robustness in their processes in order to minimize customization, which leads to money and time losses. - As Körber is moving towards a multi-tenant microservices cloud architecture, its customers may face several future upgrades in order to avoid full re-implementation as the migration occurs. The company's long-term strategy and alignment may also be impacted by its restructuring.

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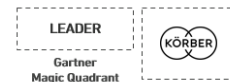
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MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | KÖRBER

Software Specifications



Product Deployment	On-premise Cloud-based/SaaS
Pricing Model	License or Subscription-based Minimum commitment of 1 year is required
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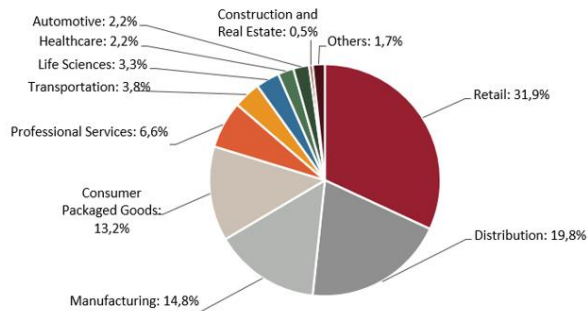
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4. MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | KÖRBER

Reference Sectors



Reference Customers



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4. MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | ORACLE

Presentation

- Oracle WMSs are cloud-compatible solutions that enable organizations of all sizes to optimize warehouse capacity, boost productivity, improve accuracy, and maximize resource utilization by coordinating all material and information flows.
- The provider presents four systems to help increase revenues and reduce inventory and operating costs:
 - Oracle Fusion Cloud WM:** a pure multitenant SaaS/cloud WMS for basic materials management and Level 1 warehouse functionality.
 - Oracle JD Edwards EnterpriseOne WM:** robust extended solution with a web-based architecture at significantly lower total cost of ownership. It uses open standards (REST APIs) that make integration easier.
 - Oracle Retail WMS:** streamlines the SC for multichannel retailers, including store, catalog, and e-commerce retailers.
 - Oracle Enterprise Business Suite (EBS) WM:** comprehensive solution that manages logistics, human resources, procurement, projects, finance and the asset lifecycle.
- Oracle's customers are well distributed across Levels 2 to 5 warehouse operations, being most clustered at Level 3. Approximately 20% of its customers own facilities that use automated materials handling equipment (MHE).
- These software programs predominantly serve the retail, manufacturing and distribution industries, while also having a presence in the automotive and financial services sectors.

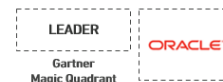
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4. MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | ORACLE

Software Specifications



Key Features

- Streamlined Task Management:** Productivity assessment of people by areas and processes, measurement of task completion time and replenishment planning (mins and maxs, push and pull (kanban) strategies, periodic automated and forward pick).
- Increased Warehouse Mobility:** Mobile RF-based customizable execution, material handling equipment integrations, voice directed picking and RFID support.
- Inbound and Outbound Control:** Advanced Ship Notice generation, standard and ASN-based reception, cross-docking planning, returns processing, quality assurance, rule-based directed storage and picking and consolidation, staging, and truck loading.
- Accurate Inventory Control:** Lot control, sub-lots, serial and revision control, dual unit of measure control, cycle counts, support for multi-client inventory management and control of product status and characteristics.
- Improved Warehouse Intelligence:** Real-time operational analysis through intelligent dashboards with configurable alerts, schedules and reporting capabilities to increase stock and operations visibility and monitoring.
- Value-added services:** Compliance labelling, kitting/de-kitting and multi-level BOM.
- Some of its **limitations** include lack of accounting integration with QuickBooks or Xero and inability to deploy on a Mac OS X operating system.

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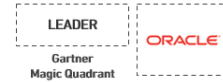
4.

MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | ORACLE

Software Specifications



Strengths	Cautions
Its cloud SCM solution strategy is among the most coherent and mature in the market. Oracle has achieved zero downtime with the cloud due to use of Oracle Cloud Infrastructure's Autonomous Database, and enhanced tools such as its WMS state analyzer.	Oracle's WMSs lack some extended functionalities, such as workforce management or labor optimization. Its current focus is on API creation, usability and solution integration, <u>lagging behind</u> in software features compared to other providers.
Oracle's WMSs have a strong customer base, especially in processing-intensive industries such as retail and consumer goods. However, its solutions are cross-cutting and cover criteria corresponding to 17 sectors <u>at the moment</u>.	It is planned to be focusing on warehousing solutions for manufacturing processes in the future, however it is currently not highly developed.
Oracle differentiates itself in user experience through its UX platform (Redwood), its mobile application development platform (Visual Builder) and its voice-enabled Digital Assistant. Moreover, its architecture supports a Platform as a Service (PaaS) layer that allows the creation of converged applications and leverages AI, Machine Learning and IoT technologies to create predictive dashboards.	Customers need to evaluate the experience and knowledge of system integration partners since 80% of WMS implementations are performed by them. Many partners may not be familiar with the warehouse design and best practices of process integration and automation.

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4.

MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | ORACLE

Software Specifications



On-premise
Cloud-based/SaaS



License-based: starting at \$9.595 per application user for a minimum of 20 users and updates at \$2.110
Subscription-based: starting at \$50.00/month/1.000 warehouse transactions
Minimum of 20 user licenses are required for the on-premise model



Oracle EMEA Ltd |
Eastpoint Business Park,
Dublin 3, Ireland

Contact:
Cintia Carrasco Reyes
Business Development Consultant | IBERIA

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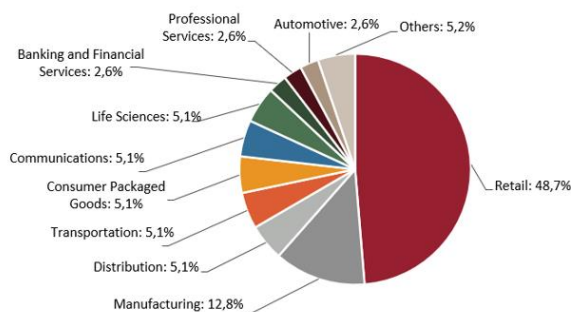
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MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | ORACLE

Reference Sectors



Reference Customers



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4.

MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | SAP

Presentation



- SAP WMS applications supports the automation of different warehouse processes by improving their organization and accuracy through inventory management at bin level, detailed mapping of physical article locations and the integration of external control modules such as forklift control and stock removal solutions.
- These solutions connect with ERP systems to optimize daily logistics, finance and inventory operations.
- SAP provides four warehouse management solutions:
 - SAP Extended WM:** frequently employed in Level 2 and 3 warehouses but it is capable of scaling up to Level 5. Since this is an advanced solution with extended functionalities, it is too complex for stand-alone Level 1 operations. It is estimated that 84% of customers hold EWM on-premises, 13% cloud hosted, and 3% as multi-tenant.
 - SAP ERP WM (Legacy):** the former version, suitable for simpler and less complex warehouse environments.
 - Stock Room Management:** a component of SAP ERP that focuses on inventory management in specific areas, such as production or maintenance. Designed to serve small and manual warehouses, this solution supports the migration from SAP ECC to S/4HANA.
- SAP has a strong presence in the consumer goods, retail (electronics, grocery and food service), automotive and industrial machinery industries.

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4.

MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | SAP

Software Specifications



Key Features

- Effective Hazardous Materials Management: Safety control of storage and handling of hazardous items by monitoring accurate product records and generating detailed reports.
- Storage Bin Management: Storage facility mapping by defining storing (block staking, drive-in, flow track, high rack, AS/AR) and location (fixed or dynamic) systems and management of stock at storage bin level.
- Improved Planning and Monitoring: Anticipated workload overview for the forthcoming days and control of the actual operation via RF monitor.
- Radio Frequency Connections: through RF mobile terminals it is possible to track resources and share information in a quick and accurate way. Using barcodes information can be registered and verified while registering.
- Advanced Warehouse Control: ALE interface for integration of external systems (warehouse control units) such as automatic putaway, stock removal systems or forklift control systems
- Process Optimization: programming of picking, packing and shipping in two waves, optimization of load units through augmented reality and voice picking, support for multiple movements among warehouses (cross-docking).
- Some of SAP WM limitations include system inflexibility, low capacity to support automated warehouses, lack of labor management features, limited BI functionalities such as activity dashboards (integrated with SAP Business Objects BI platform), lack of billing management support (integrated with SAP Hybris Billing tool) and no integration with tools such as QuickBooks or Xero.

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4.

MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | SAP

Software Specifications



Strengths	Cautions
With a worldwide presence in 65 countries, SAP has nearly 7000 WMS customers, with its SAP EWM solution representing one of the largest customer bases for a single WMS solution. Its network of implementation and consulting partners is one of the strongest, with EWM practices and experience.	Even though its WMS can be integrated standalone in several ERPs, it remains best suited for SAP exclusive businesses. Its cloud implementation strategy is not as developed as other providers, given that SAP presents numerous implementation options, mostly carried out by third parties, which can lead to costs and delays.
The EWM solution offers enough functionalities for most SAP customers (SAP ECC or SAP S/4HANA), however material handling integration is only achieved with the advanced option of SAP MFS (Material Flow System).	SAP WM customers will either have to replace their system or adopt the SAP Stock Room Management solution, with less functionalities, as its common support will end in 2 years for S/4HANA and in 4 years for ECC.
Its strategy for solution convergence is well established as the WMS integrates with both SAP ECC and S/4HANA on various levels: trade conformity, transport management, healthcare, security, environment and process integration.	SAP EWM's total cost of ownership is one of the highest in the market, presenting a high-price structure for companies with significant transaction volumes.

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4. MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | SAP

Software Specifications



Cloud-based/SaaS



Subscription-based



Delaware is responsible for the SAP 4/HANA Projects.

Contact:
☎ PT 800849195

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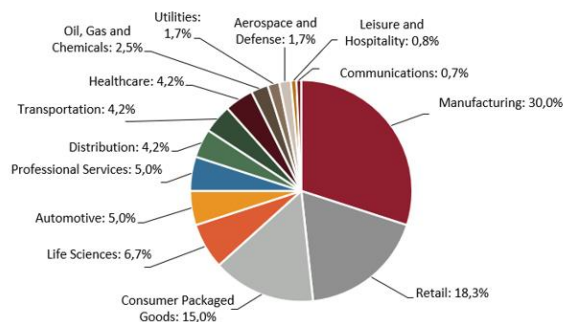
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4. MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | SAP

Reference Sectors



Reference Customers



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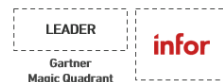
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4. MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | INFOR

Presentation



- Infor presents a WMS solution, known as **Infor WMS**, which combines functionalities for managing inventory, labor, transport and invoicing in a unified and scalable database. It is a cloud-based application that provides real-time visibility into logistics operations and service level through 3D virtual analytics, while enabling task prioritization, inventory cost reduction and bottleneck mitigation.
- Its users have reported achieving:
 - 15 to 20% reduction in fulfillment costs
 - 15 to 40% increase in labor productivity
 - 5 to 20% decrease in space requirements
 - 5 to 12% improvement in inventory throughput
 - 5 to 25% savings in transportation costs
 - Bin inventory accuracy over 99%
- Its WMS generally serves Level 3 operations, but can support more complex Levels 4 and 5, with a growing presence in 4. In its ERP systems, Infor provides the Factory Track solution suitable for low complexity warehouses (Level 1 and 2).
- 3PL, retail/grocery, wholesale distribution, pharma, fashion, automotive and industrial are its strongest sectors.
- Infor prefers a multi-tenant deployment in the cloud but also installs on-premises and favors subscription-based pricing model but supports perpetual licenses.

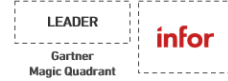
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4. MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | INFOR

Software Specifications



Key Features
- Enhanced Visualization: Visual queries of inventory, locations and orders for operation and layout optimization (slotting), bottleneck congestion analysis, task visualization (historical and active) with color heat indicators and travel path analysis. - Integrated Manpower Management: resource standardization (worker performance, goal tracking by activity and optimal routes determination), workload planning (1-7 days), calculation of the number of workers required and activity scheduling. - Personalized User Experience: Multilingual support, report customization, visible alerts/notifications and label/documents formatting. - Improved Warehouse Management: Inbound planning, quality control inspection support, directed put-away, cross-docking operations support, returns management, obsolete stock reduction with configurable rotation rules and real-time cycle counting. The system also supports order, cluster, and consolidation picking, dynamic replenishment, task prioritization and interleaving, customer-level billing and small parcel shipping systems integration. - Value-Added Services: Customized manufacturing and delivery services such as kitting, bundling, light assembly, compliance labeling and special packs. - Seamless Automation Integration: RF and voice support for all operations and management of human-machine cooperation. - Continuous Innovation: Version-less cloud updates do not require any updates or upgrades. - Some of its limitations include poor report exporting, lack of integration with FedEx or UPS to manage transportation, no Material Requirements Planning (MRP) and insufficient support for document management.

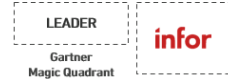
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4. MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | INFOR

Software Specifications



Strengths	Cautions
- To enhance the capabilities of its WMS, Infor leverages developed innovations such as Birst for analytics, Coleman for AI, ION for integration between Infor and external applications, and its own Infor OS (base system that connects the entire IT framework, contextualizes data and performs predictive analytics). - Mongoose's Object Data Modeling (ODM) library supports Infor's extensibility in the customization of its WMS by allowing users to make "no code" improvements and providing a "full code" option that empowers technicians to configure more advanced application modifications. - Infor's WMS is deployed in 65 countries and has a major presence in North America and Asia. Also, Koch brought experience and financial stability to Infor and its products, focusing on the cloud and limited microservices architecture.	- Infor lacks the expertise across multiple sectors (including healthcare), functional depth and the breadth of other providers. There is no evidence of sector differentiation through a verticalization of its WMS product. NAS EXTENDED - Infor's market recognition is limited as customers mostly derive from its ERP and are unaware of the breadth of functionalities and resources for data storage and collection. 60% of its customers present outdated systems that cannot be easily upgraded and transitioning to the next system will require re-implementation.

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4. MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | INFOR

Software Specifications



Product Deployment	On-premise Cloud-based/SaaS
Pricing Model	License or Subscription-based Minimum commitment of 1 year is required
Support	Headquarters: 641 Avenue of the Americas New York, NY 10011 (+1) 646 336-1700 (866) 244-5479

Contact:
CustomerExperienceTeam@infor.com

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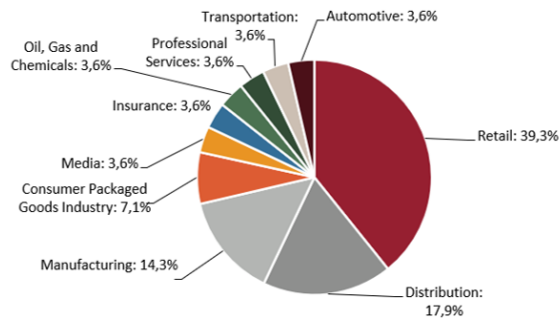
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4.

MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | INFOR

Reference Sectors



Reference Customers



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4.

MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | REPLY

Presentation

- Reply provides a suite of products to ensure the management and supervision of execution processes throughout the Supply Chain, from production plants to distribution warehouses. Regarding warehouses, these solutions enable continuous inventory control (finished goods, semi-finished or spare parts), optimization of space allocation, reduction of lead time, and easier real-time monitoring of activities.
- The provider offers two flexible and scalable WMS solutions:
 - Click Reply:** its legacy system with 146 clients mainly from the automotive, industrial, service, high tech and 3PL sectors. Click Reply serves Level 3 and 4 (up to 5) warehouses globally, often using material handling automation. It can be hosted on-premises as a dedicated cloud solution.
 - Logistics Execution Architecture (LEA Reply):** a multi-tenant cloud-based WMS built on a contemporary microservices architecture with 143 customers mainly in retail, e-commerce, food and beverage, fashion and luxury. This system is most suitable for Level 2 and 3 operations, but it can support Level 4 and 5 warehouses.
- Reply systems help users maximize profits, reduce operating costs and better control inventories and service levels, by offering modules for warehouse management, yard and labor management, warehouse performance and billing.
- These can be integrated with all major ERPs and are compatible with highly automated warehouses, automated guided vehicles (AGVs), automated storage and retrieval systems (AS/RS), and the latest supporting technologies: RFID, smart tags, Pick-to-Light, voice solutions and wearables.



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MARKET RESEARCH FOR IT SOLUTIONS

4.3 WMS | REPLY

Software Specifications



Key Features

- Improved Warehouse Management:** Support for voice recognition and RF terminals, dedicated assistants on the web application, management and personalization of e-mails and text alerts, kitting and de-kitting, serial numbers, component back-flushing and labelling functionalities. The system's automated alerts save monitoring time within the company.
- Efficient Yard Management:** Management and monitoring of vehicles through yard mapping, truck and trailer analysis, movement tracking through task creation, flow supervision by recording incoming and outgoing vehicles and assignment of loading and unloading docks.
- Enhanced Labor Management:** Evaluation of staff availability, shift management, determination and planning of resources needed to implement work plans, personnel performance monitoring through analytical progress reports and statistical analysis (working times, delays...).
- Warehouse Performance Evaluation:** Monitoring of KPIs, detailed data analysis and resource utilization information. The integration of the system with a BI solution, Qlik Sense, allows data gathering in self-service mode.
- Warehouse Invoicing Support:** Definition of rules to assign the correct rates to warehouse activities through the system modeling functionality, association of contracts based on modeling and report generation based on cost category, LSP, period, contract, bill, cost center and activities.
- Reply supports deployment on Microsoft and Android platforms, integration of the JVoice module to handle hands-free and eyes-free systems, and control of RFID devices for reading and label creation. Some of the **limitations** of Click Reply WMS include no integration support with CRM tools such as Salesforce, no robust Invoicing and Labor Management functionalities (partially integrated with the Click Reply Labor module) and the inability to integrate with tools such as QuickBooks or Xero and to implement on MAC OS or Linux OS.

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4. MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | REPLY

Software Specifications



Strengths	Cautions
- For Reply's size, its WMS business presents strong IS consulting and customization capabilities as it is part of a large global organization present in 19 countries. - The company has a roadmap to implement its platform as an asset having prototyped, commercialized and delivered features such as microservices, wearables (smart glasses and AR), real-time locating, MHE automation, support for micro fulfillment center, drop shipping and in-store logistics. - LEA Reply has pioneered the extensibility of building in a multi-tenant cloud platform based on microservices and aims to increase its visibility, usability and ML. - On the other hand, LEA EDGE integrates the cloud-implemented WMS with other MHE applications software as well as other supporting technologies such as robots or IoT devices.	- Reply is the only one responsible for the technical support of its systems having its operation focused on Italy and the UK. Its main business is consulting and IS services, with only 3% of its revenue coming from its WMS package. - Its two WMS offers have overlapping functionalities and significant differences in their maturity, adaptability and architecture. While LEA Reply is recent and offers advanced features such as drop ship, supplier portal and parcel management, Click Reply still lacks a comprehensive SCE convergence strategy.

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4. MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | REPLY

Software Specifications



Product Deployment	On-premise Cloud-based/SaaS
Pricing Model	License or Subscription-based Minimum commitment of 1 year is required
Support	UNITED KINGDOM LONDON 38 Grosvenor Gardens London SW1W 0EB, United Kingdom Tel: +44 (0) 207 730 6000 Fax: +44 (0) 207 259 8600

Contact:
click@reply.com

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4. MARKET RESEARCH FOR IT SOLUTIONS



4.3 WMS | REPLY

Reference Sectors and Customers



Food & Beverage 	3PL
Fashion & Retail 	Automotive
Pharma & Chemicals 	Consumer Goods
	Manufacturing

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5.
COMPARISON OF IT SOLUTIONS

inegi driving science & innovation

Poor Fair Neutral Good Excellent

WMS Provider	Manhattan Associates	BlueYonder Holds your potential	KÖRBER	ORACLE	SAP	infor
Core WMS						
Extended WMS						
User Experience (UX)						
Analytics/BI						
Implementation Tools						
Adaptability						
Supporting Technologies						
Material Handling Integration						
Simplicity						

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5.
COMPARISON OF IT SOLUTIONS

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Poor Fair Neutral Good Excellent

WMS Provider	Softeon	REPLY	EPG Enterprise Performance Group	tecsys	Microsoft Dynamics 365	SCHAPER
Core WMS						
Extended WMS						
User Experience (UX)						
Analytics/BI						
Implementation Tools						
Adaptability						
Supporting Technologies						
Material Handling Integration						
Simplicity						

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5.
COMPARISON OF IT SOLUTIONS

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Poor Fair Neutral Good Excellent

WMS Provider	SYNERGY	MADE4NET The power of open to print	generix	MECALUX Software Solutions	mantis an infor company	Vinculum Building Multi Channel Retailing
Core WMS						
Extended WMS						
User Experience (UX)						
Analytics/BI						
Implementation Tools						
Adaptability						
Supporting Technologies						
Material Handling Integration						
Simplicity						

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Appendix B: Contact with providers

Email:

Dear xxx,

As part of the [Management and Industrial Engineering Consulting](#) team of [INEGI](#) [Institute for Science and Innovation in Mechanical and Industrial Engineering] I am developing a study on the functionalities and requirements of WMS - Warehouse Management Systems.

Therefore, I would be interested in attending a demonstration of the WMS of xxxxx in order to further my knowledge on the main functionalities and respective applicability of your software.

I look forward to receiving your feedback, being naturally available to clarify any question that may eventually arise.

Kind regards,

Catarina Galante

Interview Questions:

- Can you provide an overview of your company's experience in delivering WMS solutions?
- What differentiates your WMS solution from the competition in terms of functionalities?
- How does it support inventory management and tracking, picking, and packing?
- Can it support different types of products (e.g., perishables, hazardous materials)?
- Can you highlight its analytical features and predictive models?
- Can it provide real time insights into KPIs?
- How easily it integrates with other systems, such as ERP, transport management or e-commerce platforms?
- How does your WMS handle returns and reverse logistics processes?
- What is the preferred pricing and implementation model? Could you give me details?
- What type of training and ongoing support do you provide?
- What is your roadmap for future enhancements or updates to the WMS?

Provider	Systems	Contact (status)
Manhattan Associates	Manhattan SCALE Manhattan Associates WM for IBMi (WMI) Manhattan Active WM	Reunião + visita
Blue Yonder	Luminate Logistics JDA Dispatcher (Legacy)	Email
Körber	K.Motion Warehouse Edge K.Motion Enterprise 3PL K.Motion Warehouse Advantage K.Motion WMS X	Formulário + projeto
Oracle	Oracle Fusion Cloud WM Oracle JD Edwards EnterpriseOne WM Oracle Retail WMS Oracle Enterprise Business Suite (EBS) WM	Email + formação Oracle University de Explorer de WMS Oracle Consulting
SAP	SAP Extended WM SAP ERP WM (Legacy) Stock Room Management	Demonstração
Infor	Infor WMS	Enviaram catálogo
Tecsys	Tecsys WM Omni WMS	Formulário – enviaram email a dizer que não estão em Portugal info@tecsys.com
EPG - Ehrhardt Partner Group	EPG LFS	Email info.uk@epg.com
SSI SCHAEFER	WAMAS	Email info@ssi-schaefer.com
Reply	Click Reply LEA Reply	Email click@reply.com
Softeon	Softeon WMS	Formulário e demonstração (https://www.youtube.com/watch?v=9KFuT2E6IQw&t=211s) contact@softeon.com
Generix Group	Generix Group WMS Solochain WMS	Formulário – disseram que não faziam demonstrações portugal@generixgroup.com
Made4net	SCExpert Platform Synapse WMS	Email info@made4net.com
Mecalux	Mecalux Easy WMS	Formulário
Synergy Logistics	SnapFulfil	Formulário info@snapfulfil.com
Mantis	Logistics Vision Suite (LVS)	Formulário info@mantis.email
Vinculum	Vin eRetail WMS	Formulário – Responderam que iam contactar
Microsoft	Microsoft Dynamics 365 SCM	Formulário + chamada

Appendix C: Example of a WMS catalogue (Manhattan)

WAREHOUSE MANAGEMENT CAPABILITIES BY INDUSTRY

Industry-specific capabilities are designed to increase product velocity, customer service and efficiency across unique distribution operations.

FOOD DISTRIBUTION AND GROCERY RETAIL

TRACEABILITY

- Lot management
- Catch weight
- Inventory recall
- Event tracking
- Date rotation
- Fast flow for perishables
- Product aging, including “first expire, first out” (FEFO), “first in, first out” (FIFO), and “last in, first out” (LIFO) food picking and loading functionality
- Flexible question and answer framework
- Multi-order pallet and/or work assignment creation
- Picking using label, radio frequency (RF) and voice
- Load sequence by stop/route

MULTI-TEMPERATURE DISTRIBUTION

- Locating, allocation and picking rules by zone (dry, fridge and freezer)
- Task prioritization by zone

WORK ORDER PROCESSING

INVENTORY CONTROL

- Real-time visibility into product status, product aging and product batches
- Advanced cycle counting

RETAIL

CROSSDOCKING

FLOW THROUGH

TRANSLOADING

VENDOR COMPLIANCE

UNIFIED INBOUND AUDIT

PUT-TO-STORE

DYE-LOT MANAGEMENT

FLOOR-READY PROCESSING

GARMENT-ON-HANGER SUPPORT

LOAD BUILDING

DIRECTED LOADING BY STOP

DIRECT TO CONSUMER

HIGH-VOLUME ORDER PROCESSING

SINGLES AND SMALL-ORDER PROCESSING

MULTIPLE PICK METHODS

(CLUSTER PICKING AND ZONE PICK)

HIGH SKU-COUNT SUPPORT

– Scalability

– Item placement/slotting

COLLATE (INVOICE) DOCUMENT GENERATION

CONFIGURABLE MATERIAL HANDLING

MATERIAL HANDLING EQUIPMENT (MHE) INTEGRATION

DYNAMIC LOCATION ASSIGNMENT AND LOCATION REPLENISHMENT

RETURNS DISPOSITION PROCESSING

PRODUCT ASSORTMENTS (GIFT PACKS)

CUBISCAN CUBING, WEIGHING AND DIMENSIONING SYSTEM INTEGRATION

PARCEL SHIPPING

APPAREL AND FOOTWEAR

APPAREL SKU CHARACTERISTICS

– Style, color, size and width tracking

– Quality and version support

– Release date support

HIGH SKU-COUNT SUPPORT

– Scalability

– Item placement/slotting

FLEXIBLE DIMENSION AND WEIGHT SUPPORT

– Advanced cartonization algorithms

– CubiScan cubing, weighing and dimensioning system integration

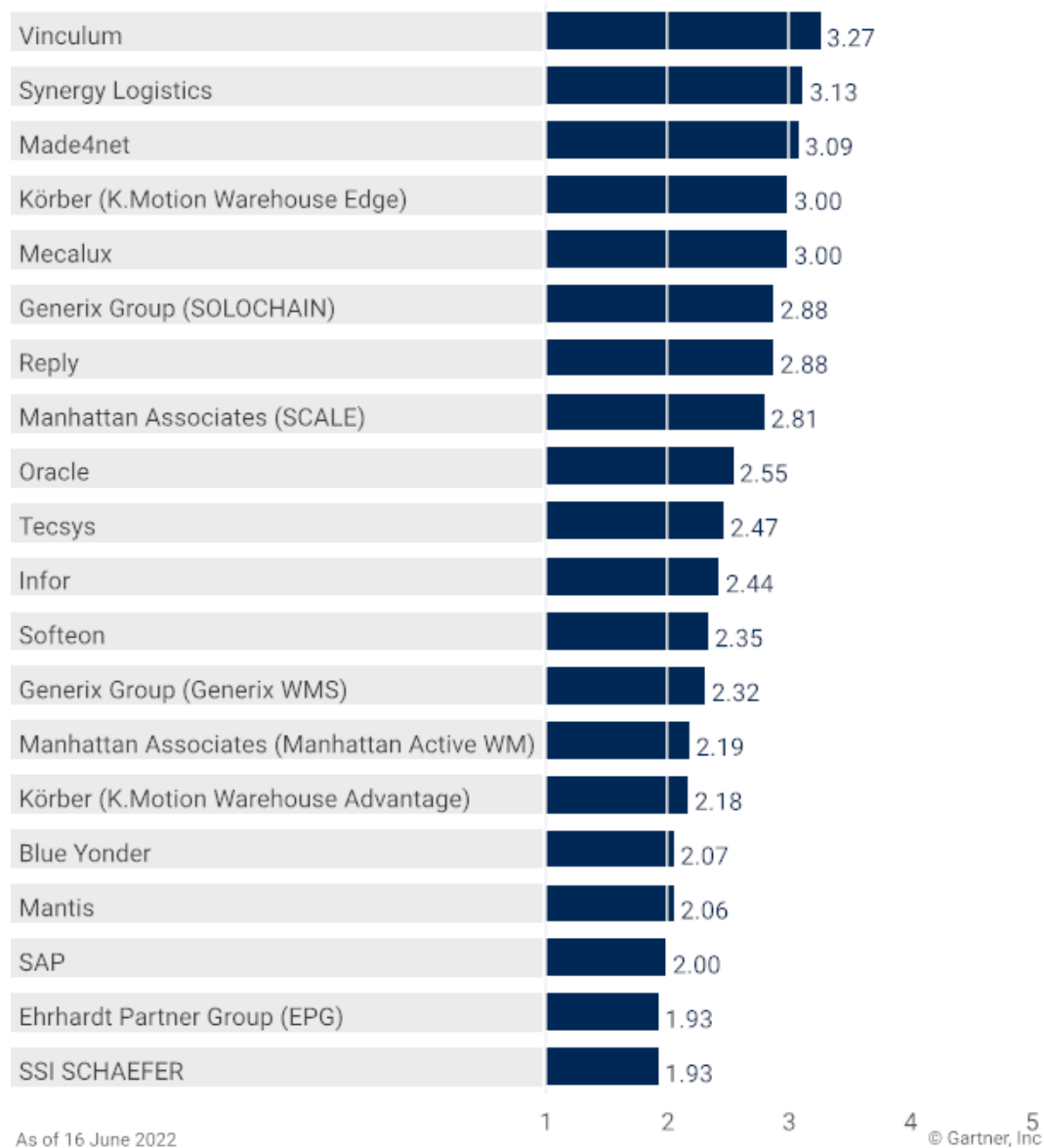
CONFIGURABLE MHE INTEGRATION

ADVANCED OUTBOUND ALLOCATION, PICKING AND REPLENISHMENT STRATEGIES

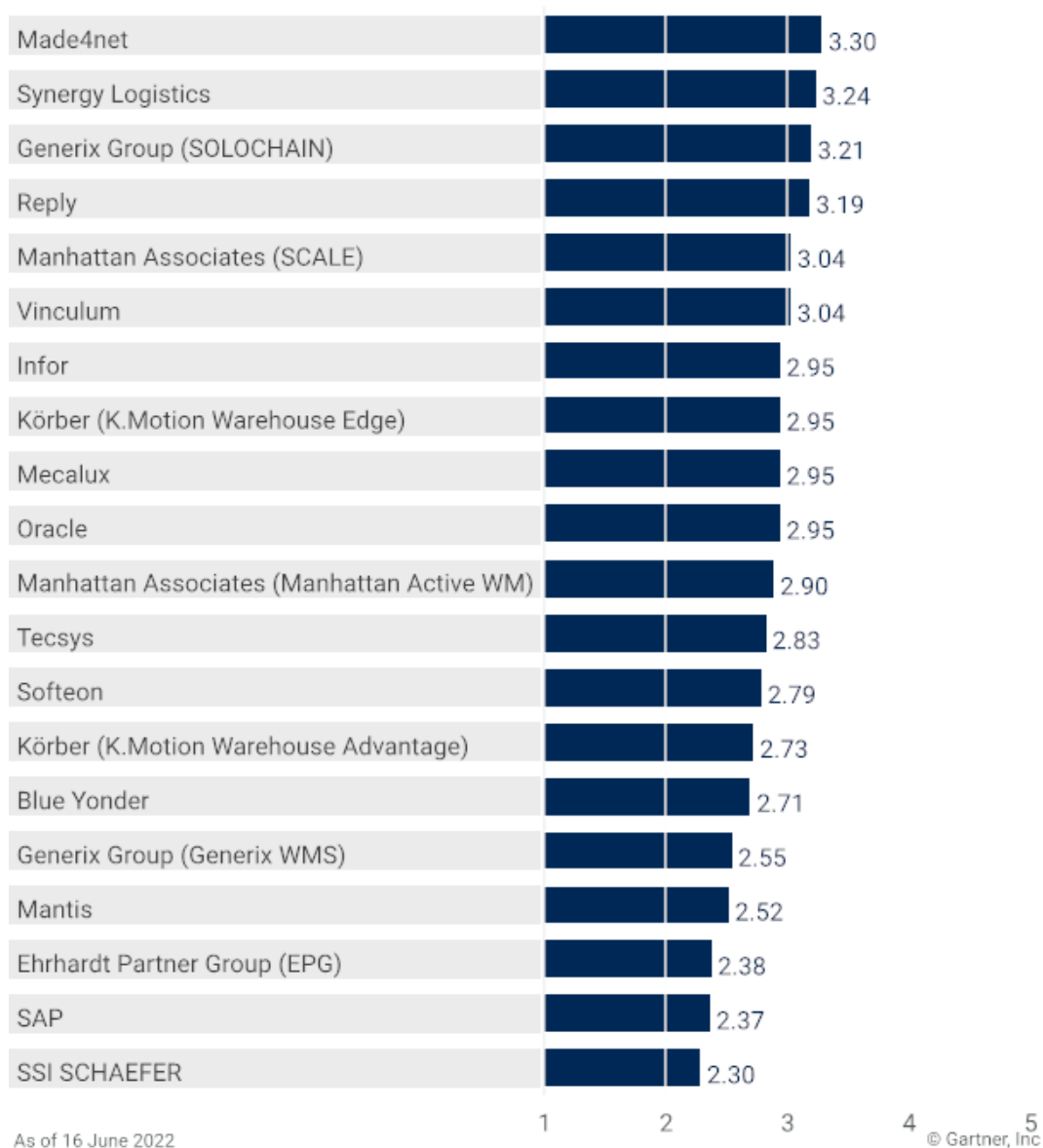
PARCEL SHIPPING

Appendix D: WMS solutions best suited according to the level of warehouse operation

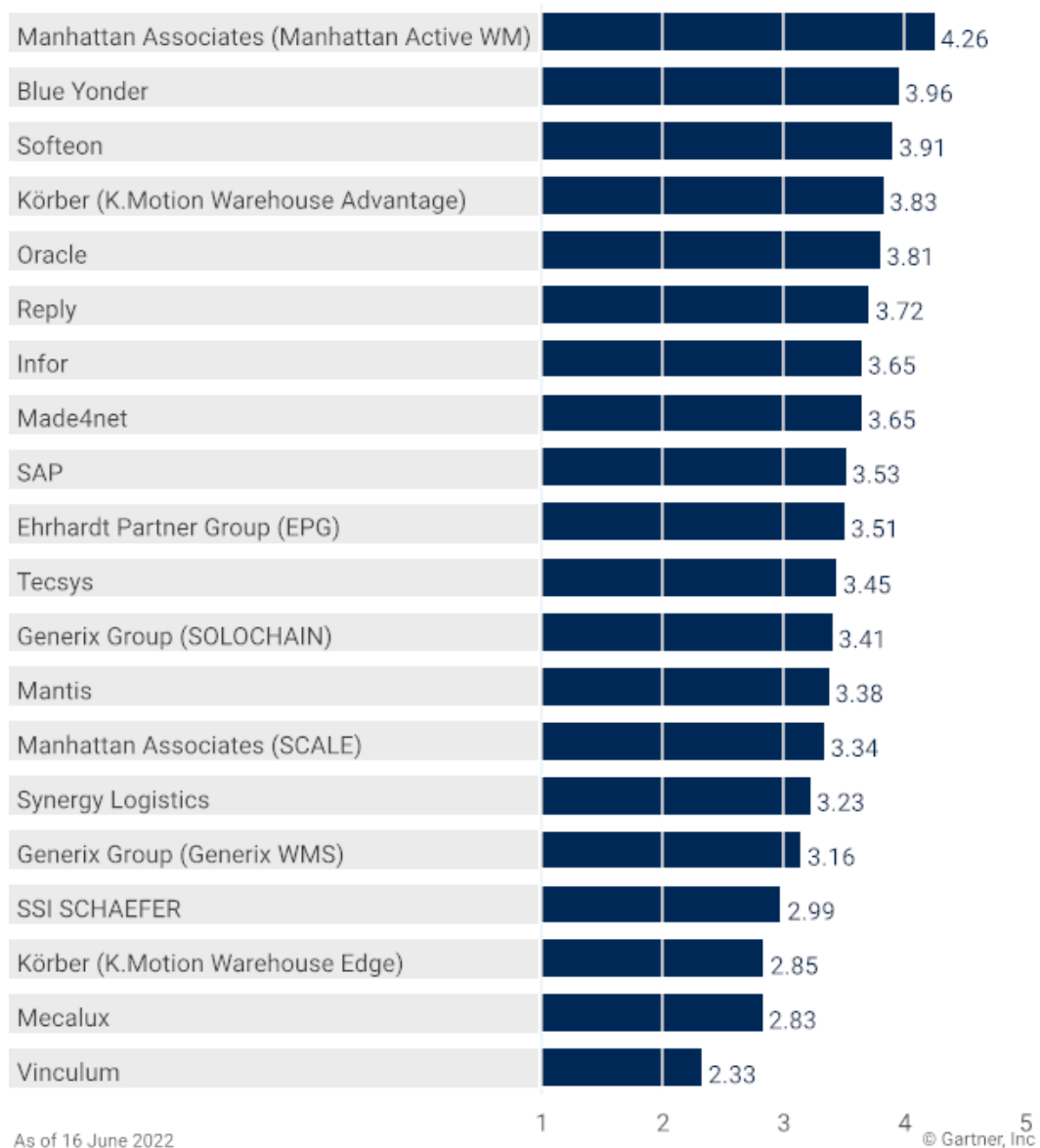
Product or Service Scores for Level 1 Warehouse Operation



Product or Service Scores for Level 2 Warehouse Operation

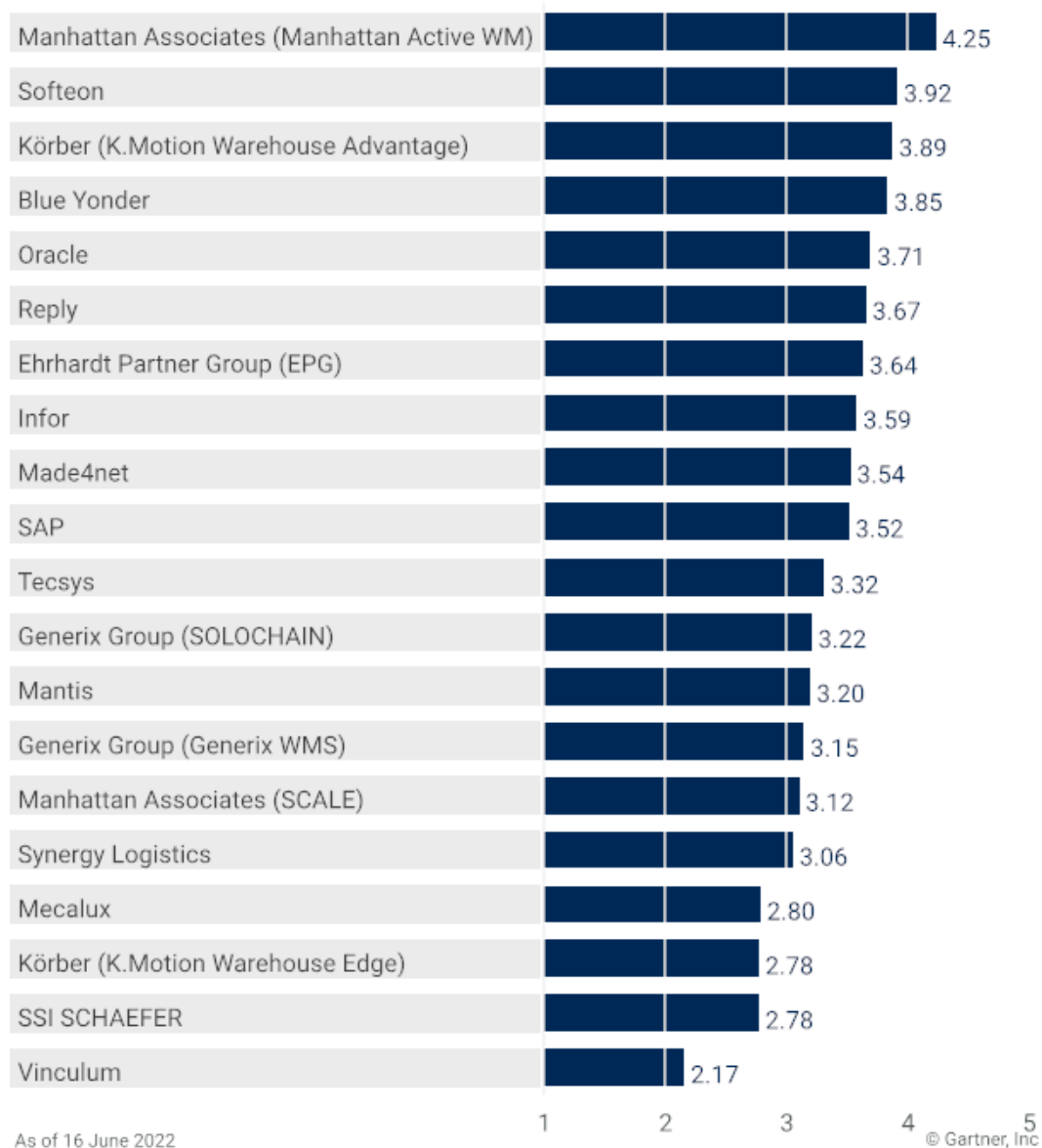


Product or Service Scores for Level 3 Warehouse Operation



Gartner

Product or Service Scores for Level 4 Warehouse Operation



Product or Service Scores for Level 5 Warehouse Operation

