As we will see, warehousing plays an indispensable role in business and supply-chain strategy.

Warehousing adds value in customer service, by facilitating high inventory availability, shorter response times, value-added services, returns, customization, and consolidation among others. Fill rate is the portion of a customer’s demand satisfiable from on-hand inventory. In most cases, a significant investment in safety stock is required to provide high customer fill rates. That safety stock must be housed somewhere, and that somewhere is typically a warehouse.

正如我们将看到的，仓储在业务和供应链战略中起着不可或缺的作用。通过促进高库存可用性，更短的响应时间，增值服务，退货，定制和合并等方面的工作，仓储可增加客户服务的价值。 填充率是可以从现有库存中满足的客户需求的一部分。 在大多数情况下，需要大量的安全库存投资才能提供高的客户填充率。 该安全库存必须存放在某个地方，通常在某个地方是仓库。

Dr. Edward H. Frazelle. World-Class Warehousing and Material Handling, Second Edition (McGraw-Hill Education: New York, Chicago, San Francisco, Athens, London, Madrid, Mexico City, Milan, New Delhi, Singapore, Sydney, Toronto, 2016). <https://www.accessengineeringlibrary.com/content/book/9780071842822>

The latest data from Beroe Inc. suggests that global warehousing is in the midst of a boom. Figures indicate that the industry expanded by 6 to 8 percent over the last year.

Beroe Inc.的最新数据表明，全球仓储业正处于繁荣之中。 数字表明，该行业在去年增长了6％至8％。

The versatile business nature of the e-commerce industry is a key market driver of WMS, which is forecasted to be $1.5 billion by 2017, with a CAGR of 13.9 percent between 2015 and 2029.

电子商务行业的多功能业务性质是WMS的主要市场驱动力，预计到2017年将达到15亿美元，2015年至2029年的复合年增长率为13.9％。

In fact, the length of supply chains owing to global sourcing and the potential for disruption as a result of increasing numbers and severity of climatic and security incidents are increasing the need for warehousing and the value warehousing adds in businesses and supply chains. As all these disruptions take hold, the role and mission of warehouse operations are changing and will continue to change dramatically.

实际上，由于全球采购导致供应链的长度以及由于气候和安全事件的数量和严重性增加而造成的破坏的可能性正在增加对仓库的需求，并且仓库的价值在企业和供应链中增加了。 随着所有这些干扰的发生，仓库运营的角色和使命正在发生变化，并将继续发生巨大变化。

The warehouse is an important element in the supply chain. It is defined as a functional and organizational unit created for storing material goods (supplies) in a special area of warehouse building. Storage can consist of material stocks, raw materials, semi-finished products and goods which temporarily are not in demand. To store all of them, special conditions and methods are necessary, according to their individual physiochemical properties (Krzyżaniak, Niemczyk, Majewski, Andrzejczyk, 2014).

仓库是供应链中的重要元素。 它被定义为为在仓库建筑物的特定区域中存储物料（供应）而创建的功能和组织单位。 仓库可以包括暂时不需使用的物料库存，原材料，半成品和货物。 要存储所有这些，需要根据其各自的理化特性（Krzyżaniak，Niemczyk，Majewski，Andrzejczyk，2014）采用特殊的条件和方法。

The warehouse in the supply chain is the main element combining supplies with production and the market (Makaci et al., 2017; Ben Moussa et al., 2019). Receiving goods, their periodic storage and conveying them to the following links of rotation are its functions (Galińska, 2016). However, there are two basic functions of a warehouse, independent on its placement in the organizational structure of enterprise, that is the function of stock protection, which has a static character, and material handling (manipulation function) concerning the time of receiving and goods issue, and the time of waiting for shipment (Matwiejczuk, 2014). The time of all those activities decides on the efficiency of the warehouse. Material handling is characterised by high dynamic (Ellram & Ueltschy Murfield, 2019).

On the one hand storage is a necessary activity, but on the other it is very expensive. The quest for limiting the complex cost of storing has generated a demand for, and following it creation of, a completely new kind of enterprises and warehouse services (Coyle, Bardi, Langley, 2010).

供应链中的仓库是将供应与生产和市场相结合的主要要素（Makaci等人，2017； Ben Moussa等人，2019）。 收货，将其定期存储并将其传送到以下轮换环节是其功能（Galińska，2016年）。 但是，仓库有两个基本功能，与仓库在企业组织结构中的位置无关，即库存的功能具有静态特性的保护，以及有关收货和发货的材料处理（操纵功能）以及等待装运的时间（Matwiejczuk，2014年）。 所有这些活动的时间取决于仓库的效率。 物料搬运的特点是动态性强（Ellram＆Ueltschy Murfield，2019）

一方面，存储是一项必要的活动，但另一方面，它却非常昂贵。 对限制复杂的存储成本的追求产生了对一种全新的企业和仓库服务的需求，并随之产生了这种需求（Coyle，Bardi，Langley，2010年）。

A key feature of logistics is its warehouses, which today is becoming more and more critical to the overall success and failure of organizations (Frazelle, 2002). The warehouse holds much significance given it plays an intermediary role between various supply chain stakeholders, thus influencing supply chain costs and service (Kiefer & Novack,1999). Furthermore, in recent times many organizations have taken steps to centralized production and warehouse facilities, in a bid to rationalize supply chain processes and manage them more efficiently(Faber, de Koster, & Smidts, 2013). As a consequence, this has led to the proliferation of larger warehouses in control of distribution to a larger, more diverse customer base, in a greater region and, therefore, with more complex internal logistic processes (ELA/AT Kearney, 2005). Due to such significance, the focus for this research is the logistics warehouse.

物流的一个关键特征是其仓库，如今，仓库对于组织的整体成败越来越重要（Frazelle，2002）。 仓库在各个供应链利益相关者之间起着中介作用，因此具有很大的意义，从而影响了供应链的成本和服务（Kiefer＆Novack，1999）。 此外，近来许多组织已采取措施集中化生产和仓库设施，以合理化供应链流程并更有效地进行管理（Faber，de Koster和Smidts，2013年）。 结果，这导致了更大的仓库的扩散，以控制向更大地区的更大，更多样化的客户群的分配，因此，内部物流流程也更加复杂（ELA / AT Kearney，2005年）。 由于这种重要性，本研究的重点是物流仓库。

The eMarketer (2019) estimated that global e-commerce would reach $5 trillion by 2021.

根据ELA / AT Kearney（2004）的调查，2003年，被调查公司的物流成本中，仓储费用占20％（其他活动包括增值服务，管理，库存成本，运输和运输包装的老化）。仓库显然是重要的公司物流系统的一部分。他们很常见用于存储或缓冲产品（原材料，中间和中间的半成品，成品起源点和消费点。

Smart of art

自动化仓储技术阶段，自动化技术对仓储技术和发展起了重要的促进作用。 50年代末和60年代，相继研制和采用了自动导引小车（AGV）、自动货架、自动存取机器人、自动识别和自动分拣等系统。70年代和80年代，旋转体式货架、[移动式货架](https://baike.baidu.com/item/%E7%A7%BB%E5%8A%A8%E5%BC%8F%E8%B4%A7%E6%9E%B6)、巷道式堆垛机和其他搬运设备都加入了自动控制的行列，但这时只是各个设备的局部自动化并各自独立应用，被称为"自动化孤岛"。随着计算机技术的发展，工作重点转向物资的控制和管理，要求实时，协调和一体化，计算机之间、数据采集点之间、机械设备的控制器之间以及它们与主计算机之间的通信可以及时地汇总信息，仓库计算机及时地记录订货和到货时间，显示库存量，计划人员可以方便地作出供货决策，他们知道正在生产什么、订什么货、什么时间发什么货、管理人员随时掌握货源及需求。[信息技术](https://baike.baidu.com/item/%E4%BF%A1%E6%81%AF%E6%8A%80%E6%9C%AF)的应用已成为仓储技术的重要支柱。

集成自动化仓储技术阶段，在70年代末和80年代，自动化技术被越来越多地用到生产和分配领域，显然，“自动化孤岛”需要集成化，于是便形成了“集成系统”的概念。在集成化系统中，整个系统的有机协作，使总体效益和生产的应变能力大大超过各部分独立效益的总和。

集成化仓库技术作为[计算机集成制造系统](https://baike.baidu.com/item/%E8%AE%A1%E7%AE%97%E6%9C%BA%E9%9B%86%E6%88%90%E5%88%B6%E9%80%A0%E7%B3%BB%E7%BB%9F" \t "_blank)（CIMS-Computer Integrated Manufacturing System）中物资存储的中心受到人们的重视。人们在80年代已经注意到系统集成化，在集成化系统里包括了人、设备和控制系统

**Machine learning in warehouse labor planning systems**

[Market leaders like Amazon](https://searchaws.techtarget.com/feature/How-Amazon-launched-the-warehouse-robotics-industry) have reaped many rewards of labor planning systems that rely on machine learning. A number of companies are following suit.

Voice-activated technology integrates with the warehouse management system or [the ERP system](https://searcherp.techtarget.com/feature/10-top-ERP-systems-CIOs-and-business-leaders-should-consider). **集成方式：**语音激活技术与仓库管理系统或[ERP系统](https://searcherp.techtarget.com/feature/10-top-ERP-systems-CIOs-and-business-leaders-should-consider)集成。

### 太阳能和其他可再生能源

由于仓库的高耗电量，许多组织[都在探索](https://www.computerweekly.com/news/252493456/Amazon-goes-public-with-record-breaking-renewable-energy-generation-plans)可再生能源，特别是太阳能。

**谁来购买：**购买建筑物电源的员工（可能是公司一级的人员）和可持续发展负责人。

麻省理工学院房地产创新实验室的商业房地产技术负责人史蒂夫·韦卡尔（Steve Weikal）说**：“为什么”：**仓库的屋顶有很大的跨度，因此在这里放置太阳能农场是有意义的。可再生能源降低了能源运营成本，并且由于它增加了建筑物的运营收入，建筑物的价值也随之上升。

此外，使用可再生能源的公司也会获得回报。

韦卡尔说，例如，马萨诸塞州政府提供了可再生能源激励措施。

**集成方式：**可再生能源与能源管理系统，WMS以及硬件和机器人控制系统集成。公司可以计算一天中产生最大能量的时间，并安排无人驾驶的车辆和机器人在有最大可用能量时进行充电。

智能自动化仓储技术，[人工智能技术](https://baike.baidu.com/item/%E4%BA%BA%E5%B7%A5%E6%99%BA%E8%83%BD%E6%8A%80%E6%9C%AF)发展了自动化技术，人工智能技术发展了自动化技术向更高级的阶段——智能自动化方向发展。现在，智能自动化仓储技术还处于初级发展阶段，到二十世纪仓储技术的智能化将具有广阔的应用前景。

eMarketer于2019年估计，到2021年，全球电子商务将达到5万亿美元。In 2019, the eMarketer estimated that global e-commerce would reach $5 trillion by 2021. The increase in demand will put pressure on warehouse technology.

Warehouse Activities In general, warehouse activity consists of receiving, put away, storage, picking and shipping [5] Receiving is operation that involve the assignment of trucks to dock and the scheduling and execution of unloading Activities [6]. Put away is activity of placing a product or material that has been purchased in the warehouse. This activity including material handling activities verifying the location of the product material and the placement of the product [5]. Storage is movement of material from unloading area to its designated place [7]. Order Picking is order preparation. It is regarded as the main and laborintensive activity of warehouses [8, 9]. Shipping is activity that involves scheduling and assignment of trucks to docks the orders, packing after picking and the loading of trucks [6]. Warehouse activity based on Frazelle model [5] is depicted in Figure 1.

仓库被定义为在仓库建筑物的特定区域中存储物料（供应）而创建的功能和组织单位 [2]。仓库有两个基本功能，与其在企业组织结中的位置无关，即库存的功能，储存包括暂时不需使用的物料库存，原材料，半成品和货物，具有静态特性的保护，以及有关收货发货的材料处理功能。

[2] Adam Marcysiak, 2020."The scope of diversification of the warehouse space market in a regional configuration," Entrepreneurship and Sustainability Issues, VsI Entrepreneurship and Sustainability Center, vol. 8(1), pages 10-23, September.

<https://ideas.repec.org/a/ssi/jouesi/v8y2020i1p10-23.html>

# Warehouse robots

According to Dubois and Hamilton [1], the demand of warehouse robot is increasing and expect to growth 12% in 2018 in the USA. These warehouse robots helped to pick and pack USD 394.8 billion worth of goods in 2017. Markets and Markets [2] projected that the value will further increase to USD4.44 billion by 2022.

从近年的发展来看，仓储自动化系统技术主要目标是为完成自动搬运和存取任务的仓储物流机器人技术和相应的软件控制技术。

PERFORMANCE

Chen et al. (2017) believed that the majority of studies on warehouse management systems have focused on three factors viz. time, cost and profit.

There are several warehouse operational processes: receiving, transfer and storage, order picking/selection, accumulation/sorting, cross-distribution, and transportation,

It is critical that the flow affords the best efficiency of warehouse operation.

Accessibility---->capacity----->

Warehouse flow

Receiving is operation that involves the assignment of trucks to dock and the scheduling and execution of unloading Activities [6]. Put away is activity of placing a product or material that has been purchased in the warehouse. This activity including material handling activities verifying the location of the product material and the placement of the product [5]. Storage is the movement of material from the unloading area to its designated place [7]. Order Picking is order preparation. It is regarded as the main and labor-intensive activity of warehouses [8, 9]. Shipping is activity that involves scheduling and assignment of trucks to docks the orders, packing after picking and the loading of trucks [6].

接收是指将卡车分配到停靠点，并安排和执行卸货活动[6]。 收起是将已购买的产品或物料放入仓库的活动。 该活动包括物料搬运活动，以验证产品物料的位置和产品的位置[5]。 储存是指物料从卸货区到指定地点的运输[7]。 订单拣配是订单准备。 它被认为是仓库的主要劳动密集型活动[8，9]。 运输是一项涉及调度和分配卡车以停靠订单，拣选后打包和装载卡车的活动[6]。

The receiving activity includes the unloading of products from the transport carrier, updating the inventory record, inspection to find if there is any quantity or quality inconsistency. Transfer and put away involves the transfer of incoming products to storage locations. It may also include repackaging (e.g. full pallets to cases, or standardised bins), and physical movements (from the receiving docks to different functional areas, between these areas, from these areas to the shipping docks). The order picking/selection is the major activity in most warehouses. It involves the process of obtaining the right amount of the right products for a set of customer orders. The accumulation/sortation of picked orders into individual (customer) orders is a necessary activity if the orders have been picked in batches. In such a case the picked units have to be grouped by customer order, upon completion of the picking process. After picking, orders often have to be packed and stacked on the right unit load (e.g. pallet).

接收活动包括从运输公司卸下产品，更新库存记录，检查以发现是否存在数量或质量上的不一致。转移和存放涉及将进来的产品转移到存储地点。它还可能包括重新包装（例如，将完整的货盘放到箱子或标准化的垃圾箱中）和物理移动（从接收码头到不同的功能区域，在这些区域之间，从这些区域到运输码头）。订单拣选/选择是大多数仓库中的主要活动。它涉及为一组客户订单获取正确数量的正确产品的过程。如果已分批拣选订单，则将拣选的订单累积/分类为单个（客户）订单是一项必要的活动。在这种情况下，必须在完成拣选过程后根据客户订单对拣选的单位进行分组。领料后，通常必须以正确的单位负载（例如托盘）包装和堆放订单.

Receiving activities include unloading the product from the transport vehicle, updating inventory records, and inspecting to detect any quantity or quality discrepancies. Transfer and storage involve the transfer of incoming products to a storage location. It may include repackaging (for example, placing complete pallets into boxes or standardized bins) and physical movement (from the receiving terminal to different functional areas, between those areas, and from those areas to the shipping terminal). Order picking/selection is the primary operation of retrieving goods from specified storage locations based on customer orders. It is necessary to accumulate/sort picking orders into individual (customer) orders if picking orders have been batched. Shipping involves scheduling and assignment of trucks to docks the orders after the product is collected.

Increasing competition in the global market requires continuous improvement of warehouse performance.

In the context of a dynamic supply chain, continuously improving performance has become a critical issue for most suppliers, manufacturers, and related retailers to gain and sustain competitiveness.

在动态的供应链中，不断提高绩效已成为大多数供应商，制造商和相关零售商获取并维持竞争力的关键问题。

In the context of dynamic supply chain, continuous improvement of warehouse performance has become a key issue for most suppliers, manufacturers and related retailers to gain and sustain competitiveness in the international market.

it should be emphasized that warehouse design decisions are strongly coupled and it is difficult to define a sharp boundary between them. Therefore, our proposed classification should not be

regarded as unique, nor does it imply that any of the decisions should be made independently. Furthermore, one should not ignore operational performance measures in the design phase since operational efficiency is strongly affected by the design decisions, but it can be very expensive or impossible to change the design decisions once the warehouse is actually built

Jinxiang Gu强调仓库设计决策是紧密耦合的，很难在它们之间定义明确的界限。 因此，我们建议的分类不应视为唯一的分类，也不意味着任何决定均应独立做出。 此外，由于设计决策会极大地影响运营效率，因此在设计阶段不应忽视运营绩效指标，但是一旦实际建造了仓库，更改设计决策可能会非常昂贵或无法实现

**Gu et al.(2009) emphasized that warehouse design decisions are tightly coupled and difficult to define clear boundaries. Furthermore, since design decisions can significantly impact operational efficiency, operational performance metrics should not be ignored during the design phase. Once the warehouse is operational, changing design decisions can be very expensive or even impossible.**

there is not a consensus of a group of measures used to assess warehouse performance (Keebler and Plank 2009)

Keebler, J. S., and R. E. Plank. 2009. “Logistics Performance Measurement in the Supply Chain: A Benchmark.” Benchmarking: An International Journal 16 (6):785–798.

This paper differs from the prior literature reviews: by using a structured research process including content analysis, which is a systematic way to extract information from papers, transforming it in summarised results; and by focusing particularly on operational warehouse performance evaluation. To make clear the interpretation of warehouse performance management, we refer to the performance analysis as ‘the periodic measurement and comparison of actual levels of achievement with specific objectives, measuring the efficiency and the outcome of corporation’ (Lu and Yang 2010). Also, in the following discussion, the terms ‘metric’, ‘performance measure’ and ‘performance indicator’ are used as synonyms, as commonly done in the literature (Franceschini et al. 2006).

The performance research method can be grouped into three types: benchmarking, analytical and simulation methods.

Hence, the enrichment of the indicators and the method to measure KPIs of SWMS is necessary (Bank and Murphy, 2013). The other challenge that needs more attention is the total effect of each indicator (weight), which constitutes the SWMS (Staudt et al., 2015). By weighting indicators, a manager will be able to calculate the inherent impact of indicators on SWMS, thus enabling them to identify weaknesses and strengths of the system accurately. Although the total effect of each indicator is a powerful tool which gives manager useful insights, it has not received enough attention in the existing literature.

因此，有必要丰富指标和测量SWMS KPI的方法（Bank and Murphy，2013）。 另一个需要更多关注的挑战是构成SWMS的每个指标（权重）的总体效果（Staudt等人，2015）。 通过加权指标，管理人员将能够计算指标对SWMS的内在影响，从而使他们能够准确地识别系统的弱点和优势。 尽管每个指标的总效果是一个强大的工具，可为经理提供有用的见解，但在现有文献中并未得到足够的重视。

The ISO 22400 standard defines the KPIs used in the production sector. This standard specifies and classifies a set of KPIs in current practice.

Professor Faveto defined a set of key performance indicators for automated warehouses. This paper is based on previous research and aims to analyze the indicator system through systematic research methods, establish the relative relationship between indicators, and determine each indicator's inherent effect in the system.

In a traditional automated storage and retrieval system (AS/RS), unit loads are handled using aisle-captive storage cranes that move simultaneously vertically and horizontally. In an AVS/RS, unit loads are handled by vehicles that move horizontally along rails within the storage racks, while vertical movement is provided by lifts mounted along the rack periphery (Ekren and Heragu 2012).

Based on the format of vehicle assignment to storage tiers, there are two main configurations (Heragu et al. 2011): • AVS/RS with a tier-to-tier configuration; • AVS/RS with a tier-captive configuration.

仓库的系统的发展主要经历了以下几个阶段：

人工仓储技术：物资的输送、存储、管理和控制主要靠人工实现，其实时性和直观性是明显的优点。

机械化仓储：物料可以通过各种各样的传带，工业输送车、机械手、吊车、堆垛机和升降机来移动和搬运，用货架托盘和可移动货架存储物料，通过人工操作机械存取设备，用限位开关，螺旋机械制动和机械监视器等控制设备的运行。机械化满足了人们速度、精度、高度、重量、重复存取和搬运等要求。

自动化仓储技术：随着自动化技术的发展，AS/RS, AVS/RS,自动货架，自动存取机器人，自动识别和分拣等系统被相继应用于仓库系统中。

集成自动化仓储技术：在工业4.0时代，信息技术向制造业的全面深入，促进了现有硬件设备的扩容与升级，改善了仓储物流运作流程，提高了仓储技术装备的柔性化应用水平，使总体效益和生产的应变能力使远远超过各部分独立效益的总和。目前广泛被采用的仓库管理系统是将信息技术集成于自动化仓库的体现，此外企业资源计划（ERP）系统，客户关系管理（CRM），订单管理系统（OMS）也被应用于供应链管理中。

当前已被广泛采用的仓库管理系统（WMS）是将信息技术集成到自动化仓库中的体现。 此外，企业资源计划（ERP）系统，客户关系管理系统（CRM）和订单管理系统（OMS）也已应用于某些供应链管理（SCM）中。

智能自动化仓储技术：在自动化仓储的基础上继续研究，实现与其他信息决策系统的集成，朝着智能和模糊控制的方向发展，人工智能推动了仓储技术的发展，即智能化仓储。目前，智能化仓储技术还处于初级发展阶段。

The development of the warehouse system has mainly gone through the following stages:

* **Manual warehouse:** The handle of materials is mainly realized manually, and its real-time and intuitive nature are apparent advantages.
* **Mechanized warehouse:** Materials can be moved and handled by various conveyors, industrial conveyors, manipulators, cranes, stackers, and elevators. Use shelf pallets and movable shelves to store materials and manually operate mechanical access equipment. Use limit switches, screw mechanical brakes, and mechanical monitors to control the operation of the equipment. Mechanization meets people's requirements for speed, accuracy, height, weight, repeated storage, and retrieval.
* **Automated warehouse:** With the development of automation technology, AS/RS, AVS/RS, automatic shelves, automatic storage, and retrieval robots, automatic identification and sorting have been successively applied to the warehouse system.
* **Integrated automated warehouse**:In the industry 4.0 era, information technology is fully and deeply penetrated the manufacturing industry, which promotes the expansion and upgrade of existing hardware equipment, improves the warehousing logistics operation process, and improves the level of flexible application of warehousing technology and equipment, so that the overall the efficiency and the adaptability of production far exceed the sum of the independent benefits of each part. Warehouse Management System (WMS), which has been widely adopted at present, is the embodiment of integrating information technology into the automated warehouse. Besides, enterprise resource planning (ERP) system, customer relationship management system(CRM), and order management system (OMS) have also been applied to some supply chain management（SCM）.
* **Intelligent automated warehouse:** Continue to research based on automated warehousing, realize integration with other information decision-making systems, and develop in the direction of intelligence and fuzzy control. Artificial intelligence promotes the development of warehousing technology, that is, intelligent warehousing. At present, intelligent storage technology is still in the initial stage of development. The application of artificial intelligence can make the warehouse fully intelligent, such as JD's unmanned warehouse, which maximizes the performance of the warehouse.

Figure.2 below demonstrates the three layers of drivers behind the growing automation trend.

下面的图2展示了不断增长的自动化趋势背后的三层驱动因素。

京东亚洲一号仓是亚洲首个实现无人化操作的自动化立体仓库，在很大程度上降低了物流成本，提高了仓储作业的效率。其无人操作技术主要体现在以下几个方面。首先，自动化立体仓库的基础设施配置和现代化的货架、穿梭车、识别系统、输送系统及控制系统，为无人化的运行奠定了设施基础。其次，智能机器人如同人体中的血液在全身流动一般，在仓库的各个角落工作，使整个仓库运作起来。不同的机器人有着不同的分工，例如负责搬运的AGV机器人，负责分拣的DELTA机器人，还有负责货架移动的货架穿梭车等。整个物流仓储的各个环节都按照机器人的不同功能和特性，明确其作业分工。再次，人工智能算法和自动识别感应射频技术就像人的大脑和眼睛一样，分别负责信息的处理和识别。智能算法是整个无人仓库的技术核心，整个仓库的运行全部受智能算法的调配[4-5]。京东亚洲一号仓让京东物流走在了行业前端，同时扩大了京东的影响力和知名度，并且实现了京东的社会责任和企业利益的双重价值。

The application of artificial intelligence can make the warehouse fully intelligent, such as JD's unmanned warehouse, which maximizes the performance of the warehouse.

如今，在5G的背景下，智能自动化仓库的前景广阔。

Nowadays, in the context of 5G, intelligent automated warehouse has a broad prospect.

自动化仓库不是最近才发明的, 实际上仓库自动化（第一批AGV）起源于1950年代，但在如今仍然是仓库系统最热门的趋势。 下面的图3展示了不断增长的自动化趋势背后的三层驱动因素 [9]。 简而言之，这种趋势是由更高的消费者期望所引起的运营挑战所导致的成本上升驱动的。

Automated warehouses were not invented recently. In fact, warehouse automation (the first batch of AGVs) originated in the 1950s, but it is still the hottest trend in warehouse systems today. Figure 3 below shows the three drivers behind the growing automation trend [9]. In short, this trend is driven by rising costs due to operational challenges caused by higher consumer expectations.

Warehouse performance evaluation measures efficient use of warehouse space, customer satisfaction level, quality of goods stored and transport, level of inventory, and environmentally friendly delivery. Managers and decision-makers are keen to know very rapidly which decisions need extra attention and have more impact on overall warehouse performance.

仓库绩效评估可衡量仓库空间的有效利用，客户满意度，存储和运输的货物质量，库存水平以及环保交付。 经理和决策者渴望很快地知道哪些决策需要特别注意，并且对整体仓库绩效产生更大的影响。

A typical automated warehouse consists of four units: cargo handlers, storage mechanism (shelf system), conveying equipment, and control devices.

货物存取器可在轨道上水平方向移动，也可以在本身的立柱上沿垂直方向移动，以完成货物的访问操作。仓库的单位时间内的货物吞吐量取决于存取器的速度。输送设备通常是指将货物存取机与其他长距离的运输装置联系起来的输送设备，例如铲车、引导车、穿梭车和辊筒链条输送机。控制装置把自动化仓库的一切设备有机地联系在一起，使其按照预定的程序和要求动作，形成一个自动控制系统。

A typical automated warehouse consists of four units: cargo handlers, storage mechanism (shelf system), conveying equipment, and control devices. The cargo handlers can move horizontally on the track or move in the vertical direction on its column to complete the storage and retrieval operation. The cargo throughput per unit time of the warehouse depends on the speed of the handle device. Conveying equipment usually refers to the conveying equipment that connects the cargo storage machine with other long-distance transportation devices, such as forklifts, guided vehicles, shuttle cars, and roller chain conveyors. The control device organically links all the automated warehouse equipment to make it act according to the predetermined procedures and requirements to form an automatic control system.

不断增长的仓库操作复杂性和易于访问的信息，导致公司需要进行有效而高效的仓库绩效评估。 决策者需要一个系统，该系统可帮助他们衡量他们根据长期决策标准（战略和战术）做出的决策对短期（运营）和整体仓库绩效的影响。

~~The performance research method used in studies can be grouped into three types: benchmarking, analytical and simulation methods [6].~~

warehouse performance evaluation has been explored in different ways by researchers. These works differ from one another with respect to the objectives (long- or short-term decisions), the way to measure these objectives (variety of performance indicators), the type of warehouse systems (distribution center, cross-dock platforms, etc.), the focus area inside the warehouse (storage, picking, etc.) and the tools used for measurement (statistical tools, mathematical programming, etc.).

研究人员已经以不同的方式探索了仓库绩效评估。 这些工作在目标（长期或短期决策），衡量这些目标的方式（各种绩效指标），仓库系统的类型（配送中心，跨码头平台等）方面彼此不同。 ），仓库内的重点区域（存储，拣配等）和用于测量的工具（统计工具，数学编程等）。

Sustainable warehouse is an important part of SSCM which includes the process of receiving, storing, retrieving and shipping of raw materials, work in process or final products. In sustainable warehouses, companies not only consider financial factors such as ordering costs and holding costs, but also maintain a balance of the warehouse's operational impact on the surrounding social and environment [13]. A balance between economic, social and environmental factors must be maintained because one factor with another can impact each other. For example, there are three types of activities to reduce the environmental impact of warehouse operations, i.e. tree planting, carbon credits and modification of material handling devices. All these activities will increase the warehouse operating costs, so that the allocation of funds for employee training and some other investments will be reduced.

文献计量学是一门利用数学，统计等计量方法研究文献信息的分布结构，定量关系，变化规律和定量管理，探索学科的科学技术体系，特征和规律的学科。

Bibliometrics is a discipline that uses mathematics, statistics and other measurement methods to study the distribution structure, quantitative relationship, change law and quantitative management of literature information, and to explore the scientific and technological system, characteristics and laws of the discipline[].

M. K. McBurney and P. L. Novak, "What is bibliometrics and why should you care?," Proceedings. IEEE International Professional Communication Conference, 2002, pp. 108-114, doi: 10.1109/IPCC.2002.1049094.

This paper differs from the prior literature reviews: by using a structured research process including content analysis, which is a systematic way to extract information from papers, transforming it in summarised results; and by focusing particularly on operational warehouse performance evaluation.

本文不同于以往的文献评论：采用包括内容分析在内的结构化研究过程，系统地从论文中提取信息，在总结结果中进行转化：并特别注重运营仓库绩效评估。

Sustainable warehouse is an important part of SSCM which includes the process of receiving, storing, retrieving and shipping of raw materials, work in process or final products. In sustainable warehouses, companies not only consider financial factors such as ordering costs and holding costs, but also maintain a balance of the warehouse's operational impact on the surrounding social and environment [13]. A balance between economic, social and environmental factors must be maintained because one factor with another can impact each other. For example, there are three types of activities to reduce the environmental impact of warehouse operations, i.e. tree planting, carbon credits and modification of material handling devices. All these activities will increase the warehouse operating costs, so that the allocation of funds for employee training and some other investments will be reduced.可持续仓库是 SSCM 的重要组成部分，包括原材料的接收、储存、检索和运输、加工或最终产品运输过程。在可持续仓库中，公司不仅考虑订购成本和持有成本等财务因素，而且还保持仓库对周围社会和环境的运营影响的平衡 [13]。必须保持经济、社会和环境因素之间的平衡，因为一个因素与另一个因素可以相互影响。例如，有三种类型的活动来减少仓库操作对环境的影响，即植树、碳信用和材料处理设备的改装。所有这些活动都将增加仓库的运营成本，从而减少员工培训和其他一些投资的资金分配。

There are some other studies that attempt to incorporate other factors apart from economic indicators. He et al. (2017) was developing low-carbon logistics, and a Performance Measurement System (PMS) has been proposed to evaluate low-carbon logistics considering economic, social and environmental performance. However, the proposed indicators are adopted to assess logistics enterprises’ performance rather than focusing on warehousing as a whole. Calzavara et al. (2017) evaluated the operational efficiency of order picking in a warehouse by developing economic and ergonomic performance measures. Foroozesh et al. (2018) proposed a multi-criteria decision-making model to evaluate the sustainability of warehouse locations considering three aspects of sustainability to determine the most sustainable warehouse location. Tan et al. (2010) developed a sustainable simulation model focusing on warehouse location, using social and environmental criteria. He developed a balanced scorecard along with a sustainable There are some other studies that attempt to incorporate other factors apart from economic indicators. He et al. (2017) was developing low-carbon logistics, and a Performance Measurement System (PMS) has been proposed to evaluate low-carbon logistics considering economic, social and environmental performance. However, the proposed indicators are adopted to assess logistics enterprises’ performance rather than focusing on warehousing as a whole. Calzavara et al. (2017) evaluated the operational efficiency of order picking in a warehouse by developing economic and ergonomic performance measures. Foroozesh et al. (2018) proposed a multi-criteria decision-making model to evaluate the sustainability of warehouse locations considering three aspects of sustainability to determine the most sustainable warehouse location. Tan et al. (2010) developed a sustainable simulation model focusing on warehouse location, using social and environmental criteria. He developed a balanced scorecard along with a sustainable.

除了经济指标之外，还有其他一些研究试图纳入其他因素。他等人（2017年）正在开发低碳物流，并提议建立一个绩效测量系统（PMS），以评估低碳物流，考虑经济、社会和环境绩效。然而，建议的指标是为了评估物流企业的业绩，而不是侧重于整体仓储。卡尔扎瓦拉等人（2017年）通过制定经济和人体工程学性能指标，评估了仓库中订单采摘的运营效率。Foroozesh 等人（2018 年）提出了一个多标准决策模型，以评估仓库位置的可持续性，考虑三个方面的可持续性，以确定最可持续的仓库位置。Tan等人（2010年）利用社会和环境标准，开发了一个以仓库位置为重点的可持续模拟模型。他开发了一个平衡的记分卡，以及一个可持续的还有其他一些研究，试图纳入其他因素，除了经济指标。他等人（2017年）正在开发低碳物流，并提议建立一个绩效测量系统（PMS），以评估低碳物流，考虑经济、社会和环境绩效。然而，建议的指标是为了评估物流企业的业绩，而不是侧重于整体仓储。Calzavara 等人（2017 年）通过制定经济和符合人体工程学的性能指标，评估了仓库中订单采摘的运营效率。Foroozesh 等人（2018 年）提出了一个多标准决策模型，以评估仓库位置的可持续性，考虑三个方面的可持续性，以确定最可持续的仓库位置。Tan等人（2010年）利用社会和环境标准，开发了一个以仓库位置为重点的可持续模拟模型。他开发了一个平衡的记分卡以及可持续的记分卡

这也是[精益仓库管理的](https://articles.cyzerg.com/lean-warehouse-management-and-why-you-need-it)本质 。跟踪仓库KPI不仅使您可以监视仓库流程的效率，还可以采取纠正措施来提高生产率和资产利用率。结果是持续的运营改进和更高的客户满意度。

Lean warehouse

The term 'lean warehousing' is relatively new in literature (Sharma and Shah, 2016). Analyzing the level of waste in the warehouse system is the first step towards understanding leanness implementation in the organization (Womack and Jones, 1996). Seeking perfection through reducing or eliminating waste is central to lean philosophy and implementing lean principles and techniques (Villarreal et al., 2016). Lean warehousing seeks to maximize the use of available warehouse resources and activities through reducing or eliminating wastes in the logistics system. As a result, this would lead to improve the quality of offered goods and services and optimize the use of resources (Villarreal et al., 2016). Because of the unique characteristics of service processes (Piercy and Rich, 2009), most service industries were reluctant to borrow lean principles from manufacturing literature (Swank, 2003; Piercy and Rich, 2009). However, since companies started to recognize that competitive advantage in service sectors can be attained through improved efficiencies, waste reduction practices were adopted in the service industry (Douglas et al., 2015; Salhieh et al., 2018) and distribution function (Villarreal et al., 2016). Because firms are seen as a collection of processes, waste reduction practices were successfully adapted to and applied in the service industry (Piercy and Rich, 2009).

Lean in the warehouse focuses on assembling warehouse orders in the most efficient way, minimizing non-value-adding activities in receiving, put-away, picking, packing and shipping (Myerson, 2012). Therefore, to minimize non-value-adding activities, warehouses have to identify wastes in these activities.

The importance of Lean concepts and their ultimate aim of eliminating waste for warehouse operations have been discussed by several scholars.

几位学者讨论了精益概念的重要性及其消除仓库运营废物的最终目标。

Various studies have investigated the effect of Lean production on performance (e.g. Swank, 2003; Shah and Ward, 2003; Brandao de Souza, 2009; Demeter and Matyusz, 2011; Jaca et al., 2012; Vinodh et al., 2014). Many practitioners and researchers claim that Lean contributes to significant cost reduction, more productive workforce, shorter lead times and better quality (e.g. Krafcik, 1988; MacDuffie, 1995; Holweg, 2007; Shah and Ward, 2007; Aamer, 2018). Regarding warehouses, Bowersox et al. (2007) asserted that Lean provides the warehousing operations with a competitive edge by ensuring the following:

• on-time delivery and low cost service to its customers through improved efficiency and productivity, together with high quality and accuracy in preparing orders;

• improved stock integrity and better control over services by preventing picking disruptions, lack of material availability and loss of sales opportunities;

• accurate levels of information flow and traceability between the warehouse and other echelons of the supply chain; and

• management of the ever-changing customer requirements and market complexities by adapting to demand changes to meet seasonal and new customer demands

通过提高效率和生产力，以及高质量和准确性，为客户提供准时交货和低成本服务：

• 通过防止拾取中断、缺乏材料可用性和失去销售机会，改善库存完整性和更好地控制服务;

• 仓库与供应链其他梯队之间信息流和可追溯性的准确水平;和

• 通过适应需求变化以满足季节性和新客户需求，管理不断变化的客户需求和市场复杂性

The challenge of supply chain performance

Improving supply chain performance is a continuous process that requires both an analytical performance measurement system, and a mechanism to initiate steps for realizing KPI goals; herein we call the mechanism to achieve KPI goals as “KPI accomplishment”, which connects planning and execution, and builds steps for realization of performance goals into routine daily work. To measure supply chain performance, there are a set of variables that capture the impact of actual working of supply chains on revenues and costs of the whole system [21]. These variables as drivers of supply chain performance are always derived from supply chain management practices [21].

Recently, some decision-making tools have been used to solve problems of performance metrics' trade-off by weighing the importance of different KPIs. One of them is use of the Analytic Hierarchy Process (AHP) approach, as a quantitative decision-making tool for linking the scorecard's KPIs to the overall mission, objectives, and strategies [13,16]. However, it is argued that AHP is not stable in its theoretical foundation, and could cause revisions in decision-makers' preferences because a pairwise comparison matrix fails to perfectly satisfy the consistency required by the AHP approach [7]. Meanwhile, using AHP is only to determine the “weight” or relative importance of individual KPIs; it does not specify the relationships among KPIs and their role in accomplishment efforts, which are very important factors for continuous supply chain performance improvement in a dynamic environment. Another decision-making technique is grey relational analysis, which has been extended to analyze the financial performance of businesses, instead of using the traditional statistical methods. Kung and Wen [15] applied theweighing of grey relationalmatrix to select significantfinancial performance measures. Similar to the AHP approach, grey relational analysis is used at strategic levels, but not to dynamically select and tradeoff KPIs within a variable supply chain environment. And then the grey relational analysis depends more on the correlation degree of factors that actually generate a grey relational grade, without considering any related strategies and activities. In other words, grey relational analysis has not been adopted to make decisions in a wide range of dynamic situations.

最近，一些决策工具被用来通过权衡不同 KPI 的重要性来解决绩效指标权衡问题。其中之一是使用分析等级流程 （AHP） 方法，作为将记分卡 KP 与总体任务、目标和战略 [13，16] 联系起来的定量决策工具。然而，据认为，AHP的理论基础并不稳定，并可能导致决策者偏好的修正，因为双向比较矩阵未能完全满足AHP方法[7]所要求的一致性。同时，使用AHP只是确定单个 KP 的"重量"或相对重要性：它没有具体说明 KPI 之间的关系及其在成就努力中的作用，这是动态环境中持续改善供应链绩效的重要因素。另一种决策技术是灰色关系分析，它已被扩展为分析企业的财务业绩，而不是使用传统的统计方法。孔和文[15]运用灰色关系矩阵来选择重要的财务绩效指标。与 AHP 方法类似，灰色关系分析用于战略层面，但不用于在可变供应链环境中动态选择和权衡 KPI。然后，灰色关系分析更多地取决于实际产生灰色关系等级的因素的相关程度，而不考虑任何相关的策略和活动。换言之，在各种动态情况下，没有采用灰色关系分析来作出决定。

Once critical KPIs have been identified and selected effectively, another challenge is that it is difficult to coordinate the parallel steps required for accomplishment of improvement in identified KPIs. Generally speaking, there are two methodological streams to cope with this problem in previous literature. One stream involves finding out the bottlenecks in the supply chain by implementing the KPIs. For instance, the Theory of Constraints (TOC)[20] is a set of concepts and tools that can be used to implement the widely used continuous improvement management philosophy. TOC improves performance in a system by focusing attention of management on the system's constraints. Thus, by preventing distractions from its primary purpose and concentrating limited resources on efficacious management of the constraint, decisionmakers are able to gain significant leverage, sufficient to attain the desired performance levels [20]. In the TOC theory, the method is to find a suitable approach to identify and solve bottlenecks in production, delivery, and service processes. However, the TOC method does not deal with selection of crucial bottlenecks and it doesn't provide the optimal solution of performance improvement for each KPI. Sometimes, the KPIs are coupled or correlated, and it is hard to find the precise bottleneck; improving one KPI might undermine performance of another.

一旦有效地确定和选定了关键的 KPI，另一个挑战是难以协调实现已确定 KPI 改进所需的平行步骤。一般来说，在以前的文献中，有两种方法流来处理这个问题。一条流涉及通过实施 KPI 来找出供应链中的瓶颈。例如，约束理论 （TOC）[20] 是一组概念和工具，可用于实施广泛使用的持续改进管理理念。TOC 通过将管理层的注意力集中在系统的约束上，从而提高了系统中的性能。因此，通过防止偏离其主要目的，将有限的资源集中到有效管理约束上，决策者能够获得巨大的影响力，足以达到预期的绩效水平[20]。在 TOC 理论中，该方法是找到一种合适的方法来识别和解决生产、交付和服务流程中的瓶颈。但是，TOC 方法不涉及关键瓶颈的选择，也没有为每个 KPI 提供性能改进的最佳解决方案。有时，KPI 是耦合或关联的，很难找到精确的瓶颈：改善一个 KPI 可能会破坏另一个 KPI 的性能。

The second stream focuses on performance optimization; the optimization philosophy assumes that there is an optimal performance point, when maximizing or minimizing the identified indicators. Although the performance optimization approach, in theory, is widely accepted by researchers, it is difficult to ensure that an optimized KPI accomplishment strategy is implemented by different members of the supply chain. First, it is difficult to apply in practice, in terms of both data acquisition and computing. It is also difficult for decision-makers to understand in real SCM situations. Second, it does not take into account the relationships among indicators. Though classified into different categories, different measures in a measurement system are often correlated. The correlations among different measures arise from the inherent internal relations of different SCM processes, and the interdependent influences of different KPIs' accomplishment tasks. Therefore, a feasible methodology of identifying and analyzing the relationships among KPIs related to different SCM processes is important and necessary for improving SCM performance. For supply chain performance optimization, identifying important measures at multiple levels is more important than just maximizing or minimizing the identified indicators. One approach towards evaluating important indicators is the fuzzy logic technique, which is a problem-solving tool for handling vague and imprecise information, to get a definite decision [10]. Although specific applications of the fuzzy logic tool for decision-making have been presented in the hierarchical measurement system [8], there have been few studies of using this tool in performance management, in practice, in comparison to other practical areas (e.g., project management [10]).

In practice, organizations are prone to making rushed decisions, when faced with continuously changing goals and tight deadlines. Managers are short of time to compare all the options when situations demand immediate solutions. Therefore, it is important to describe the mutually dependent relationships among KPIs, and to optimize their accomplishment, based on their complex interdependence. However, most of the previous researches do not provide specific operational procedures for analyzing KPI accomplishment. Considering pros and cons of different methods, this paper provides a framework of supply chain performance measurement and improvement, based on a systematic approach to analyzing KPI accomplishment

第二个流侧重于性能优化：优化理念假定在最大化或最小化已确定的指标时具有最佳性能点。虽然性能优化方法在理论上被研究人员广泛接受，但很难确保供应链的不同成员实施优化的 KPI 成就策略。首先，在实际操作中，在数据采集和计算方面都很难应用。决策者也很难在实际的 SCM 情况下理解。 第二，它没有考虑到指标之间的关系。虽然分为不同的类别，但测量系统中的不同测量结果通常相互关联。不同措施之间的相关性源于不同 SCM 流程的内在关系，以及不同 KPI 完成任务的相互依存影响。因此，确定和分析与不同 SCM 过程相关的 KPI 之间关系的可行方法对于提高 SCM 性能非常重要和必要。对于供应链穿孔优化，在多个级别确定重要措施比仅最大化或最小化已识别指标更重要。评估重要指标的一种方法是模糊逻辑技术，它是处理模糊和不精确信息的解决问题的工具，以获得明确的决策 [10]。虽然模糊逻辑工具用于决策的具体应用已在分层测量系统[8]中提出，但与其他实际领域（例如项目管理[10]）相比，在绩效管理中使用该工具的研究很少。

在实践中，当面临不断变化的目标和紧迫的最后期限时，组织容易仓促决策。当情况需要立即解决时，管理者没有时间比较所有选项。因此，必须描述KPI之间的相互依赖关系，并根据其复杂的相互依存关系优化其成就。但是，大多数以前的研究没有提供分析 KPI 成就的具体操作程序。考虑到不同方法的利弊，本文在系统分析 KPI 成就的基础上，提供了供应链绩效测量和改进的框架