

A Service of



Leibniz-Informationszentrum Wirtschaft Leibniz Information Centre for Economics

Chou, Tung-Hsiang; Chen, You-Sheng; Pan, Chung-Wei; Chang, Hung-Hsuan

Article

A smart scale for efficient inventory management based on design science research principles

Contemporary Economics

Provided in Cooperation with:

University of Finance and Management, Warsaw

Suggested Citation: Chou, Tung-Hsiang; Chen, You-Sheng; Pan, Chung-Wei; Chang, Hung-Hsuan (2024) : A smart scale for efficient inventory management based on design science research principles, Contemporary Economics, ISSN 2300-8814, University of Finance and Management in Warsaw, Faculty of Management and Finance, Warsaw, Vol. 18, Iss. 2, pp. 153-170, https://doi.org/10.5709/ce.1897-9254.531

This Version is available at: https://hdl.handle.net/10419/312947

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.



https://creativecommons.org/licenses/by/4.0/

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.





A Smart Scale for Efficient Inventory Management Based on Design Science Research Principles

Tung-Hsiang Chou o, You-Sheng Cheno, Chung-Wei Pano, Hung-Hsuan Chango

ABSTRACT

Even in the context of Industry 4.0, conventional warehouse management continues to encounter challenges. Amidst these obstacles, innovative solutions are imperative. Order picking, a critical process with significant implications for customer service, remains labor-intensive within warehousing operations. Current manual methods result in prolonged inventory cycles and inherent accuracy complexities. To address these issues, this research has used the Design Science Research (DSR) method for developing a device called the Smart Scale, which helps optimize warehouse inventory management. This device, which is tailored specifically for lightweight items such as chewing gum, screws, and fasteners, uses weight sensors to calculate real-time quantities dynamically. By reducing human error and enhancing item supervision, the Smart Scale improves inventory precision and time and cost efficiencies.

KEY WORDS: Industry 4.0, DSR, IoT, intelligent warehousing, order picking.

JEL Classification: C80, L86.

Department of Information Management, National Kaohsiung University of Science and Technology, 1 University Rd, Yanchao District, Kaohsiung City, Taiwan

1. Introduction

Industry 4.0 has existed for a while, yet traditional issues such as inventory problems persist in warehouse management. The rise of e-commerce has led to increased production speed and an increase in the number of orders for some factories, resulting in reduced lead times, shorter product lives, and increased inventory turnover rates, all of which increase the pace of work in warehouses (Tompkins & Smith, 1998). Order picking—which is the process of retrieving a product from a warehouse in response to a customer request—is a pivotal procedure consuming a significant amount of labor and directly affecting the service quality perceived by downstream customers (Bartholdi & Hackman, 2019).

Most labor-intensive operations in warehouses with manual systems involve high operational

costs and are time-consuming (Deshpande & Kumar, 2020). To address these problems, warehouse managers can choose from various technologies. According to Koster (2008), warehouses that must quickly handle many customer order lines can use techniques involving a "split-case order-picking" system (i.e., a picker-to-parts system).

There is no one best technology for split-case order picking. Pick-to-light systems, which use electronic labels and related software, are standard in the inventory industry driven by the Internet of Things (IoT) (Su et al., 2019). Other technologies used in split-case order picking include radio-frequency systems, barcode scanners, vision picking, put-to-voice systems—each having a distinct set of applications (Berger & Ludwig, 2007; Fang & An, 2020).

Thanks in part to its reputation for high-quality production and fast delivery, Taiwan has established

Correspondence concerning this article should be addressed to: **Tung-Hsiang Chou**, Department of Information Management, National Kaohsiung University of Science and Technology, University Rd, Yanchao District, Kaohsiung City, Taiwan. **E-mail:** sam@nkust.edu.tw

itself as a significant manufacturer in the global market for screws and nuts (Huang, 2021). The screws and nuts stored in Taiwanese warehouses are diverse and numerous, making the counting of these products both costly and prone to error. Indeed, throughout the world, efficient inventory management remains a problem for industries dealing with small, lightweight materials. To tackle these issues, a common practice is to divide the materials into batches packaged in plastic bags or boxes. However, counting errors still occur in the production department owing to the difficulty of precisely counting small objects. Also, not all products are able to have an attached radio-frequency identification (RFID) tag. In short, there is no precise and fool-proof method for counting small objects individually in warehouse inventory.

Most existing research on order picking focuses on reducing travel and balancing problems by optimizing routing. For example, the retrieval-order request in a warehouse can be viewed as a traveling salesperson problem (TSP) that can be efficiently solved with computer algorithms (Hall, 1993; Roodbergen & Koster, 2001). Another popular topic of research is the bucket-brigade system, where each worker passes an item from one station to another and from one stage of processing to another (Alligood et al., 1996; Bartholdi & Eisenstein, 1996). These and other studies have offered valuable insights into order-picking problems and solutions, but intricate challenges persist with respect to the management of small-item inventories (Li et al., 2023; Mugoni et al., 2023).

In the present study, its central aim is to show how both IoT technology and cloud technology, when based on the DSR method, can improve the orderpicking process for small materials. This study revolves around the following research question: how can companies leverage the DSR method to develop a technical service that reduces manual-picking errors and that improves real-time calculations of small-item inventory? To answer this question, this research has set out to achieve three primary research goals:

1. Use the DSR method to develop the Smart Scale, which is a device that should enable precise, real-time calculations and tracking of small items in an inventory. 2. Assess the effectiveness of the Smart Scale regarding warehouse efficiency and operational costs while iteratively optimizing the design of the Smart Scale according to expert opinions.

3. Investigate the economic value of implementing the Smart Scale in small- and medium-sized enterprises (SMEs) in Taiwan.

This study proposed Smart Scale should encompass real-time management functionalities and data-inquiry capabilities, facilitating instant information dissemination and manipulation through a web or mobile interface. The algorithm embedded within the device should help to reduce both human errors and labor costs. In the end, this research hopes to address managerial and economic issues in ways that benefit SMEs and consumers alike (Chaopaisarn & Woschank, 2021; Özşahin et al., 2022).

The structure of this paper is as follows: In Section 2, this research reviews the literature on related topics. In Section 3, this research discusses the research method. In Section 4, this research discusses the requirements and the architectural design for its proposed Smart Scale. In Section 5, this research reports the results of the initial implementation of Smart Scale. Finally, in Section 6, this research concludes the paper, point out limitations of its findings, and suggest directions for future research.

2. Literature Review

In this study, it explores the dynamic interplay between traditional and cutting-edge methods in the contemporary landscape of inventory management. This section comprehensively examines three distinct yet interconnected domains pivotal to the evolution of contemporary inventory control: intelligent warehousing, counting-scale technology, and DSR.

2.1. Intelligent Warehousing and Order Picking

The term 'warehousing' refers to the largescale storing of goods that are not immediately used or sold (Kadwe & Saha, 2018). The term 'intelligent warehousing' refers to a storagemanagement concept that integrates information and communication technology (ICT) through the IoT, cloud computing, and mechanical circuits in ways that reduce storage costs, improve efficiency, and improve the ability of management to respond quickly to changes in demand.

Order picking is a critical sub-process of warehousing and typically requires that warehouse workers traveling to a specific location in a warehouse, find the desired item, and retrieve it. Even with the introduction of robots to decrease labor and streamline the search and retrieval of items in aisleways, human workers are still responsible for executing straightforward physical and cognitive tasks throughout warehouses, including in packing stations (Su et al., 2019). As a result, the travel time required to retrieve an order is a non-value-adding expense and wastes labor hours. Much research has been conducted on reducing travel time by optimizing routing algorithms that consider the geometric layout of a warehouse and that quickly identify optimal TSPbased solutions to travel-time problems (Hall, 1993; Roodbergen & Koster, 2001).

Xu et al. (2020) argue that management can

streamline warehouse operations by integrating picking tasks and storage-location tasks into a single process without altering the given picker's existing walking path. Some scholars have suggested that methods using differential equations can optimize workflows in complex, dynamic systems (Alligood et al., 1996; Bartholdi & Eisenstein, 1996).

2.1.1. The Split-Case Order-Picking System

Management systems and order-picking systems are crucial for warehouses that need to connect with the world affordably. For order picking, most warehouses rely on human workers who retrieve one or more unit loads and bring them to a designated warehouse location by foot or by vehicle. To improve the efficiency and accuracy of order picking, many warehouses use multiple methods, such as split-case order picking (i.e., each picking, piece picking, or break case; Bartholdi & Hackman, 2019), which involves selecting individual units that are then packed into a carton. Multiple technologies can augment the efficiency

Туре	Operation	Features	Study citations
pick-to-light (PTL) systems	Uses software, electronic la-	(1) Is suitable for numerous	(Su et al., 2019; Swenja et
	bels, and illuminated digital	orders involving a small	al., 2022)
	instructions in place of a	product count.	
	traditional paper system to	(2) Can process multiple	
	guide employees.	orders simultaneously.	
		(3) Supports the grouping	
		of orders.	
voice-picking (put-to-	Provides warehouse work-	(1) Permits hands-free and	(de Vries et al., 2016; Lager
voice) systems	ers instructions through	user-friendly interaction	et al., 2021)
	headsets for picking tasks,	between warehouse work-	
	followed by system confir-	ers and the system.	
	mation.	(2) Decreases training time	
		and standardizes work-	
		flows.	
		(3) Facilitates flexible per-	
		sonnel scheduling.	

Table 1Types of Split-case Order-picking Systems

Table 1

Types of Split-case	Order-picking System	is (Continued)

Туре	Operation	Features	Study citations
radio-frequency (barcode) systems	Enables employees to scan RFID or barcodes from multiple locations to ensure the correct selection and packaging of items.	 (1) Enhances the user- friendliness of warehouse operations. (2) Decreases training time. (3) Simplifies shipping pro- cesses. 	(Kubáňová et al., 2022; Sarkar et al., 2022)
vision-picking systems	Employs software-based augmented-reality (AR) technology to facilitate warehouse tasks dependent on precise inventory loca- tions and times.	 Requires minimal training. Rapidly locates inventory. Facilitates simple tracking operations. 	(Fang & An, 2020; Gialos & Zeimpekis, 2020)
goods-to-person (GTP) systems	Permits the roller-conveyor transport of containers to selectors for retrieval of re- quired items.	 Reduces picking errors. Offers ergonomic han- dling. 	(Ashgzari & Gue, 2021; Bozer & Aldarondo, 2018)

and accuracy of order picking, but the suitability of a particular technology varies according to the scenario. Research has identified five types of splitcase order-picking systems: pick-to-light (PTL) systems, voice-picking (put-to-voice) systems, radio-frequency (barcode) systems, vision-picking systems, and goods-to-person (GTP) systems. Each one presents distinct operational methods and features suitable for diverse scenarios and needs, as shown in Table 1.

Through IoT technology, an intelligent orderpicking service can use sensors to obtain real-time information on the quantity, type, temperature, humidity, weight, and location of goods in a warehouse. The data are then transferred to a cloud system, allowing real-time and remote monitoring of goods and orders. With advances in IoT, robots, and big-data technology, warehouse management systems can track and process goods and orders with ever increasing efficiency. This research will demonstrate, in this paper, that Smart Scale stands out for its ability to enable both real-time calculations and the precise, streamlined tracking of small inventoried items.

2.2. Counting Scale

Smart Scale relies chiefly on a weight sensor with an electronic counting scale. This scale accurately calculates quantities of inventoried items, improves the efficiency of warehouse labor, and reduces labor costs.

2.2.1. Internet of Things (IoT)

The IoT refers to interconnected digital devices that handle large amounts of data in communication networks such as the internet. IoT technology has widespread applications in various industries and fields, including smart homes, logistics, agriculture, and healthcare. To tap into the potential of the IoT, current research focuses on addressing key issues such as data collection, management, security, and privacy Moreover, emerging technologies, such as artificial intelligence, blockchains, and edge computing have greatly enhanced the functionality and performance of IoT systems.

2.2.1. Weight Sensors

The load cell inside a weight sensor uses a strain gauge, which measures the stress and force—and ultimately the weight—applied to surrounding metal components. Specifically, the resistance value of the strain gauge changes in relation to the degree of bending and deformation that the metal components undergo. The strain gauge then calculates weight according to the Wheatstone bridge principle (Nachazel, 2020).

The following diagram is an example of how weight sensors with strain gauges work: R1, R2, R3, and RX are four resistors in a Wheatstone bridge circuit. Three resistors (R1, R2, and R3) have fixed resistance values. When the fourth resistor (RX) changes, the voltage of the circuit between points A and B changes. By measuring the difference in voltage between A and B (VAB), the strain gauge can determine changes in physical weight and quantity in the environment and can thus achieve the measurement objective.

For example, assume that the current flow through R1 and R2 is I1 (Equation 1), the current flow through R3 and the sensor (RX) is I2 (Equation 3), and the bridge supply voltage is VCC. These relationships are expressed in Equations (1) through (5), as shown below (Wasson, 2000). Using Ohm's law, one can calculate the voltage at each end of the resistors. The R1 and R2 circuits divide the voltage of the voltage at both ends of the R2 resistor is VA (Equation 2). In the R3 circuit and the sensor (RX), R3 and RX divide the voltage of the VCC, and the resulting voltage at both ends of the VCC, and the resulting voltage at both ends of the VCC, and the resulting voltage at both ends of the VCC, and the resulting voltage at both ends of the VCC, and the resulting voltage at both ends of the VCC.

R3 resistor is VB (Equation 4). Let us use Ohm's law to calculate VA and VB here:

$$I1 = \frac{VCC}{R1 + R2} \tag{1}$$

$$VA = I1 \times R2 = VCC \times \frac{R2}{R1+R2}$$
(2)

$$I2 = \frac{VCC}{R3 + RX} \tag{3}$$

$$VB = I2 \times R3 = VCC \times \frac{R3}{R3 + Rx}$$
(4)

$$\Delta V = V1 - V2 = VCC \times \left(\frac{R2}{R1 + R2} - \frac{R3}{R3 + Rx}\right)$$
$$= VCC \times \left(\frac{R2 \cdot Rx - R3 \cdot R1}{(R1 + R2)(R3 + Rx)}\right)$$
(5)

The voltage is in equilibrium if VA - VB = 0, meaning that R1 = R2 = R3 = RX. In this state, one can measure a physical quantity by measuring the change in the voltage difference VAB, as described above in Equation (5). This concept originates from bridge-circuit research conducted by Wasson (2000). Any alteration in the resistance values results in an imbalance in the bridge and leads to a detectable change in the voltage difference. This change is directly proportional to the variation in the measured physical quantity.

The resistance-bridge principle is a reliable and accurate method for measuring physical quantities because it exploits the balanced voltage equilibrium in a circuit. The implementation of this principle rests on

Figure 1



The Configuration of the Wheatstone Bridge Circuit Used in this Study for Sensor Analysis and Voltage Calculation

Note: (Adapted from Plunkett & Cross, 2014; Wasson, 2000)

a combination of a microcontroller unit (MCU), such as the LinkIt7697 by MediaTek Inc., and an analog-todigital (A/D) converter. Together, these components enable the conversion of analog signals into digital data, facilitating efficient data processing, calculation, and interfacing with external systems.

When integrated into an IoT system, weight sensors that are equipped with environment sensors can facilitate the real-time analysis of not just weight and quantity but also type of product, temperature, humidity, and location. The data, upon being transferred to a cloud system, can promote real-time and remote warehouse management.

In summary, counting scales accurately measure quantities by employing a weight sensor and by following the Wheatstone bridge principle. When integrated into weight sensor, components like MCUs and A/D converters enable efficient data handling and interfacing, providing an effective solution to the challenges of warehouse management.

2.3. Design Science Research (DSR)

Design science research (DSR) is the systematic development and evaluation of solutions to problems that arise in real-world scenarios (Hevner et al., 2004). Because DSR is a science, it promotes the sharing of research findings with the broader academic and professional community. This exchange of data and the repeatability of DSR experiments benefits the generation of rigorous knowledge. DSR is an approach to research that focuses on the development of innovative artifacts, such as new technologies, systems, or processes. Like any research method, DSR has its advantages and disadvantages. The DSR has some advantages, it emphasizes the creation of practical solutions to real-world problems and encourages innovation by promoting the development of novel artifacts. Researchers have the opportunity to design and implement creative solutions that address specific challenges in various domains. DSR also is problem-centric, meaning it starts with identifying and understanding a problem before proposing and creating a solution. This ensures that the research is relevant and addresses actual needs. DSR often involves an iterative process of designing, building, and evaluating artifacts. This iterative cycle allows researchers to refine and improve their solutions based on feedback and testing. However, DSR may produce artifacts that are specific to particular contexts, making it challenging to generalize findings to other settings. The focus on solving specific problems may limit the broader applicability of the developed solutions. The design process involves subjective decisions, and the researcher's background, experiences, and biases can influence the outcome. This subjectivity may raise questions about the validity and reliability of the research. Designing, building, and evaluating artifacts can be time-consuming. The iterative nature of the process, while valuable, may extend the duration of the research project. DSR may require significant resources, including financial, technological, and human resources. Access to specialized expertise and equipment may be necessary for the successful implementation of designed artifacts. It's important to note that the advantages and disadvantages of DSR depend on the specific goals of the research and the context in which it is applied. Therefore, this research need to consider these factors when choosing the appropriate research methodology for this study.

In summary, Design Science Research in management focuses on creating practical solutions to organizational challenges through an iterative and stakeholder-involved design process. While it offers advantages in terms of innovation and tailored solutions, challenges related to complexity and resource requirements should be carefully considered. Successful DSR in management can lead to improved managerial practices and organizational outcomes.

3. Methodology

Drawing on the DSR approach described by Hevner et al. (2004), this research has developed the Smart Scale, which facilitates the real-time calculation of small-item inventory quantities and reduces manual picking errors. This technological innovation directly optimizes warehouse efficiency, reduces costs, and improves customer satisfaction. All of these outcomes have huge potential commercial value. In developing the Smart Scale, it generally adhered to a widely accepted process consisting of six stages: problem identification, objective identification, design and development, demonstration, evalu-

The Application of DSR to the Environment and Knowledge Contexts of the Proposed Smart Scale



ation, and communication (Sarkar et al., 2022). The only change that this research made to this process was to turn the communication stage into a guideline for its demonstrations and evaluation stages. Thus, in this study, Smart Scale rested on five, not six, stages. Also, this research should note that DSR architecture addresses two contexts: the environment context and the knowledge context. In this study, the environment context (i.e., relevance) concerns the order-picking challenges faced by Taiwanese SMEs with respect to inventories; and the knowledge context (i.e., rigor) encompasses system analysis applied to current developments in the IoT, industry 4.0, intelligent warehousing, and split-case order-picking systems. Figure 2 illustrates these two contexts in a DSR framework.

In conducting system analysis (SA), it used unified modeling language (UML) notation to present system structures and processes with greater clarity (Dennis et al., 2020). One of the primary advantages of UML notation is that it provides standardized symbols and diagrams that effectively convey the relationships among different elements within a system. it used UML notation to construct use-case diagrams that precisely define system functions. This research also used two types of interaction diagrams: it used sequence diagrams to illustrate the interplay between various objects, and it used activity diagrams to illustrate the interplay between various actions.

As it noted, the DSR process in this study consists of five stages: problem identification, objective identification, design and development, demonstration, and evaluation (with communication serving not as a stage but as a guideline for the last two stages). In the problem-identification stage, it identified errors related to both manual order picking and the realtime calculation of small-item inventory quantities. In the objective-identification stage, this research established goals that would guide development of the Smart Scale Service. In the design-and-development stage, it created the architecture for the Smart Scale Service. Then, it undertook the final two stagesdemonstration and evaluation-to validate the research findings. Table 2 shows how this research applied the five DSR stages to the current study.

le 2

The Six DSR Stages in Development of the Smart Scale Service

DSR Stages	Description	DSR-Stage Meth-	DSR Guidelines	Source
		ods		
Stage 1: Problem	Defining challenges	Perform a literature	Guideline 1:	
Identification	in a system.	review and follow the	Conceptualize the	Academic literature
		AEIOU framework.	problem.	Case studies
			Guideline 2:	Company data
			Assess the relevance	
			of the problem.	
Stage 2: Objective	Defining ways of	Consider previous	Guideline 3:	
Identification	overcoming chal-	prototypes and con-	Conceptualize the	
	lenges in a system.	sult stakeholders.	objective.	Company feedback
			Guideline 4:	
			Review the literature.	
Stage 3: Design	Creating a service-	Methodically apply	Guideline 5:	
and Development	in this study, the	knowledge to the cre-	Follow rigorous R&D	Existing theories
	Smart Scale—that	ation of the service.	methods.	Our own problem-solv-
	will achieve the de-		Guideline 6:	ing knowledge
	fined objectives.		Focus on search pro-	
			cesses.	
Stage 4: Demon-	Performing the ser-	Present the device	Guideline 7:	
stration	vice.	to stakeholders and	Communicate re-	Communicate research
Stage 5: Evaluation	Assessing the service	seek their assessment	search.	
	performance.	of the device.		

Note: revised from Hevner et al. (2004) and van der Merwe et al. (2020)

4. The System Architecture

The following section describes the DSR process that this section followed when designing the initial framework for the Smart Scale Service.

4.1. Problem identification: Initial Conceptual Design

In designing Smart Scale, it conducted field visits to a logistics company that was located in Kaohsiung, Taiwan and that relied on PTL systems. (Owing to confidentiality concerns on the part of the company, this research did not have access to video recordings of the operation.) This research identified company requirements and prevalent problems with company operations by using the AEIOU framework. It served as a design-conceptualization tool for interpreting and coding data collected during its ethnographic research of the Taiwanese company (Xu et al., 2020). More specifically, the AEIOU framework identifies five types of elements to be coded in research: activities (usually goal-oriented actions), environments (the contexts in which the activities occur), interactions (people's activities as they relate to other people and objects in the environment), objects (the non-human things that people use in activities), and users (the people who carry out the above activities). Table 3 presents application of the AEIOU framework to the Kaohsiung-based company whose operations this research observed for the present study.

Author A of the present study visited the Kaohsiung company in March 2019 and observed the challenges faced by employees dealing with warehouse items. Author A noted that employees who packed items faced the challenge of counting small items. Order picking is a standard aspect of PTL systems and it helps employees quickly identify the items on order and retrieve the correct number of items from the relay area. The logistics company it visited required a relatively large workforce to count items

A Smart Scale for Efficient Inventory Management Based on Design Science Research Principles

Observe the		A logistics company	in Kaoheiung Taiwan	
observe the		Ti logistics company	in Raonstung, Taiwan	
theme				
Observer		Au	thor A	
Date		March	23 2019	
Date	Marcii 23, 2019			
Time		13:30	0-16:00	
Place	Renwu District, Kaohsiung City (814036), Taiwan			
		AEIOU		
Activity	Environment	Interaction	Obiect	User
				0501
A1: Pack chewing	E1: An inventory	I1: Worker uses the	O1: The gum and its	
A1: Pack chewing	E1: An inventory	I1: Worker uses the	O1: The gum and its	U1. Packing employees
A1: Pack chewing gum	E1: An inventory space for small goods	I1: Worker uses the item-quantity calcu-	O1: The gum and its packaging	U1: Packing employees
A1: Pack chewing gum	E1: An inventory space for small goods	I1: Worker uses the item-quantity calcu- lation system.	O1: The gum and its packaging	U1: Packing employees
A1: Pack chewing gum A2: Pick order	E1: An inventory space for small goods E2: A packing-and-	I1: Worker uses the item-quantity calculation system.I2: Worker oper-	O1: The gum and its packaging O2: The item-retriev-	U1: Packing employees
A1: Pack chewing gum A2: Pick order	E1: An inventory space for small goods E2: A packing-and- conveying area	I1: Worker uses the item-quantity calculation system.I2: Worker operates the PTL system	O1: The gum and its packaging O2: The item-retriev- al tools	U1: Packing employees
A1: Pack chewing gum A2: Pick order	E1: An inventory space for small goods E2: A packing-and- conveying area	I1: Worker uses the item-quantity calculation system.I2: Worker operates the PTL system and then uses the	O1: The gum and its packaging O2: The item-retriev- al tools	U1: Packing employees U2: Picker employees

quantity-calculation

bar-scanning system.

I3: Worker uses the O3: The packaged

vehicle

system.

Table 3

The AEIOU Framework as Applied in the Present Study (EthnoHub. 2017)

for packing. Thus, this research identified problems in the field and moved to the second stage: identification of objectives

shipment

E3: A warehouse for

4.2. Objective Identification

A3: Deliver pack-

aged goods

In the objective-identification stage, it comprehensively explored the actual challenges faced by companies engaged in order picking, drawing on the empirical insights that Author A had drawn from the real-world scenarios at the logistics company in Kaohsiung, Taiwan. In addition, Author A interviewed three industry consultants: a managerial professional from an automation company with thirty years of experience, a software-design professional with twenty years of experience, and a university professor with over twenty-two years of work experience in the software industry. This combination of observed data and expert feedback provided us invaluable insights into the challenges confronting workers who undertake order-picking tasks.

gum and the delivery U3: Shipping employees

4.3. Design and Development

Stages 1 and 2 led us to Stage 3: the design-anddevelopment stage. It created the Smart Scale by following the system-architecture diagram shown in Figure 3. The diagram intricately illustrates the relationships among pivotal components of Smart Scale Service, including its MT7697 microcontroller, an HX_mod weight sensor, an MQTT Server for messaging services, a Python controller, a Web server, a database, and the users of these components.

This research divided the Smart Scale into a coreoperations unit and a sensor unit. The core-operations unit had to accurately determine the weight and quantity of items and connect to a Wi-Fi network to transfer and receive relevant data. The server that functions in this network receives data from the storage station, sends it to the database, and presents a graphical-operation interface through the website, management console, and other applications, allowing the client to access the data in the database by using terminal devices. The system then instantly shows the number of items and their status in the warehouse environment.

To design and develop the Smart Scale, this research first developed a prototype of the device, which had basic counting functionality, and it created a report on the device's architecture. Through academic network, it got in touch with—and consulted—two senior executives from an automation company, one executive from a logistics company, and a professor with expertise in Industry 4.0. These experts assessed the prototype, regarded it as workable, but suggested that it needed to improve (a) the precision of the weight sensor, (b) the item-counting speed, and (c) the MCU controller's ability to connect to multiple weight sensors. All in all, its prototype and the experts' assessment of it validated initial concept of the Smart Scale Now, it was ready to design and develop the final version of Smart Scale.

In the design phase, it used UML diagrams to represent the Smart Scale visually. UML is a standard technique for modeling systems development (Dennis et al., 2020). This research relied on usecase diagrams, sequence diagrams, and activity diagrams to preserve, modify, and make sense of information about the services and stakeholders were considering.

Figure 4 presents use-case diagram. This research knew that Smart Scale needed to be able to add and remove items and to perform individualized output. In order to ensure long-term use, it integrated a standby mode into the design: this mode, which suspends the device's sensing and calculation operations, reduces the load on not only the device but network traffic, as well. Because workers can operate the device from a management terminal, the device effectively provides remote-control functionality.

Using the complete version of architecture de-



Figure 3 Smart Scale Architecture Diagram

The UML Use-case Diagram of Smart Scale



sign, it drew up a sequence diagram detailing the Smart Scale's various system interactions, as shown in Figure 5. In the initialization stage of sequence diagram, the Smart Scale connects to the network, sends an initialization request to the network for the Smart Scale's synchronization with the network's database status, and then enters the waiting mode to receive commands. The Smart Scale judges and sets the client's commands. When a warehouse worker uses the Smart Scale, the MQTT server relays this information to the database. In case of network disconnection, it added an offline mode to the Smart Scale so that it can continue operating (e.g., displaying status codes on the LCD) while attempting to reconnect. The activity diagram provides a visual roadmap of intricate process flows and the interdependencies among system components during system operations. By clearly presenting a system's sequence of operations, the diagram can help identify potential bottlenecks and other areas in need of optimization. Figure 6 presents the activity diagram for Smart Scale. In the initial steps that the diagram outlines, the smart scale loops through sensors to ensure their proper configuration. Once all sensors are properly configured, the stabilizer identifies the weight values of individual items. With this information, the Smart Scale can determine the current quantity of items.

The activity diagram, by outlining proposed service's sequence of operations, can help identify potential areas for improvement and thus can help refine the service's operational workflow.

The background research and device testing led us to determine that circuit interference played a significant role in current study's findings. Throughout the design process, it encountered severe circuit interference. In response, this research harnessed its expertise in circuitry to develop a custom-designed printed circuit board (PCB), capable of establishing an exceptionally stable and interference-resistant circuit environment for the Smart Scale.

Collectively, the three diagrams illustrate framework for the Smart Scale. Of course, the diagrams are the result of an iterative process of conceptualization, refinement, and expert validation, all of which laid the foundation for Smart Scale. Therefore, this research adopted these UML diagrams to illustrate various activity to manage different information of each stage with DSR model.

Design Science Research (DSR) in the context of management involves applying the principles of design to create innovative solutions for man-

The UML Sequence Diagram for Smart Scale



Figure 6

The UML Activity Diagram for Smart Scale



agement problems. This approach integrates the development of practical artifacts with the goal of improving managerial practices, decision-making processes, and organizational effectiveness. Here are some considerations, advantages, and potential challenges associated with Design Science Research in the field of management:

* Problem Identification: DSR in management begins with identifying specific problems or challenges within the organizational context. This could include issues related to decision-making, workflow, communication, or strategic planning.

• Stakeholder Involvement: Engaging stakeholders, including managers, employees, and other relevant parties, is crucial. Their input is valuable in understanding the nuances of the problems and ensuring that the designed solutions meet practical needs.

• Iterative Design Process: DSR involves an iterative process of design, implementation, evaluation, and refinement. This allows researchers to continuously improve the designed artifacts based on feedback and real-world testing.

• Practical Solutions: The primary goal is to create practical and applicable solutions for managerial challenges. These solutions may include decision support systems, process redesigns, or innovative management practices.

• Knowledge Transfer: DSR emphasizes the transfer of knowledge from the research context to practical applications. This knowledge transfer is essential for implementing the designed artifacts in real-world management settings.

Therefore, DSR in Management, DSR enables the development of innovative management practices, tools, or systems that can enhance organizational performance and efficiency. The smart scale can provide more convenient measurement by web and mobile application. This solution is designed to address specific management challenges within a particular organizational context, ensuring that they are tailored to the unique needs of the organization. The iterative nature of DSR allows for the generation of actionable insights. As artifacts are implemented and evaluated, researchers gain valuable knowledge about what works and what needs improvement in the management domain such as warehouse management. This research can have a direct impact on organizational success by improving decision-making processes, streamlining operations, or fostering a more effective management culture of warehouse.

5. Discussion: Scenario-based Validation

Let us show how Smart Scale operates in an order-picking area. Driven by the MT7697 MCU controller, the device facilitates not just order picking but also item-status reporting for easy monitoring and management.

The server application, written in Python, acts as the controller, mediating MQTT and databaseaccess services. The application can display the status and history of items on a website. Below (and in Figure 7), it demonstrates the five main steps that the device can take based on seven guidelines. These steps outline the order-picking process as following:

1. Upon startup, the device automatically checks for network settings. In the absence of any existing settings, it switches to an access-point mode. The device proceeds to retrieve item-status information from the server and initializes a sensor system, which permits the device to respond to user instructions.

2. By pressing and holding the setting button for one second, users of the device initialize the measurement of a single item, while a three-second press offers the option to modify the current selection or reset it to zero.

3. At this point, users are guided to place a single item on the device's scale platform.

5. Following item placement, the device automatically sets the quantity to one.

6. The device smoothly transitions into a standby mode but remains primed to commence counting if triggered to do so by a user command or an automatic timer.

7. Concurrently, both the website and the mobile application display some information on the home page and mobile application, granting users of the device instant access to general updates about inventoried items.

8. Concurrently, both the website and the app display comprehensive current and past informa-

The Five Main Steps in the Smart Scale Design Based on Seven Guidelines of DSR



tion about a selected item and grant users of the device remote-control functionalities.

This research presented Smart Scale Service device at two exhibitions: the 2020 and 2021 Taiwan InfoTech Expo. These presentations align with the suggestion, made by Sonnenberg and vom Brocke (2012), that demonstrations of a new technology at the end of a DSR process can help justify and validate the technology. The exhibitions that it chose hosted approximately thirty companies in diverse industries ranging from medicine and biotechnology to food, and manufacturing. At the two exhibitions, both general attendees and a panel of nine experts evaluated device. Their feedback proved highly valuable. These individuals expressed particular interest in device's combination of weightbased quantity calculations and IoT technology for storage and order picking of small items. While the company representatives appreciated innovative approach, they noted two areas in which the device could benefit from improvements: the device's lack of automatic operations and the device's inability to differentiate between two types of items, for example, two screws of different sizes.

Following the feedback this research received at the two exhibitions, it meticulously reworked the entire device, this time placing a much stronger emphasis on flexibility. Part of this reworking entailed a new exterior appearance, which was made to resemble a suitcase and which, hence, offered exceptional mobility. The new iteration of the Smart Scale System device featured two weighing sensors and two LED displays. Moreover, this research simplified the power-supply requirement by creating a portable power bank that would provide the device all necessary power. Owing to time and technological limitations, this research did not upgrade the device so that it would operate automatically or differentiate between items. Also, its device, being tailored to small, lightweight items, is not capable of handling large or heavy items.

In this study, it has comparative analyzed various warehouse item-picking technologies. The literature has extensively discussed traditional technologies such as RF barcode scanning, voice picking, vision picking, and pick-to-light and put-to-light systems. These technologies, while beneficial, exhibit certain limitations, including high costs, low flexibility, and restrictions on co-worker interaction (Füchtenhans et al., 2021; Pinto et al., 2023). Moreover, the performance of the technologies depends largely on the efficiency with which operators handle them. Smart Scale stands out as a major technological asset for warehouse management. The device offers distinct advantages over established technologies: it reduces search times and calculation errors while improving data transmission, worker well-being, and overall efficiency (Żebrowska-Suchodolska & Karpio, 2022; Zhao et al., 2022). The scalability and adaptability of the Smart Scale make it a viable solution for addressing the evolving demands of contemporary warehouse management.

The present study achieved three primary objectives:

1. Development within the DSR Framework: This study's first objective was to create the Smart Scale according to DSR principles. Through this approach, it successfully engineered a scale capable of conducting real-time calculations and of accurately tracking small-item inventory.

2. Evaluation and Iterative Optimization: This study's second objective was to evaluate and optimize the Smart Scale's operational and cost effectiveness. Through rigorous assessments and expert feedback, this research identified areas needing improvement and optimized the device's design accordingly.

3. Exploration of Commercial Viability: This study's third objective was to evaluate the commercial and economic potential of implementing the Smart Scale in the context of Taiwan-based SMEs. Its engagement in industry exhibitions, along with constructive feedback from industry experts, showcased the practicality and applicability of the Smart Scale in authentic logistics environments.

In summary, this research successfully developed the Smart Scale within the DSR framework, evaluated the device's effectiveness, and iteratively optimized the device's design, which proved to have commercial viability at least in the context of Taiwan-based SME warehouses.

The Smart Scale aligns with the growing need for efficient, accurate, and technologically driven solutions in warehouse operations, and is thus a promising tool for meeting dynamic market demands and enhancing customer service. Future research in this area would do well to further explore both the managerial aspects of technology-driven warehouse operations and the potential roles played by DSR therein.

6. Conclusions

In the present study, it has presented a Smart Scale device that—on the basis of DSR principles, UML tools, and IoT and Industry 4.0 technology facilitates split-case order picking for small inventoried items.

The Smart Scale received positive feedback from a variety of manufacturers. Specifically, the device has the potential to improve the real-time monitoring of inventories, streamline supply-chain processes, reduce manufacturing costs, and enhance customer service (Brzeziński & Bitkowska, 2022).

6.1. Limitations and Future Research

As with any study, its current one has its share of limitations. One limitation was focused on small, lightweight warehouse items. Future research should extend this line of research to larger items and heavier items, which present unique measurement challenges. IoT devices that service such items require powerful-and costly, resourcedemanding-hardware. Another limitation of this study concerns cost effectiveness. Because this research did not extensively explore this aspect of the Smart Scale, further investigation is necessary to assess the economic viability of implementing a large-scale IoT service in warehouse settings. A rigorous evaluation in this direction would necessarily involve the analysis of not only potential savings but also initial investment costs and long-term maintenance costs in terms of both technology and labor. A particularly interesting topic of research would be the effects, positive or negative, that this technology might have on employee morale.

For unavoidable reasons, the findings of this study rest on a small set of empirical data. Future research must accumulate comprehensive data sets and analyze them in line with reliable empirical quantitative and qualitative methods. Only in this way can it accurately grasp the impact of smart technology on industrial settings, customer service, and—more broadly—market economies. This research focused current study on warehouse operations. Of course, smart technology has a vast number of actual and potential applications. One area that interests us is the integration of big data and augmented reality (AR) technologies into unmanned vehicles. Research in this and other areas may revolutionize the efficiency and accuracy of warehouse operations.

Finally, although the setting of this research was Taiwan, the technology that it is proposing has obvious applications across national and international contexts. Future research can explore whether national and regional settings affect the performance of such Smart Scale devices.

6.2. Challenges of DSR in Management

The management issues can be complex, and designing effective solutions may require a deep understanding of organizational dynamics, human behavior, and cultural factors. However, implementing new management practices or tools may require integration with existing organizational systems, and this can pose challenges in terms of compatibility and user adoption (Adeel et. al, 2023 and Bachev, 2013) This research developing and implementing designed smart scale may demand significant resources, both in terms of time and financial investment. The design decisions may be subjective and influenced by the researcher's perspectives, potentially leading to biases in the designed solutions. This research implementing a smart scale in management involves integrating technology and intelligent service strategically to enhance warehouse performance across various domains. However, it's important to consider ethical implications, data privacy, and potential challenges associated with adopting advanced technologies in the management context of DSR.

Acknowledgments

We extend our gratitude to the organizers of the ACIEK 2023 conference and all of its participants. By having the opportunity to share our research findings at the conference, we were able to receive valuable insights and feedback.

References

Adeel, S., Daniel, A. D., & Botelho, A. (2023). The effect of entrepreneurship education on the determinants of entrepreneurial behaviour among higher education students: A multigroup analysis. *Journal of Innovation & Knowledge*, 8(1), 100324.

- Alligood, K. T., Sauer, T. D., & Yorke, J. A. (1996). *Chaos:* An Introduction to Dynamical Systems. Springer.
- Ashgzari, M. S., & Gue, K. R. (2021). A puzzle-based material handling system for order picking. *International Transactions in Operational Research*, 28(4), 1821–1846. https://doi.org/10.1111/itor.12886
- Bachev, H. (2013). Risk management in the agrifood sector. Contemporary Economics, 7(1), 45- 62. https://doi.org/10.5709/ce.1897-9254.73
- Berrone, P., Fosfuri, A., Gelabert, L., & Gomez-Mejia, L. R. (2013). Necessity as the mother of 'green'inventions: Institutional pressures and environmental innovations. *Strategic Management Journal*, 34(8), 891-909. https://doi.org/10.1002/smj.2041
- Berger, S. M., & Ludwig, T. D. (2007). Reducing Warehouse Employee Errors Using Voice-Assisted Technology That Provided Immediate Feedback. *Journal of Organizational Behavior Management*, 27(1), 1–31. https://doi.org/10.1300/J075v27n01_01
- Bozer, Y. A., & Aldarondo, F. J. (2018). A simulation-based comparison of two goods-to-person order picking systems in an online retail setting. *International Journal of Production Research*, 56(11), 3838–3858. https://doi.org/10.1080/00207543.2018.1424364
- Brzeziński, S., & Bitkowska, A. (2022). Integrated business process management in contemporary enterprises-a challenge or a necessity? *Contemporary Economics*, 16(4), 374-386. https://doi.org/10.5709/ ce.1897-9254.488
- Chaopaisarn, P., & Woschank, M. (2021). Maturity model assessment of SMART logistics for SMEs. Chiang Mai University Journal of Natural Sciences, 20(2), 1-8.
- de Vries, J., de Koster, R., & Stam, D. (2016). Exploring the role of picker personality in predicting picking performance with pick by voice, pick to light and RFterminal picking. *International Journal of Production Research*, 54(8), 2260-2274. https://doi.org/10.1080/ 00207543.2015.1064184
- Dennis, A., Wixom, B., & Tegarden, D. (2020). Systems Analysis and Design: An Object-Oriented Approach with UML. John Wiley.
- Deshpande, A., & Kumar, M. R. (2020, 15-17 July 2020). An Optimized Cluster based Warehouse Pick-up Process Second International Conference on Inventive Research in Computing Applications (ICIRCA), Coimbatore, India.
- EthnoHub. (2017). AEIOU Framework. Retrieved August 14, 2023, from https://help.ethnohub.com/guide/ aeiou-framework
- Füchtenhans, M., Grosse, E. H., & Glock, C. H. (2021). Smart lighting systems: state-of-the-art and potential applications in warehouse order picking.

International Journal of Production Research, 59(12), 3817-3839. https://doi.org/10.1080/00207 543.2021.1897177

- Fang, W., & An, Z. (2020). A scalable wearable AR system for manual order picking based on warehouse floor-related navigation. *The International Journal* of Advanced Manufacturing Technology, 109, 2023– 2037. https://doi.org/10.1007/s00170-020-05771-3
- Gialos, A., & Zeimpekis, V. (2020). Vision picking technology: defining design parameters via a systematic literature review. *International Journal* of Logistics Systems and Management, 37, 106–139. https://doi.org/10.1504/IJLSM.2020.10030521
- Hall, R. W. (1993). Distance approximations for routing manual pickers in a warehouse. *IIE Transactions*, 25(4), 76–87. https://doi. org/10.1080/07408179308964306
- Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, 28(1), 75–105. https://doi. org/10.2307/25148625.
- Huang, W.-J. (2021). From January to July this year, the export value of screws and nuts grew by more than 30%. R.O.C Ministry Of Economic Affairs. https:// www.moea.gov.tw/MNS/dos/bulletin/Bulletin. aspx?kind=9&html=1&menu_id=18808&bull_ id=9234
- John J. Bartholdi, I., & Eisenstein, D. D. (1996). A production line that balances itself. Operations Research, 44(1), 21–34. https://doi.org/10.1287/ opre.44.1.21
- John J. Bartholdi, I., & Hackman, S. T. (2019). Warehouse & distribution science release 0.98.1. School of Industrial and Systems Engineering Georgia Institute of Technology.
- Kadwe, R., & Saha, A. (2018). The study of efficiency and effectiveness of warehouse management in the context of supply chain management. *Journal* of Emerging Technologies and Innovative Research, 5(10), 129–135.
- Koster, R. B. M. D. (2008). Warehouse assessment in a single tour. RSM Erasmus University. https://doi. org/10.1007/978-1-4471-2274-6_17
- Kubáňová, J., Kubasáková, I., Čulík, K., & Štítik, L. (2022). Implementation of Barcode Technology to Logistics Processes of a Company. Sustainability, 14(2), 790–790. https://doi.org/10.3390/ su14020790
- Lager, H., Virgillito, A., & Buchberger, T.-P. (2021). Digitalization of logistics work: Ergonomic improvements versus work intensification. Springer. https://doi.org/10.1007/978-3-030-58430-6_3

- Li, S., Gao, L., Han, C., Gupta, B., Alhalabi, W., & Almakdi, S. (2023). Exploring the effect of digital transformation on Firms' innovation performance. *Journal of Innovation & Knowledge*, 8(1), 100317. https://doi.org/10.1016/j.jik.2023.100317
- Mugoni, E., Nyagadza, B., & Hove, P. K. (2023). Green reverse logistics technology impact on agricultural entrepreneurial marketing firms' operational efficiency and sustainable competitive advantage. *Sustainable Technology and Entrepreneurship*, 2(2), 100034. https://doi.org/10.1016/j.stae.2022.100034
- Nachazel, T. (2020). What is a Strain Gauge and How Does it Work? Retrieved August 13, 2023 ,from https://www.michsci.com/what-is-a-strain-gauge
- Özşahin, M., Çallı, B. A., & Coşkun, E. (2022). ICT adoption scale development for SMEs. Sustainability, 14(22), 14897. https://doi. org/10.3390/su142214897
- Pinto, A. R. F., Nagano, M. S., & Boz, E. (2023). A classification approach to order picking systems and policies: Integrating automation and optimization for future research. *Results in Control* and Optimization, 12, 100281. https://doi.org/ https://doi.org/10.1016/j.rico.2023.100281
- Plunkett, E. V. E., & Cross, M. E. (2014). Wheatstone bridge. In *Physics, Pharmacology* and *Physiology for Anaesthetists: Key Concepts* for the FRCA (2 ed., pp. 65-65). Cambridge University Press. https://doi.org/DOI: 10.1017/ CBO9781107326200.030
- Roodbergen, K. J., & Koster, R. d. (2001). Routing order pickers in a warehouse with a middle aisle. *European Journal of Operational Research*, 133(1), 32–43. https://doi.org/10.1016/S0377-2217(00)00177-6.
- Sarkar, B., Takeyeva, D., Guchhait, R., & Sarkar, M. (2022). Optimized radio-frequency identification system for different warehouse shapes. *Knowledge-Based Systems*, 258, 109811. https://doi. org/10.1016/j.knosys.2022.109811.
- Sonnenberg, C., & Vom Brocke, J. (2012). Evaluations in the science of the artificial-reconsidering the build-evaluate pattern in design science research. In Design Science Research in Information Systems. Advances in Theory and Practice: 7th International Conference, DESRIST 2012, Las Vegas, NV, USA, May 14-15, 2012. Proceedings 7 (pp. 381-397). Springer Berlin Heidelberg. https://doi. org/10.1007/978-3-642-29863-9_28
- Su, T.-S., Lee, S.-S., Hsu, W.-H., & Fu, S.-H. (2019). A fuzzy-based approach to improve the human pick-to-light efficiency incorporated with robots

behavior in an intelligent distribution center. *Procedia Manufacturing*, 38, 776-783. https://doi. org/10.1016/j.promfg.2020.01.105.

- Swenja, S., Maximilian, P., & Thomas, S. (2022). Evolution of Pick-by-Light Concepts for Assembly Workstations to improve the Efficiency in Industry 4.0. Procedia Computer Science, 204, 37-44. https://doi.org/10.1016/j.procs.2022.08.005.
- Tompkins, J., & Smith, J. D. (1998). *The warehouse management handbook*. Tompkins Press.
- van der Merwe, A., Gerber, A., & Smuts, H. (2020). Guidelines for Conducting Design Science Research in Information Systems. In B. Tait, J. Kroeze, & S. Gruner, *ICT Education* Cham.
- Wasson, C. (2000). Ethnography in the Field of Design. *Human Organization*, 59(4), 377-388. https://doi. org/10.17730/humo.59.4.h13326628n127516
- Xu, X., Ren, C., & Scarpiniti, M. (2020). Research on dynamic storage location assignment of pickerto-parts picking systems under traversing routing method. *Complexity*, 2020, 1–12. https://doi. org/10.1155/2020/1621828
- Żebrowska-Suchodolska, D., & Karpio, A. (2022). Study of the skills of balanced fund managers in Poland. *Contemporary Economics*, *16*(2), 151-167. https://doi.org/10.5709/ce.1897-9254.474
- Zhao, Y., Wen, S., Zhou, T., Liu, W., Yu, H., & Xu, H. (2022). Development and innovation of enterprise knowledge management strategies using big data neural networks technology. *Journal of Innovation & Knowledge*, 7(4), 100273. https://doi. org/10.1016/j.jik.2022.100273