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Key Performance Measures and Digital-Era Technologies in Warehouses

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ABSTRACT

The manuscript aims to benchmark warehousing industries in developing and developed countries in terms of performance measures from the perspective of industry professionals and the potential impact of digital-era technologies. Compared with the US-based Warehousing Education Research Council's reports published in 2018 and 2019, this paper presents that "on-time shipments" is the most critical performance measure in Turkey in both 2018 and 2019 while "order picking accuracy" is in the US. This study also presented that mobile technologies are considered as the most influential digital-era technology in terms of supporting ongoing improvements in warehousing operations and providing a competitive advantage to the companies in both Turkey and the US. Moreover, some digital-era technologies such as driverless vehicles or drones, 3D printing and simulation are considered the least supportive or competitive technologies according to the professionals in Turkey.

Keywords: *warehousing, performance measures, digitalization, technology, warehouse operations*

1. INTRODUCTİON

Jack Welch, the former chair and CEO of General Electrics highlighted that "If the rate of change on the outside exceeds the rate of change on the inside, the end is near" (Allison, 2014). For the last decades, the rate of change on the outside of companies has been mainly driven by exponentially growing technologies and increasing customer expectations. Two of the most influenced industries by these changes are the logistics and warehousing industries, which actually play a critical role in moving products in both national and global supply chains. Moreover, warehouses are usually accounted as the backbone of the logistics industry because they keep buffer stocks to compensate uncertainties in customer demands, supplies, transportation, and to become close to customers for providing quick response to orders. In today's supply chains, the importance of warehouses is increasing because higher customer expectations in terms of logistics customer service, also known as the "Amazon effect" (Melnyk and Stanton, 2017), have become the norm rather than the exception. In order to provide a high service level to customers while maintaining cost efficiency, warehouse managers try to tackle determining the most critical performance measures that they need to monitor and improve. Therefore, this study first aims to reveal the critical performance measures that are prioritized by warehouse managers. Additionally, it aims to present whether the importance of the measures changes or not over a while.

With the support of growing technology, ~~the~~ digital solutions have been increasingly placed in industries to improve the main performance measures, also known as competitive priorities, such as productivity, cost, quality, flexibility, speed, and sustainability. However, according to the World Economic Forum, the rates of change and adaptation of technologies are high mainly in developed countries (Leopold *et al*., 2016) because of their high level of industrialization, technology, and research and development investment, education, etc. Sands and Bakthavachalam (2019) presented that the developing countries lag behind the developed countries in technological business and data skills. Additionally, World Robotics 2019 Industrial Robots showed that five countries, China, Japan, the Republic of Korea, the United States, and Germany possess 73% of the robots in the world (International Federation of Robotics, 2019). Therefore, this study also aims to explore the warehouse managers' views on the potential effect of emerging technologies on the warehousing industry in both developing and developed countries.

The organization of this paper is as follows. The following section discusses the most relevant previous studies. Section 3 outlines the research questions. Section 4 presents the research methodology, descriptive statistics, findings, and our practical remarks on the industry. The last section provides concluding remarks.

2. PREVİOUS STUDİES

Warehouses could be accounted for as the backbone of a supply chain system due to their critical role in connecting suppliers to customers. Even though transportation takes the highest portion of logistics cost for a company, warehouses perform critical tasks that may affect both logistics cost and customer satisfaction. For instance, incorrect inventory

information in the warehouse may increase searching and picking times. Picking wrong items may cause returns, increase logistics costs and even reduce customer satisfaction. There are many studies that measure the picking performance in terms of time or distance according to the layouts or operations of a warehouse (Öztürkoğlu and Hoşer, 2019; Öztürkoğlu *et al*., 2018; Kocaman *et al.,* 2021). Last but not the least, mismanagement of the stocks in a warehouse may cause obsolescence and deterioration costs.

Warehouse tasks could be categorized into four main operations: receiving, put-away, picking, and shipping. Whereas the first two operations are called inbound operations, the latter are called outbound operations. Receiving operation is mostly triggered by the notification of the arrival of a truck. An arriving truck is scheduled to a dock and then it is unloaded. After inspecting goods, they are put-away to the selected locations by workers or automated equipment. Goods stay in the storage until an order is received. The arrival of an order triggers the order-picking stage. After workers or automated equipment pick the required goods, they are sorted and consolidated before packing. Next, the ready orders are loaded onto trucks and shipped to customers. Every task in each stage should be carefully monitored using appropriate measures and managed using an efficient combination of the resources such as workforce, material handling equipment, software, and technological devices for more sustainable warehouses (Demirkıran and Dizbay, 2020). **Figure 1** simply demonstrates the flow of materials through the main warehouse operations and the possible usage of some digital-era technologies in these operations.

Measuring performances and benchmarking them with world-class businesses play a critical role in a company's success. Therefore, many studies focused on determining appropriate performance measures for the efficient management of warehouses and benchmark warehouses to show how a warehouse could be efficiently managed. The words used in these studies such as performance measure (PM), performance indicator, key performance indicator (KPI), critical success factors (CSF) and metric are considered synonyms in this study. Frazelle (2002) defined one metric for each main warehouse operation and metric category (financial, productivity, utilization, quality, and cycle time) to provide a base for warehouse managers to monitor their operations.

Axelsson and Frankel (2014) investigated the most important KPIs used by a Sweden based logistics company's customers, which operate their own or 3PL warehouses or distribution centers, through a survey study. In the study, the 68 respondents mainly located in Europe highlighted that out-bound metrics are the most critical metrics. The authors also revealed that high quality, on-time delivery, and reliability are very important to be successful in the warehousing industry according to survey results.

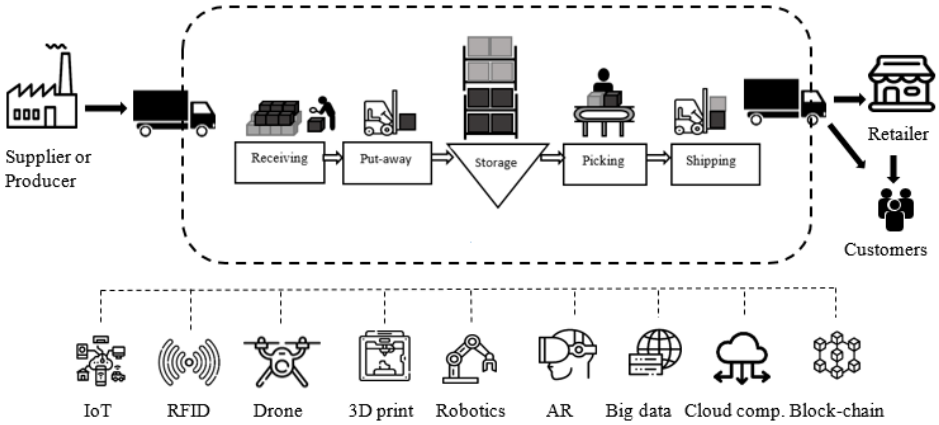

Figure 1 Warehouse operations and related digital-era technologies
(The icons in the figure are retrieved from www.flaticon.com and are declared to be free to use. For referencing, the icons were made by monkik, freepick, smalllikeart, srip, Good Ware and photo3idea_studio.)

Staudt *et al*. (2015) reviewed 43 academic articles, which were published between 1991 and 2012, to extract operational performance measures in warehouses. The authors classified 38 direct (quantitative) measures according to time, quality, cost, and productivity, and presented 8 indirect (qualitative) measures with their detailed definitions. The authors found that there are fewer metrics for inbound operations than outbound, metrics by type of warehouses were not previously considered and key performance metrics are more likely to change over time as goals change.

Chen *et al*. (2017) presented a process performance model for warehouses that shows relationships between key performance indicators (KPIs), critical success factors (CSF), and core capabilities to gain competitive advantage. After the authors conducted case studies in four warehouses, they extracted eight KPIs and daily management performance indicators (DMPIs) used in warehouses. Furthermore, the authors superficially recommend investing in IT systems, Internet facilities, automated systems and facilities, and customer relationship management (CRM) technologies, such as data warehousing, data mining, and on-line analysis processing (OLAP) to improve the selected KPIs. However, they did not provide any information about their potential effect on warehouse operations or performance measures.

Wudhikarn *et al*. (2018) extracted 158 performance measures from an extensive review of 111 academic articles between 1994 and 2016. The authors classified these measures according to the intellectual capability index and revealed that most of the performance measures in the

literature are related to the organization where the most mentioned measure is on-time or out of delivery.

In addition to the aforementioned academic studies on performance indicators in warehouses, the Warehousing and Educational Research Council (WERC) has been conducting a detailed benchmarking study of key performance measures, the adopted overall strategies and technological investments to monitor the warehousing industries mainly in North America. The latest WERC study, "DC Measures 2019," was finalized in July 2019. WERC (2019) showed that there are changes in the list of top ten metrics compared to WERC (2018). According to these studies, whereas the companies' focus was on employee-related metrics in 2018, it was on operations in 2019. This was explained by the increase in business activities, especially in e-commerce in 2019 (WERC, 2019).

There are also a few studies that focus on benchmarking warehouses. Hackman *et al.* (2001) proposed an input-output model to evaluate and compare the efficiencies of 57 warehouses in various fields. This DEA (Data Envelopment Analysis)-based benchmarking model makes it possible to compare the warehouses that incorporate different types of resources such as labor, space, and equipment as input and different types of output measures such as the number of orders, number of lines per order and storage index. Their findings showed that there is a negative association between warehouse size and efficiency and between the level of automation and efficiency. Long travel distances, poor workflows, communications and supervision in them caused the reasons for low efficiency in large warehouses. Moreover, the existence of static automation systems, the lack of maintenance, and the inappropriate selection of the automation systems were the causes of low efficiency. McGinnis *et al*. (2002) used Hackman *et al*. (2001)'s model and developed an Internet-based Data Envelopment Analysis for Warehousing (iDEA) to provide a rapid evaluation of warehouses. The authors provided similar findings to Hackman *et al*. (2001). Moreover, they presented that "a large equipment investment also tends to have a large labor cost" even though the opposite was expected. De Koster and Balk (2008) extended Hackman *et al*. (2001)'s model and compared the operations' efficiency of 65 European origin distribution centers (EDC), which are responsible for distributing European, American, Asian and African manufacturers' goods, located in the Netherland considering their performances between 2000 and 2004. Their extended model considered four input factors such as number of workers, warehouse size, number of SKU (stock-keeping units), and degree of automation, and five output measures such as number of daily order lines picked, the level of value-added logistics, number of special processes, the percentage of error-free orders and order flexibility. The results of DEA demonstrated that European warehouses were doing better than Americans and Asians because the majority of the European warehouses were operated by the public. However, the authors also discussed that the efficiency of warehouses, especially the public warehouses, decreased between 2000 and 2004 because of economic fallback despite an improvement in technology in the same period. Moreover, the benchmarking studies showed that the degree of automation, the level of technology and their usage in warehouses affect warehouse efficiency.

3. THE GAPS İN THE LİTERATURE AND THE CONTRİBUTİON OF THİS STUDY

The following gaps in the warehousing literature are obtained after reviewing the previous studies related to performance measures in warehouse management and warehouse benchmarks.

1. Although Staudt *et al.* (2015) and Wudhikarn *et al*. (2018) presented detailed and comprehensive lists of performance measures (PMs) in warehouses; it was declared that determining few but sufficient valuable, important, focused, financially and non-financially balanced, and goal-oriented performance measures that are also appropriately assigned over existing operations is a critical task (Thakkar *et al*, 2009). In doing this, the industries' point of view is as much important as the academies' view.

2. Chen *et al.* (2017) and Krauth *et al.* (2005) presented practical insights on PMs for warehouse management. However, their scopes are very limited to a few number of experts or companies. Furthermore, Axelsson and Frankel (2014) provided good practical insights on performance measures; however, the study has a lack of the importance of PMs and their relations. Moreover, the data seems to be limited to European or Scandinavian developed countries. WERC (2019)'s study is the most comprehensive and structured study to investigate the importance of performance measures and technological developments in warehouses; however, the presented data in the study was mainly collected from companies in developed countries such as the US and UK. Therefore, the contributions of this study can be described by answering the following questions.

a. *What are the most importantly seen performance measures by warehouse managers in developing countries?*
b. *Is there any difference between the importance of performance measures considered by warehouse managers in developing and developed countries? Does the importance of performance measures change over time?*
c. *What is the expected impact of emerging digital-era technologies on the warehousing industry in developing and developed countries? Is there any difference between them?*

4. RESEARCH METHODOLOGY AND FİNDİNGS

WERC is a US-based professional organization focused on educational events, industrial benchmarking studies, practical research, and expert insights to contribute to logistics and distribution management since 1977. For more than 15 years, WERC has also been monitoring the warehousing industry, mainly in North America, to capture critical operational measures from real-world facilities so that it can provide a strategic guide for professionals. This guide has been shared as "DC Measures Annual Survey and Report" and used by warehouse managers from small and leading logistics companies such as Amazon, UPS, FedEx, and Walmart. Thus, we designed our study relying on WERC's "DC Measures" survey to explore the warehousing and distribution industry in Turkey. Moreover, we developed

our questionnaire using WERC (2018)'s because we started to monitor the warehousing industry in 2018.

Because of the convenience of collecting data, our sample of warehouses is selected according to the origin of the researchers and their industrial relations. The observed warehouses were selected using a convenient sampling method from İzmir, the third biggest and most developed city in Turkey, and its neighbors. Izmir, historically Smyrna, has been treated as the logistics hub in Turkey for centuries because of its importance on the Silk Road to the west, developed economics, availability of seaports and productive lands for agricultural products. Moreover, Turkey is listed as an emergent market and is a developing country in the upper-middle income group by the United Nations. Therefore, we think that our findings might be a good representation of developing countries.

The adopted questionnaire was directed to warehouse managers, and the data were collected face-to-face during the field trips. To conduct cross-sectional and longitudinal analyses, we visited 62 and 74 warehouses in 2018 and 2019, respectively. Because we could not get an appointment or some managers changed their job, only 48 out of 62 managers in 2018 were also visited for the survey in 2019. As the basis for our comparisons, we took WERC (2018) and WERC (2019)'s findings that were extracted from 489 and 549 warehouse professionals' survey data, respectively. Because the majority of the WERC (2018; 2019)'s respondents, almost 90% from North America, are from the US and UK, their findings are supposed to represent warehouses in developed countries.

Although the WERC survey had 28 sections which can be simply categorized into descriptive, related to descriptive statistics, workforce, strategies, technology usage, emerging technologies, supply chain management, warehouse management system and key performance measures, all of these sections were not used in this study to reduce the length of the survey and focus only on performance measures and emerging technologies. The adopted questionnaire was divided into three sections. In the first section, we collected descriptive statistics about the warehouses. The second section consists of questions regarding the importance of the given list of performance measures. The last section aims to explore the effect of emerging technologies on warehousing. The following three sub-sections present our findings regarding the sections of the questionnaire. Our collected data in 2018 and 2019 and the findings that we extracted from them are indicated by TR-2018 and TR-2019 abbreviations, respectively.

4.1. Descriptive Statistics

This section provides the characteristics of the warehouses that were visited in our study, as well as the warehouses' characteristics in WERC's studies. As seen in **Table 1**, these characteristics are related to the types of warehouses, the types of industries that the warehouses involved, and the types of handling units mainly handled in the warehouses.

Table 1 The characteristics of the observed warehouses

		TR-2018	TR-2019	WERC(2018)	WERC(2019)
Categories	**Types**	**Percentage (%)**			
Types of warehouses	Import	17.7	18.9	2.0	2.0
	Regional	33.9	35.1	29.0	30.0
	Grocery	8.1	10.8	3.0	3.0
	Wholesale	30.6	6.8	18.0	19.0
	Local	9.7	23.0	10.0	9.0
	Omni-channel warehouse	0.0	4.1	12.0	12.0
	E-trade warehouse	0.0	1.4	7.0	6.0
Types of industries	Retail	8.1	21.6	25.4	16.0
	Wholesale/Distributor	25.8	12.2	15.8	28.6
	3rd party warehouse	9.7	5.4	22.7	19.5
	Manufacturing	56.5	43.2	28.5	26.4
	Pharmaceutical	0.0	17.6	2.7	1.7
	Medical device	0.0	0.0	1.4	2.6
	Utilities/Government	0.0	0.0	1.4	0.1
	Other	0.0	0.0	2.1	3.5
Handling units	Broken case picking	22.6	20.7	37.2	34.6
	Full case picking	31.2	45.7	40.6	42.7
	Full pallet picking	46.2	33.5	22.2	22.7

As seen in **Table 1**, almost 50% of the participants manage regional and wholesale warehouses in our and WERC's studies in the respective years. However, whereas our study consists of a substantial amount of import warehouses, where pallets are densely handled, WERC's studies include a substantial amount of omni-channel and e-trade warehouses, where smaller units than pallets are densely handled.

As seen in **Table 1**, the largest industry is manufacturing in TR-2018 and TR-2019. Pharmaceutical warehouses also take a substantial portion in TR-2019. Similarly, manufacturing, distributors, and retailers take the largest portion of WERC's studies. However, in contrast to our study, third party warehouses also take a significant portion in WERC's studies.

The types of handling units show how goods are moved through the warehouse. As seen in **Table 1**, the majority of facilities picked pallets in TR-2018 while they picked cases in TR-2019. These results are compatible with the distribution of the warehouse types because full-pallet

picking is performed mainly in manufacturing and wholesale warehouses, which constitute the majority of the participants in TR-2018, while small units are commonly handled in local warehouses, and in retail and pharmaceutical industries, which takes a significant portion in TR-2019 data. In WERC's studies, the majority of the professionals reported that they performed less than pallet picking similar to TR-2019.

In the light above mentioned discussions, we can conclude that the characteristics of the participant warehouses both in our and WERC's studies are similar to each other even though there are few and little differences. However, we think that these differences are not enough to deter us from comparing our findings with WERC (2018; 2019)'s findings to generate insights about the warehouses in developed and developing countries.

4.2 Key performance measures in warehouse management

In strategy management, in order to gain a competitive advantage and become a sustainable and successful organization, an organization's objectives should be linked to appropriate performance measures and activities (Kaplan and Norton, 2001). Thus, this section aims to explore the key performance measures prioritized by the warehouse managers in Turkey in a longitudinal analysis. We also compared our findings with WERC's in a cross-sectional analysis.

One of the most important tasks for warehouse managers is to determine appropriate measures for their facility and operations that need to be emphasized and regularly monitored in accordance with the company's objectives. As mentioned in section 2, a manager could select their measures from a list of more than 100 performance measures (Staudt *et al*., 2015; Wudhikarn *et al*., 2018). However, considering many measures would be a very overwhelming and mind-boggling task for managers. Moreover, to provide an accurate cross-sectional analysis and accurate comparisons, we preferred to use the WERC (2018)'s list of 30 key performance measures categorized under seven titles as demonstrated in **Table 2**. The performance measures are coded by "PM XY", where X shows the category and Y shows the number. For instance, PM A1 refers to "on-time shipments" measure.

We asked the participants to determine how much each measure is important for efficient warehousing. We used 5-point Likert-scale for answers: "Extremely important", "Very important", "Moderately important", "Slightly important", and "Not important". In order to determine the overall importance of the metrics based on the participants' opinions, we assigned scores of 7, 5, 3, 1 and 0 to each point in the scale, where 7 is for extremely important and 0 for not important. We then calculated the average score of each measure. **Figure 2** demonstrates the average scores of the top-10 measures, which have the highest averages scores, in TR-2019 as well as their scores in TR-2018.

Table 2 The list of WERC (2018)'s performance measures

PM A	**Customer Measures**	**PM E**	**Operations Metrics - Inbound Measures**
A1	On-time Shipments	E1	Dock to Stock Cycle Time, in Hours
A2	Total Order Cycle Time	E2	Lines Received and Put Away per Hour
A3	Internal Order Cycle Time	E3	Percent of Supplier Orders Received with Correct Documents
A4	Percentage of backorders		
PM B	**Capacity / Quality Measures**	E4	Percent of Supplier Orders Received Damage Free
B1	Average Warehouse Capacity Used	E5	On-time Receipts from Supplier
B2	Peak Warehouse Capacity Used	**PM F**	**Operations Metrics - Outbound Measures**
B3	Honeycomb Percent	F1	Fill Rate - Line
B4	Inventory Count Accuracy by Location	F2	Order Fill Rate
B5	Order Picking Accuracy (Percent by Order)	F3	Lines Picked and Shipped per Hour
PM C	**Cash to Cash Measures**	F4	Orders Picked and Shipped per Hour
C1	Inventory Days of Supply	F5	On-time Ready to Ship
C2	Average Days Payable	**PM G**	**Employee Measures**
C3	Average Days of Sales Outstanding	G1	Annual Workforce Turnover
PM D	**Financial Metrics**	G2	Overtime Hours to Total Hours
D1	Distribution Costs as a Percentage of Cost of Goods Sold (COGS)	G3	Part time Workforce to Total Workforce
		G4	Contract Employees to Total Workforce
D2	Days on Hand Finished Goods Inventory	G5	Unplanned Absence Percentage
		G6	Cross Trained Percentage

Figure 2 shows that "On-time shipments", which is a customer-related measure, is selected to be the most important measure with the average scores of 4.6 and 4.9 in TR-2018 and TR-2019, respectively. This metric is the most discussed metric in 53 studies in literature according to Wudhikarn *et al*. (2018), due to its impact on warehouses' competitive advantages. Additionally, the "Order fill rate" measure, which is mainly related to the performance of the outbound operations but also affects customer satisfaction, occupied the third place in both TR-2018 and TR-2019 with a slight increase in its score from 4.1 to 4.2. This metric is the second most discussed metric in the literature according

to Wudhikarn *et al*. (2018), due to its impact on organizations' performance and logistics costs. These results also highlight the importance of customer service over the years. However, there is a dramatic change in the second most important measure between 2018 and 2019. The score of "Order Picking Accuracy" measure, which is a quality-focused measure, decreased from 4.5 to 3.9 that caused a fall from 2nd to 7th place between 2018 and 2019. This performance metric is considered as common daily management performance indicator of four different logistics facilities, which is conducted as four cases in Chen *et al.* (2017) study. On the contrary, the score of the "Orders picked and shipped per hour" measure, which could be accounted as a productivity-related measure in outbound operations, increased from 3.3 to 4.3 that led a jump from 11th to 2nd place between 2018 and 2019. These changes might be related to shifting into the companies' objectives. "Orders picked and shipped per hour" metric was described as order picking cycle time and was emphasized as the most important metric for order picking operations in warehouses by Kusrini *et al.* (2018). Similarly, we also see an increasing focus on the "Distribution costs as a percentage of the cost of goods sold" measure with an increase in its score from 3.3 to 4.1 between 2018 and 2019. The cost of operations got closer to the professionals' look, from 10th in 2018 to 5th place in 2019, because of the economic crisis at the end of the second half of 2018 in Turkey. The performance measures are ranked according to their scores in **Table 3**. Both **Figure 2** and **Table 3** show that the scores and the places of the other measures in the top-10 were slightly changed.

It could be observed in **Table 3** that the four of the top-10 measures in TR-2019 are directly customer-service oriented while the two are related to the outbound operations of which one of them, PM F2, has an important effect on customer service. The other quality-focused measure PM B5 also has a significant effect on both customer service and cost due to returns. The two of them are related to inbound operations that show the importance of supplier relationships (PM E4) and the visibility of stocks in the warehouse management system (PM E1). The last measure PM D1 is the only financial measure in TR-2019. In TR-2018, there is a slight change in the mix of performance measures. Different from TR-2019, there is an additional one capacity- and one cost-related measure (PM B2), whereas the numbers of inbound and outbound operations related measures are reduced to one. Thus, the mix of TR-2018 top-10 measures seems to slightly diverge from TR-2019's top-10.

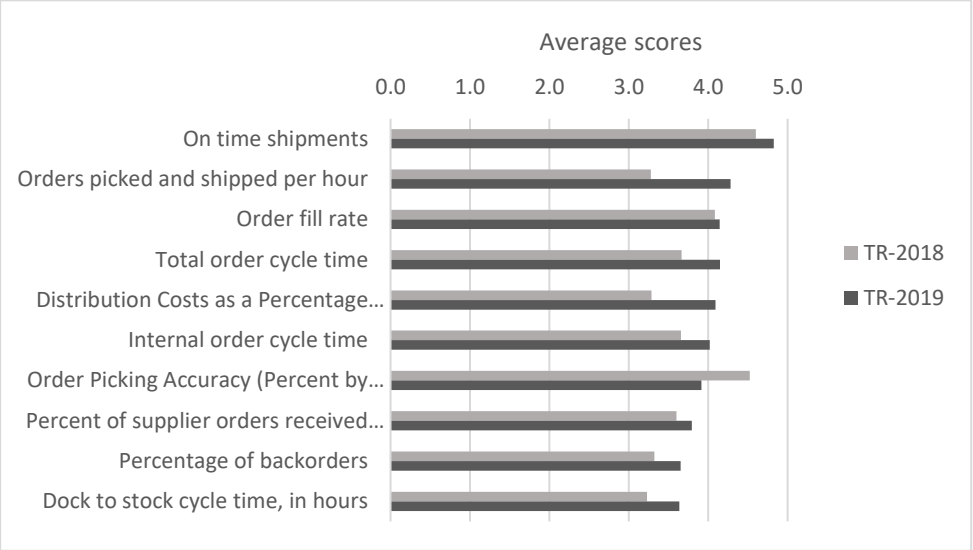

Figure 2 The performance measures and the scores in Turkey

Table 3 also presents the ranks of the measures in WERC (2018) and WERC (2019). The most important three performance measures in WERC (2018; 2019) are "Order picking accuracy", "Average warehouse capacity used" and "Peak warehouse capacity used" which highlight the importance of quality and capacity related measures. Between 2018 and 2019 there were also changes in the rank of the other top-10 measures. For instance, the most significant change occurred at the "Order fill rate (PM F2)" and "Dock to stock cycle time (PM E1)" measures. These two measures were not even in the 2018 top-10 list; however, PM F2 jumped from 14th to 7th, and PM E1 from 16th to 9th. In addition to PM E1, two more inbound operations related measures entitled PM E3 and PM E4 appeared in the top-10 list in 2019. This tendency show the importance of improving supplier relations and fastening receiving and put-away operations for making products available on the shelves so that the warehouse could have better inventory management and quick response to customer orders. The increasing importance of managing stocks in the warehouse could also be supported by the changes in the place of the "Inventory count accuracy by location (PM B4)" measure which went up to the 5th place in 2019 from the 10th in 2018. Another significant change occurred for the employee-focused "Part-time workforce to total workforce" and "Cross-trained percentage" measures. Whereas these measures were located in the 2018 top-10 list, they decreased to the 11th and 12th places in 2019, respectively.

Surprisingly, there is only one customer-focused measure in WERC (2018; 2019)'s top-ten list, which is "On-time shipments", despite its importance. Besides, the composition of the top-10 list was dramatically changed. Although there were five employee-focused measures in WERC (2018), WERC (2019) did not involve any of them.

Instead, three inbound and two outbound operations related measures appeared in the list while maintaining two quality and two capacity related measures. Hence, we can conclude that there was a considerable shift from employee to operations so that the mix of different measures was enhanced.

Table 3I Comparison of the performance measures between WERC countries and Turkey

PM #	Category	Performance measures	TR		WERC	
			2019	2018	2019	2018
A1	Customer	On-time shipments	1	1	4	5
F4	Outbound operations	Orders picked and shipped per hour	2	11	na	na
F2	Outbound operations	Order fill rate	3	3	7	14
A2	Customer	Total order cycle time	4	4	na	na
D1	Financial	Distribution Costs as a Percentage of Cost of Goods Sold (COGS)	5	10	na	na
A3	Customer	Internal order cycle time	6	5	na	na
B5	Capacity & quality	Order Picking Accuracy (Percent by Order)	7	2	1	2
E4	Inbound operations	Percent of supplier orders received damage free	8	6	6	11
A4	Customer	Percentage of backorders	9	9	na	na
E1	Inbound operations	Dock to stock cycle time, in hours	10	12	9	16
B2	Capacity & quality	Peak warehouse capacity used	11	8	3	3
D2	Financial	Days on hand finished goods inventory	12	7	na	na
E2	Inbound operations	Lines received and put-away per hour	13	14	na	na
B1	Capacity & quality	Average warehouse capacity used	14	13	2	1
B4	Quality	Inventory Count Accuracy by Location	15	15	5	10
E3	Inbound operations	Percent of Supplier Orders Received with Correct Documents	16	17	8	13
F5	Outbound operations	On-time Ready to Ship	17	20	10	12
G1	Employee	Annual Workforce Turnover	18	19	na	9
G2	Employee	Overtime Hours to Total Hours	23	22	na	6
G4	Employee	Contract Employees to Total Workforce	28	29	na	4
G3	Employee	Part time Workforce to Total Workforce	29	27	11	7
G6	Employee	Cross Trained Percentage	30	28	12	8

na: Not available/not accessebile in WERC (2018; 2019).

When our results were compared with WERC's results, it is seen that the importance of the measures is very different. For instance, while PM F4, A2, D1, and A3 were placed in the top-10 of Turkey's list, they were not located even in the top-12 of the WERC's list. While the most important measures obtained in WERC studies are related to capacity and quality management in both 2018 and 2019, Turkey's list focused on almost every aspect of warehouse management except for employee management. However, employee management seemed to be necessary to professionals in the US, especially in 2018. The reason for this might be related to the economic activity level of the countries in which the unemployment rate is high (about 13%) in Turkey (TUIK, 2019), whereas it is the lowest (about 3.5%) of the last 50 years in the U.S. (Council of Economic Advisers, 2019). Moreover, the majority of the professionals in Turkey seemed to put customer service first because of the high level of competition in the industry. However, it seemed that the majority of the professionals in the US put their facility and operations first because of the increasing demand for warehousing in the US with the growth in e-commerce and last-mile logistics (Material Handling and Logistics, 2018). Therefore, the managers in the US aim to efficiently use every available space in their facility. However, it is the opposite of warehouses in Turkey due to a lack of economic growth between 2018 and 2019. Hence, we can conclude that the level of economic activity and the unemployment rate in a country seems to affect the choice of performance measures to manage warehouses.

In developed countries, besides the economic growth increase, problems about employment increase. As the number and size of warehouses in developing countries increase, they will have the same problems as in developed countries. Therefore, the managers of warehouses in developing countries should take preventive actions about labor problems and should focus on performance metrics about employees. In addition, if enough attention is not paid to the metrics concerning employees, other performance criteria such as turnover rate will also be adversely affected.

In developed countries, the performance metrics related to quality have high importance. Warehouse managers in developed countries can expect them to attach high importance to quality criteria when working with warehouses in developing countries. The managers of warehouses in developing countries should also give similar importance to quality in order to compete in the global market.

4.2.1 Digital-era supply chain technologies

The exponentially growing technologies are expected to have a disruptive effect on businesses and industries in the new industrial era. According to Chung *et al*. (2019), the implementation of digital-era technologies has a significant potential for improving many performance measures in warehouse management. They can increase productivity, decrease costs, increase the service quality of the operations, and increase capacity utilization.

In the Logistics Trend Radar Report by DHL, Chung *et al*. (2019) listed many digital-era supply chain technologies and predicted how much they will be relevant in the next five

or ten years. Hence, some digital-era technologies such as "internet of things (IoT)", "robotic & automation", "big data analytics", "cloud logistics", "augmented reality (AR)" and "low-cost sensor solutions" are expected to be widespread within five years. In the same report, "virtual reality (VR)", "digital twins", "blockchain", "3D printing", "unmanned aerial vehicles (drones)", "self-driving vehicles" are assumed to be relevant within 10 years. Therefore, we aim to examine the warehouse managers' thoughts about the effect of some digital-era technologies on warehouse management in Turkey and the US.

In accordance with WERC (2018), we used the list of digital-era technologies that are expected to be relevant within 5 or 10 years in the warehousing industry. These technologies are "social media", "IoT", "drones/driverless vehicles", "cloud-based services (software-as-a-service/SAAS)", "mobile technology", "3D printing", "simulation software", "blockchain", "sensors", "robotics and automation", and "real-time big data and analytics". We asked the participants to comment on the impact of the digital-era technologies on warehousing and distribution operations and wanted them to select among those options: "No impact", "Support ongoing improvements", "Provide potential competitive advantage", "Potential disruptor". Due to the lack of data in WERC (2019), the findings from our questionnaires and WERC (2018) were demonstrated in **Table A.I** in the appendix. In this table, we also highlighted the number of participants who do not have any idea about the technologies, although this option does not exist in the structured WERC (2018) survey. Using the data in **Table A.I**, we extracted the following observations about the impact of the abovementioned technologies on warehousing and supply chain management.

1. About 70% of the participants in TR-2018, TR-2019, and WERC (2018) reported that sensor devices such as RFID either support ongoing improvements in existing processes or provide a competitive advantage to companies. Several research findings also support these professionals' thoughts. Liu *et al*. (2006) presented an increase in rack space utilization and a decrease in loading time, work-related errors and operation costs with the use of RFID technology. Chen *et al*. (2013) showed that RFID technology with lean management tools decreased the data transmitting time at the receiving and shipping operations in a warehouse. Fan *et al*. (2014) discussed that implementing RFID technology in a warehouse reduced inventory shrinkages. Despite the majority's opinion and the pieces of evidence in the literature, it is interesting to see that 26% of the participants in WERC (2018) claimed that sensors do not have any impact on the warehousing industry, while this group of people is tiny in TR-2018 and TR-2019.

2. Lee *et al*. (2018) demonstrated in a case study that a warehouse management system powered and supported by IoT could improve several essential measures such as order fill rate, order accuracy, dock to stock cycle time and, inventory accuracy. Whereas 68% and 70% of the professionals in TR-2018 and WERC (2018) had a supportive opinion to Lee *et al*. (2018)'s findings, only 50% of the professionals agreed that IoT supports ongoing improvements and provides a competitive advantage in TR-2019. Moreover, 27% of the professionals in TR-2019 and 20% of them in WERC (2018) claimed that IoT does not affect the warehousing industry. The lack of real-life implementations of IoT in warehouses or the lack of relevant scientific research findings may cause a lack of understanding of the potential or real impacts of IoT on warehouse operations. Especially when years pass by, some managers seem to be convinced of the advantages of implementing IoT in their warehouses by solid and clear pieces of evidence. Besides, even though the number of professionals who knows about IoT increases from 2018 to 2019, still 20% of them have no comment or idea what IoT could bring to the warehousing industry. The reason for this observation might be related to the lack of knowledge about emerging technologies in developing countries.

3. It is astonishing that 39%, 21% and 40% of the participants in WERC (2018), TR-2018 and TR-2019, respectively reported that drones and driverless vehicles will not have an impact on the warehousing industry. About 40-45% of the participants, both in the US and Turkey, expect that driverless vehicles support ongoing improvements and provide a competitive advantage. These participants might have slightly underestimated the potential impacts of driverless vehicles because of their limited number of existing implementations. Walmart recently implemented to use drones to monitor SKUs in the storage area to keep inventory data accurate and to prevent goods from theft (Chung *et al*., 2019). Drones are also shown to be supportive of the inventory counting operation, which is accounted for as one of the labor-intensive, time-consuming and tedious operations in warehouses (Xu *et al*., 2018). Moreover, Pons (2014) highlighted the advantage of using drones while counting stocks located at the upper racks such that drones could be 100 times faster and 100 times more energy-efficient than manual scanning in which a reach truck is used to lift an 80-kg worker holding 0.8 kg barcode scanner in a 100 kg-cage.

4. According to the participants both in Turkey and the US, mobile technologies seem to be the most supportive digital-era technology on the list. 88% of the professionals in WERC (2018), 84% in TR-2018, and with a slight increase 84% in TR-2019 reported that mobile technologies would play a critical role in sustaining current warehouse operations and ensuring competitive advantage for companies. The positive impacts of mobile technologies have been presented by many research findings. For instance, the use of augmented reality (AR) technology in wearable devices could reduce picking errors by about 40% (Glockner *et al*., 2014). These types of AR devices can be used to train workers about warehouse planning to improve order-picking performance of the workers. Moreover, several companies such as Knapp, SAP, and DHL have been using head-mounted displays equipped with AR in warehouses (Glockner *et al*., 2014; Powell, 2014). Thus, they also aim to provide a reduction on unnecessary travels during warehouse operations such as picking and put-away.

5. According to the participants both in Turkey and the US, 3D printing technology is reported to have the least impact on the warehousing industry among the listed technologies; 58% in WERC (2018), 33% in TR-2018, and 50% in TR-2019 noted that it has no impact. Even though the development in 3D printing or additive manufacturing technologies is expected to reduce finished goods inventory and their storage requirement (Manners-Bell and Lyon, 2012; Mohr and Khan, 2015), the warehouses are expected to get closer to point-of-consumption and play a critical role

to supply raw materials to customers (Chung *et al*., 2019). In a cooperation with Fast Radius Company, The US-based UPS parcel delivery company opened a 3D store near its Worldport air hub in Louisville, Kentucky, for printing goods in demand at the store and delivering it on the same day via air transportation in the US. (UPS, 2016). However, the limitations and disadvantages of 3D printing such as cost and volume, make this technology a complement to traditional manufacturing, not a replacement (Holweg, 2015). Therefore, the need for warehouses still seems to be viable.

6. Regarding the impact of simulation software, it seems that there is confusion among the professionals. Although 67% of the respondents in WERC (2018) consider simulation software as supportive and beneficial for competitive advantage, 40% of them reported no impact. The percentage of the respondents who said no impact in Turkey increased from 9 to 34 between 2018 and 2019. Having a high number of "no impact" votes might be caused by the limited number of applications, lack of knowledge, lack of skilled workers to develop simulations, its dependency on some other technologies such as IoT, sensors or big data analytics, or its limitation in daily usage. It is also seen that simulation software is one of the least known or understood technologies by the professionals in Turkey, about 40% in TR-2018 and 28% in TR-2019. However, as we see new applications like in Tetrapak food packaging company the professionals' thoughts or awareness might change over the years. Tetrapak has just initiated a digital twin project powered by real-time simulation of its warehouse in Singapore in cooperation with DHL to manage the warehouse efficiently (Roy, 2019).

7. A similar observation made for the impact of simulation software could be proposed for the impact of blockchain technology. Blockchain technology is the other least understood or known technology by the professionals in Turkey. Even though the awareness of blockchain technology in the warehousing industry in Turkey increased from 2018 to 2019, still one-third of the managers seem not to have any knowledge about blockchain technology or its impact. Kurpjuweit *et al.* (2019) proposed that block chain implementation in the supply chain can be developed by gathering capable blockchain engineers from the labor market and obtaining internal technical expertise.

8. Real-time big data analytics was also seen as supportive and beneficial for the warehousing industry, according to 87% of the professionals in WERC (2018). However, some of the professionals in Turkey does not agree with their American colleague. 66% of the respondents in TR-2019 shared the same opinion with an increase from 49% in TR-2018.

9. Whereas the drones and driverless vehicles are expected to be the biggest disruptor among the given digital-era technologies according to the participants (15%) in WERC (2018); robotics and automation is the most disruptive technology according to the participants (about 18%) in TR-2018 and TR-2019. The trucker shortage has been a dramatic issue in US logistics systems for a decade. According to American Trucking Association, the logistics industry needs 160,000 drivers in the next 10 years (Black, 2019). This might be only one of the reasons why the professionals in the US think that driverless vehicles might be more disruptive than other technologies. On the other side, many warehouses in Turkey mainly use digital era supply chain technologies and perform many of the operations manually, as discussed before. Thus, it is not surprising to see that automation and robotics have come into prominence in Turkey.

10. Last, it seems that the professionals in Turkey are becoming more aware of the contents and the potential impacts of the listed digital-era technologies, according to the decrease in the percentage of the participants who noted: "no comment or no idea" from 2018 to 2019.

DISCUSSION

This study focused on answering three research questions listed in the introduction section. We provided comprehensive answers and detailed explanations for each question in the previous sections. Nonetheless, the following discussions briefly answer the posed research questions.

A. What are the most importantly seen performance measures by warehouse managers in developing countries?

The most important performance measure in Turkey was "on-time shipments" in both 2018 and 2019. The list of most important ten (top-10) measures showed that the majority of the participants focused on measures that are somewhat related to customer service such as "order fill rate", "order-picking accuracy" and "internal order cycle time". Moreover, the participants also highlighted the importance of the measures that focus on cost, supplier relations, capacity usage and receiving operation in the top-10. Respectively, these measures were "distribution costs as a percentage of COGS", "percentage of supplier orders received damaged free", peak warehouse capacity used", and "dock to stock cycle time".

B. Is there any difference between the importance of performance measures considered by warehouse managers in developing and developed countries? Does the importance of performance measures change over time?

When our findings were compared with WERC's findings, we observed that the top-10 list of performance measures and their ranks are different. The participants in WERC's surveys highly focused on the capacity and quality related measures such as "average warehouse capacity used" and "order-picking accuracy" and "peak warehouse capacity used", which were also located at the top three in the list. Moreover, the most significant difference appeared in the employee-related performance measures. Whereas five of the top-10 measures in WERC (2018) and two of the top-12 in WERC (2019) were related to employee management, the warehouse managers in Turkey considered them as the lowest important ones for warehouse management. We think that the differences in unemployment rates in developed (3.5% in the US) and developing (13.5% in Turkey) countries are one of the reasons for this difference. Another reason might be economic activity. The demand for warehousing has been increasing at a higher rate in the US than in Turkey due to increasing e-commerce, last-mile logistics activities and growing supply chain networks.

There was a slight change in the top-10 list of Turkey between 2018 and 2019. The top-10 list has slightly more diverged from TR-2019. There were an additional one capacity- and one cost-related in TR-2018 as the numbers of inbound and outbound operations related measures were

reduced to one. However, there was a dramatic shift from employee-focused measures in 2018 to the measures related to inbound operations in 2019.

C. What is the expected impact of emerging digital-era technologies on the warehousing industry in developing and developed countries? Is there any difference between them?

We investigated the impact of several digital-era supply chain technologies such as the internet of things (IoT), robotics, automation, big data analytics, simulation, and sensors on warehousing. When comparing our findings with WERC (2018), it seems that mobile technologies are the most supportive digital-era technology, whereas the 3D printing technology is the least influential one according to the warehouse managers in both Turkey and the US. Additionally, the warehouse managers seem to have a lack of understanding and knowledge about some technologies such as simulation and blockchain and their impacts compared to their colleagues in the US. Last but not the least while drones and driverless vehicles are expected to be the biggest disruptor in logistics and warehousing according to the professionals in the US, robotics and automation are estimated to be the most disruptive technologies according to professionals in Turkey.

CONCLUSION

In general, this study aims to compare the developments in warehousing industries in developed and developing countries. Turkey is selected as a representative country for developing countries due to the researcher's origin. To provide an accurate comparison, we adopted the US-based Warehousing Education Research Council's questionnaire and used their findings in 2018 and 2019. Because the majority of their findings were from the US and UK, these data are assumed to represent the developed countries. We collected data from face-to-face meetings with the professionals in the warehousing industry in Izmir, which is the third biggest city and one of the most important logistics hubs in Turkey. In order to conduct cross-sectional and longitudinal analyses, we visited 62 and 74 warehouses in 2018 and 2019, respectively. Additionally, only 48 out of 62 warehouse managers were reached in 2019 due to inconveniences such as job changes. Hence, these define the scope and the boundaries of our study and findings.

The contribution of this study is threefold. First, to the best of our knowledge, this study is the first attempt to compare the warehousing industries in developing and developed countries through longitudinal and cross sectional analysis. Second, this is the first study investigating the importance of the selected performance measures according to the professionals' thoughts in a developing country and their changes over the years. Third, this study draws a picture of the future impact of the emerging technologies on warehousing from the perspective of warehouse managers in both developing and developed countries. Thus, the findings and the observations in this study might trigger future academic studies on performance measures and the technology usage in warehouse management and help practitioners to take action towards becoming a more competitive warehouse.

In future studies, the effect of digital-era technologies on critical performance measures and warehouse operations could be investigated to provide a comprehensive road map to practitioners. In addition, the digital-era technologies can be examined whether it is affected by the type of warehouse, type of industry, or handling units. In addition, performance metrics can be investigated whether it is affected by the type of warehouse, type of industries or handling units because we do not expect all performance metrics have the same significance in all kinds of warehouses. Last but not least, it might also be interesting to benchmark the warehousing industries in different developing countries.

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APPENDIX A

Table A.I. Contribution of digital-era supply chain technologies to the warehousing industry

		Social media	Internet of Things	Drones and driverless vehicles	Cloud-based services	Mobile technology	3D Printing	Simulation software	Blockchain	Sensors	Robotics and automation	Real time big data and analytics
		%										
No impact	WERC(2018)	28	20	39	13	4	58	30	34	26	21	6
Support ongoing improvements		34	43	17	39	32	19	41	30	37	35	36
Potential competitive advantage		32	29	29	43	56	17	26	29	32	33	51
Potential disruptor		6	8	15	6	8	7	3	7	5	11	7
No comment/No idea		-	-	-	-	-	-	-	-	-	-	-
No impact	TR-2018	10	3	21	27	2	33	9	8	9	9	19
Support ongoing improvements		31	27	23	23	48	9	21	21	44	35	30
Potential competitive advantage		38	41	18	11	34	11	25	25	26	19	19
Potential disruptor		8	3	9	7	5	15	6	6	11	17	14
No comment/No idea		13	25	29	32	10	33	40	40	11	20	18
No impact	TR-2019	38	27	40	12	5	50	34	26	16	12	15
Support ongoing improvements		15	23	17	29	42	8	17	16	36	32	33
Potential competitive advantage		29	27	22	38	42	22	19	21	28	32	33
Potential disruptor		12	5	7	9	9	0	2	12	14	18	8
No comment/No idea		6	18	15	12	3	20	28	26	6	6	10

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