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ORIGINAL PAPER

THE SMART WAREHOUSE TREND: ACTUAL LEVEL OF TECHNOLOGY AVAILABILITY

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ABSTRACT. Background: Some phrases become common and contemporary without justification. One such term for business activities is the term smart. In the field of logistics, the trend toward "smart" warehousing is increasingly attracting attention. It is necessary to define it and the stage where intelligence can be achieved using available state-of-the-art technology, to follow the trend of the dehumanization of warehouse and in general manufacturing operations in the direction of Industry 4.0.

Methods: The article is based mainly on observational methods, literature review, and document analysis, based on data obtained during the implementation of consulting projects. The subject is limited to warehouses designated to process palletised goods.

Results: The available state-of-the-art solutions, like IoT, automation, robots, and communication standards, are close to smart warehouse implementation. But on the other hand, lack of full cooperation between various parties of supply chain and long-term return on investment stand in opposition to implementation.

Conclusions: Smart warehouse is the matter of the future. Technology is predominantly achievable, but standardization, universalization and trust are necessary to reach the level of real implementation. Smart solutions are within the reach of a single enterprise, but only in isolation from its microenvironment.

Keywords: smart warehouse, smart storage, smart logistics, smart technologies

INTRODUCTION

Smart is the expression that is becoming contemporary and common, in some areas without real technological justification. In the field of logistics, the term smart warehouse is becoming more and more popular, though the development of this technology is far from observation in the field of mobile communication. The definition of the solution and the determination of the stage at which it can be achieved through the use of state-of-the-art technologies are necessary. The literature review points to scientific gaps, whose completion initiated the survey.

The scientific objective of the paper is to determine the advancement of warehouse technologies toward achieving a solution defined as 'smart', which should initiate the discussion of smart warehouse implementation. In addition to filling the research gap, the aim of the article is to answer the question to what extent it is possible to implement in practice smart warehouses now and soon, confronting existing or emerging technologies with real needs. The trend of technology replacing humans, directing logistic to the 4.0 level, is accelerating and cannot be ignored, especially by science.

The methodological objective of the study is to determine the degree of applicability of available storage technologies against human labour in the context of creating a smart warehouse, taking into account the justification and limitations of its implementation. A missing attempt should be made to verify the applicability of the smart warehouse idea, which is the aim of the paper. Are there technologies that can be implemented to put intelligent warehouses into practice, technologies that will allow intelligent warehousing operations? If so, can synergies be obtained from their

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simultaneous functioning? Is the potential implementation consistent?

The results of the paper indicate areas of focus in order to implement realistic intelligent technologies that authorise the term smart warehouse use. These should be further researched and given special consideration by practitioners.

LITERATURE REVIEW

‘In recent years, several studies have proposed and discussed different types of smart warehouses, identified key challenges, and proposed several solutions to cope with these challenges. (…) However, very few studies exist on how smart warehouses are designed and the transition strategy and process to these new types of warehouses” [van Geesta et al. 2021]. It can be understood that there is not any publication with holistic look a smart warehouse solutions and along with the expected or possible advanced technology participation in the warehouse process. A review of the titles and content of some scientific services confirms that "smart warehouse" in literature is treated selectively, there are a few holistic approaches and evaluations of the applied solutions when eliminating unnecessary human work. Even the publication focused on ‘smart warehouse’ focus on a part of subject matter, for example software, warehouse organization, single technology, or case study (see Table 1). A technology implemented does not “make” warehouse smart, but is often is the main subject of a publication titled with “smart warehouse” phase.

Table 1. Number of publications with the phrase "smart warehouse"

Web service	Results	Holistic approach		Results in titles of articles, focused on:					
				IoT	warehouse technology	warehouse organization	software (AI, Big Data)	case study	others
Emerald	36	none	4	■	■			■	■
Science Direct	104	2	5	■		■		■	
Springer	243	none	11	■	■	■			
Taylor & Francis	14	none	1		■	■			
Elsevier (Scopus) [1]	67	none	2	■	■		■		■

Source: own work, data from March 2022

One of the holistic approaches [van Geesta and others 2020] answers the question: What is a proper reference architecture for smart warehouses, focusing mainly on warehouse software. Another approach [Zhong-Zhong 2021] indicates picking as a “smart” warehouse ground. Still, those are only elements of the whole idea in question.

It is not easy to define when warehouse can be called smart. Without all of those things, can the solution not be described as intelligent, or are only a few of them essential? The article tries to gather all aspects of smart warehouse and decide

[1] In the theme: Physical Sciences and Engineering journals only

which level (percentage of technology autonomy) can be reached using smart solutions.

MATERIALS AND METHODS

Of the research methods used, the most significant were observational methods and case studies based on many-annual experiences during research activities and information gathered from contacts with entrepreneurs. Slightly less important was the information obtained from a literature review. The quantitative techniques used included observation and document analysis, based on data obtained during the implementation of consulting projects.

Due to the strong relationship between process automation and standardization of handled units, solutions for goods palletized into cuboid units were used for analysis. Multiple types, parameters, and conditions of these units did not allow the assumption of complete standardization of flow objects.

RESULTS

The definition of 'smart' building depends on respective times - the 'smart house' of 1935 had an electric light in every room [Weiser 1996], later the determinants were TV sets or computers. The definition of smart warehouse from Internet of Things (IoT) perspective was proposed by the IoT Agenda [2019]: "A smart warehouse is a large building in which raw materials and manufactured goods are stored that uses machines and computers to complete the common warehouse operations previously performed by humans". Although dimensions are a secondary matter, dehumanization is one of the most important factors of smart solutions.

Technology in place of manual work is not the deciding criterion. Interpretation of smart logistics definition narrows the area slightly by adding state-of-the-art to the specification of technology [Uckelmann 2008]: It enables people to focus on subjects that cannot be delegated, thus requiring more 'smartness'.

Smart warehouse is a technology driven logistics solution, where subjects, which can be delegated, are performed by state-of-the-art software and equipment, smart technologies.

The spectrum of warehouse smart technologies is wide. First, it includes dedicated software: management systems – of warehouse (WMS, EWM), yard (YMS), forklift fleet (FFM), close related transport (TMS) and finally supply chain (SCM), resource planning – of enterprise (ERP) or manufacturing (MRP). Then the manipulation and storing technologies should be included [He et al. 2018], like automatic storage and retrieving systems (AS/RS), conveyors, automated guided vehicles, autonomous machines, robots (here conv+) and the whole spectrum of equipment supporting picking activities [Stoltz and others 2017]. Those are the 'main' technologies, which can be supplemented by further ones. Their "intelligence" is demonstrated by their technological sophistication. Simple solutions, which have existed for many years, are only characterized by reflecting the reality created by humans. Smart solutions themselves create this reality, within the framework defined by the human factor.

The Internet connection opens up an additional perspective, such as software-as-a-service (SaaS), cloud computing, cloud data storage, blockchain, and direct intertechnological communication - Internet of Things (IoT) [Čolaković and others 2020]. Communication protocols (such as EDI) or automatic identification (based on barcodes or RFID) cannot be omitted, nor the application of augmented reality (AR). The newest trend, planned to be fully implemented in 30 years, is Physical Internet. The last, but not least, and perhaps the most important, is artificial intelligence (AI), the perspective of developing any smart technology and its independence from the "human factor".

Table 2. Smart warehouse activities and related example technologies

Warehouse activities	Smart technologies														
	(EDI)	ERP	MRP	WMS	TMS	YMS	IoT	RFID	Bar codes	AS/RS	Conv+	Robots (incl. AGVs)	Dedicated equipment	FFM	CCTV, sensors, gates
Communication with business environment	■	■		■	■	■									
Internal communication		■		■		■	■								
Orders of goods (restock)		■	■												
Reloading organisation (“time windows”)					■	■									
Road transport to/from warehouse					■										
Reloading organisation (availability of resources)				■	■	■									
Control of delivery compliance with the notification (warehouse access)						■									■
Control of compliance of the delivery with the orders (release for unloading)		■		■											
Unloading				■				■	■						
Preliminary quality and quantity control				■				■	■						
Detailed quality and quantity control			■	■				■	■						
Repacking, palletization and labelling of load units				■				■	■						
Manipulation – pallet load units				■						■	■	■			
Manipulation – boxes and pieces				■						■	■	■			
Picking zone replenishment				■						■	■				
Picking of pallet units				■						■	■				
Picking of boxes				■						■	■	■	■		
Picking of pieces				■							■	■	■		
Control of picking (may be skipped)				■									■		
Packing (items)				■								■	■		
Palletizing				■								■			
Loading				■									■		
Control of loading				■				■	■						
Inventorying			■	■											
Management of the distribution of goods in the warehouse				■				■	■						
Warehouse sequencing management				■				■							
Management of the directions of movement of forklifts / workers			■	■										■	
Administration - management			■	■				■							
Administration - activities				■											
Security						■									■

Source: own work

The set of technologies is ready to take over the work from warehousemen. Some of technologies can have different share in activity, for example, in case of standardized items picking manual work can be eliminated. More differentiated items lead to more sophisticated solutions. Sophistication is associated with higher expenditures and maintenance cost, which leads directly to the financial effectiveness issue. In case of complicated processes, the financial effectiveness can be lost much earlier. There is probably a technological solution for every warehouse activity, but the level of outlays and daily cost are still a barrier, growing in parallel with technological sophistication.

Activities that cannot be dehumanized, for example, road transport, can be identified. We can image autonomous trucks on the motorway, but on manoeuvre yard? We can imagine standardized load units, but standardized autonomous reloading systems for unstandardized units? Of course technologies are available but require pan-companies coordination and decades, not years, to universalize. Road transport and reloading are examples of activities that can be fully "smart" but with a long time horizon.

What are the opportunities for available (or soon to be available) technology to take over tasks for workers? An attempt of the answers is given in Table 2, indicating what the possibilities of technology are, abstracting from the level of outputs and the return on investment. The low value of the blue bar indicates the need to use the "human factor", here market with red.

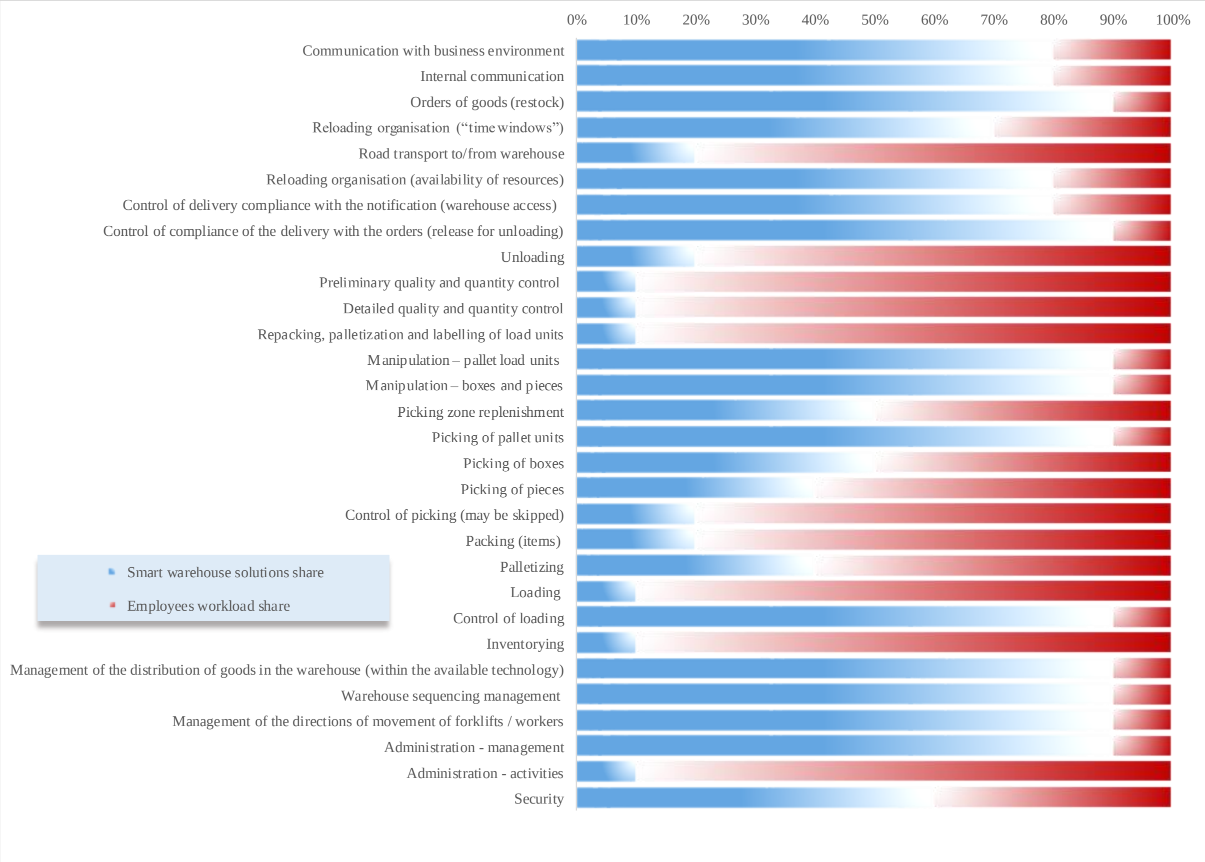
However, we as people, cannot trust artificial intelligence. A minimum of supervision is and, one must assume, will be necessary. The handling unusual situations will also be left to the human factor. The incorporation of artificial intelligence into warehouse every activity will theoretically be possible, but will it be financially effective? This assumption gives employees a minimum 10% share in all dehumanized activities.

The availability of technology has two minimum aspects. First, technological readiness, existence of proven technology. The second one is practice, when implementation is limited by other factors, like safety or lack of the standards. The example can be road transport, where theoretically technology offers solutions, especially in the case of cars. But autonomous trucks may cause threats, have to deal with congestion, different road conditions, or unpredictable humans, which practically eliminates implementation in the incoming decade.

The set of warehouse process activities with the share in estimated workload share for technology and humans is presented in the table. Additionally, there is a stated task for warehouse workers and technological solutions. And finally, technologies (software and equipment) tailored to individual tasks - this part should be treated as proposals or examples because there can be as many versions of the implementation as there are designers. But the technologies available now and in the near future are taken into consideration. The assumption is a possible usage of IoT in the whole process when the equipment and modular packages are adequately prepared. This will ensure the synergy effect.

The degree of applicability of available storage technologies against human labour is below the assumed 80% level, especially taking into account the limitations of its implementation. The justification for the implementation of smart warehouse technology is not general and requires a custom prior analysis, particularly in terms of profitability.

Table 3. Evaluation of currently available technologies compared to the requirements of the smart warehouse



Source: own work

DISCUSSION

There are technologies whose implementation makes it possible to apply the intelligent warehouse, and the synergistic effect of their implementation can be expected. Consideration should be given in determining the reasonableness of the overall implementation.

There are two main factors, indicating smart technologies. The first is the growing cost of labour, justifying proportionally larger investment outlays. The second one is the excellence of technologies in terms of accuracy, repeatability, consistent quality, and work continuity.

On the other hand, Kamali [2019] states the main disadvantages of smart warehouse, including high level of outlays related to several years to reach financial reimbursement, the need for specialised personnel, the risk of whole system stoppages, long-term dependence on particular spare parts, hardware and software providers. Two more important have to be added: the required standardization of turnover items and the fact that every complex technological system is a prototype, prone to faults in 'infancy age'. Technology is adaptable, but only within the framework agreed during the design process. The meaningful changes require additional investment, much higher than in the case of human workforce retraining. The reasonability of smart warehouse implementation has to be verified separately in every case, there is no clear indication of a universal answer.

The above comparison considers not only the available technologies but also the validity of their implementation. Theoretically, it is possible to automate or robotize all warehouse activities even for non-standard storage units. However, the return of investment period of such a system will be counted in tens of years, and for this reason it is a purely theoretical solution.

The share of human and technological factors throughout the scheme on average is equal. Today's state-of-the-art warehouse is not a smart warehouse when about 50% of activities have to be performed by workers. The assumed level is beyond the reach of differentiated supply chains. In the case of warehouses as part of an enterprise isolated from supply chain, when standardization of turnover objects is conducted, implementation opportunities are more likely.

Most publications with the phrase "smart warehouse" focus on one smart solution or a limited number of them, which does not allow the warehouse to "reach level 4.0". It is only the set of all or a significant number of solutions, possible and indicated for implementation in a given configuration, that allows a warehouse system to be called "smart". It is therefore difficult to agree with most of the authors of the mentioned publications that they touch upon a complete smart solution. However, it cannot be denied that they focus on the essential elements of a smart warehouse.

It should be emphasized that this paper is the first comprehensive approach to determine the degree of possibility of implementation of modern technologies in warehousing in the context of Industry 4.0, so there is no possibility to refer to other results of similar studies. This indicates a possible direction for further and more detailed studies.

CONCLUSIONS

The table does not give a straight answer, if the values are close enough to 100% to conclude, the set of presented technologies is a real smart warehouse, without clearly defined criteria. Even if we assume a level of 80%, this value will not be reached in many areas, which means that the smart warehouse in the holistic sense is currently unattainable. This also applies to the prospects for the next few years. However, this does not mean that we should not strive for it and make attempts, even in separate areas of warehouse logistics. It had to be underlined that the trend in the direction of dehumanization of main operation is strong.

What can be done to decrease the so-called human factor below assumed share values and reach the real smart warehouse-level value close to a minimum of 80% in every row? The first thing is standardization on a global scale. Standardization covers packages, including automatic identification means and communication protocols. Second, the automation and, in the case of road transport, standardization of road transport means. The third is trust, not only in automation effectiveness but in the honesty of cooperatives. These are very highly suspended requirements, it is hard to believe that they will be met in the next 10 to 20 years. The real smart warehouse is still far away, but some fields of storage can be “smart” now, as described, for example, by Žunić et al. [2018] or Bolu et al. [2019]. It is important to emphasize that smart warehouses can arise (and are arising) in isolation from the microenvironment. Little is in place to prevent the creation of smart solutions within the reach of an enterprise, but often in isolation from its suppliers and customers.

Despite the availability of a wide range of technological solutions, implementation constraints, including standardization, the need for close cooperation within the supply chain, and the unavoidable transfer of goods between facilities through public areas, with little control of the entrepreneur, are obstacles difficult to overcome by business practice.

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