Conceptual Framework of Intelligent Warehouse for Feed Grain in Industries 4.0 and 5.0

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***Abstract* — The research aims to describe the conceptual framework of intelligent feed grain warehouses in livestock livestock breeding, which are closely related to the development of Industries 4.0 and 5.0. The main components of a smart warehouse are reviewed: cyber physical system (CPS); cloud and peripheral computing services; Internet of Things (IoT); automated management platforms; warehouse management systems (WMS); and collaborative robots ("cobots") and drones, Through an expert evaluation using Delphi (Delphi) with the application of factor analysis, statistical processing and correction after each cycle of processing the results, the barriers faced by companies in the construction of intelligent feed grain warehouses in animal husbandry were assessed.**

Keywords — smart warehouse, barrier, industry 4.0, industry 5.0, Delphi method

I. INTRODUCTION

After the grain is timely and qualitatively harvested, the next step is storage, which strongly affects its quality. As of February 2024, the available quantities of grain in Bulgaria for 2023/2024 are shown in Table. 1. The supply of grain in the country is 11 170 811 t. Consumption is 60% (6 707 404 t), with total domestic consumption being 1 864 740 t, of which 34% (639 770 t) is feed consumption, along with grain exports of 4 842 664 t. Stocks are approximately as much as exports (4 463 407 t).

TABLE I. QUANTITY OF GRAIN IN BULGARIA TO 29.02.2024 Г.[1]

Year 2023/24	Wheat, t	Barley, t	Corn, t
1.Offering	7561490	849 691	2 759 630
2.Consumption	5 158881	601 061	947 462
2.1.Internally	995 870	204 900	663 970
2.1.1.for feed	246 450	129 600	263 720
2.1.2. others	749 420	75 300	400250
2.2.Export	4 163 011	396 161	283 492
3.Reserves	2 402 609	248 630	1 812 168

In the fodder warehouses, the following should be monitored and controlled: the temperature; the moisture; the height; aeration etc. The long-term storage of grain depends on two main factors that change during storage - temperature and humidity.

An important indicator in warehouse operation can be the CO_2 level. In laboratory and field trials, spoiled grain has been found to produce higher levels of CO_2 than good quality grain. This is usually due to a combination of factors such as the presence of mold or insect infestation. Grain spoilage can occur in localized areas (also known as "hot spots") in a grain warehouse that can be missed by temperature cables installed in the silo, making early detection of spoilage difficult. This often causes feed spoilage and has an adverse impact on the environment as well as on farm income. Detecting and monitoring CO_2 levels, using AI methods, offers valuable early warnings of spoilage on the grain, that might otherwise go unnoticed with conventional monitoring methods. [2]. Techniques and technologies allow the use of wireless sensing devices to measure small CO_2 differences in the space above the feed grain or inside the grain volume. These differences would be imperceptible to humans, but by comparing them to atmospheric CO_2 concentration and combining them with other sensor data, algorithms can detect situations where grain spoilage develops [3]. This allows timely corrective actions to be taken such as aerating, turning, selling or fumigation of the grain. Technology can be used effectively and this makes grain management easier, more sustainable and more cost-effective.

The premises in which the grain is stored must strictly meet the conditions for fire and explosion safety due to the presence of dry, flammable dust. These are ventilation, cooling, aeration, preservation. Ventilation oxygenates and cools the grain and is also a good way to control moisture. Cooling prevents the growth of harmful organisms and bacteria. Aeration is a type of ventilation, which can be both natural and artificial, and is an effective method of preserving cereal crops. Canning is a process of stopping all vital processes inside the grain, stopping the so-called "breathing", which prevents the loss of nutrients. Forced ventilation ensures the necessary access of oxygen, which contributes to the uniform flow of metabolic processes inside the grain itself during its so-called "breathing". It preserves the high quality of its properties and prevents it from overheating. There are ways to store grain in anoxic conditions (dry storage), when all processes inside the grain are stopped and all flour-milling and baking properties remain at their best.

Violation of the temperature regime of storage and increased humidity of the grain are among the biggest risks that can lead to the formation of fungal diseases and create conditions for the appearance and reproduction of insects. Untimely reaction in such cases leads to contamination of the grain with pathogenic microorganisms, reproduction of pests and, as a result, deterioration of quality. To solve the problem, humidity and temperature indicators should be observed, as well as resort to chemical treatment of the granary, by fumigation or gassing of the premises. This is an effective way to destroy existing pests.

The present study aims to describe the conceptual framework of intelligent livestock warehouses, which are closely related to the development of Industry 4.0 and Industry 5.0, as well as to review the barriers that companies face when building such warehouses. Industry 4.0 was introduced in Germany in 2011 as a long-term project and part of the country's high-tech strategy. Using technologies such as IoT, Big Data or AI, it creates much smarter solutions, aiming to minimize human intervention and prioritize process automation. Although Industry 4.0 has not yet reached its maturity, a new field is emerging and that is Industry 5.0, which unites human creativity with the precision and capabilities of robots. With Industry 5.0, it is envisaged to leave all repetitive, mechanical tasks that require effort and that can be dangerous to AI and robots. In this way, the person can have more time for tasks that only he can complete. Collaboratives called cobots are emerging. They go hand in hand with human ingenuity and creativity.

II. CONCEPTUAL FRAMEWORK OF A SMART WAREHOUSE

Traditional warehouses have a number of disadvantages, such as inefficient space management, damaged materials, inefficient operations, inefficient material handling equipment, etc. [4]. Today, we are witnessing the development of technological innovation, with one of the most notable technological transformations being the growing popularity of smart warehousing concepts.

In general, a smart warehouse can create flexible, reconfigurable warehouse environments by automating warehouse activities, monitoring and management, with communication between all computer systems, mobile devices, machines, automated guided vehicles (AGVs) and equipment.

Warehouse operations in a smart warehouse are digitally integrated and monitored based on the real-time information available on various computing devices.

The main components of a smart warehouse are: cyber physical system (CPS); cloud and peripheral computing services; Internet of Things (IoT); automated management platforms; warehouse management systems (WMS); and collaborative robots ("cobots") and drones, Fig. 1.

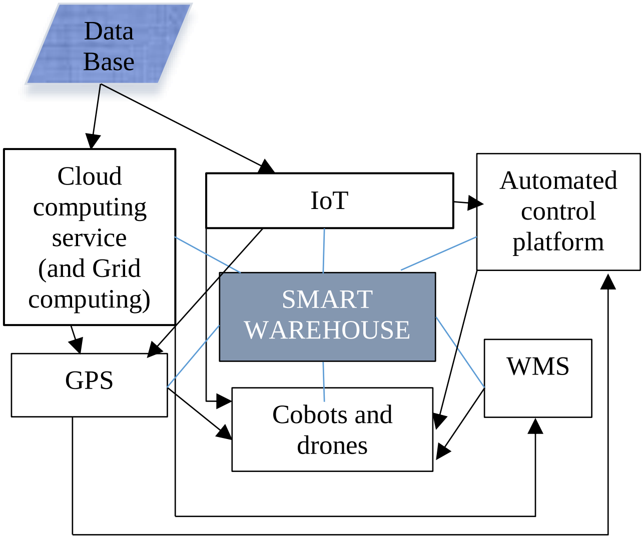

Fig. 1. Main components of a smart warehouse

At the heart of modern warehouses are cyber-physical systems (GPS) with their main components: computing; communications and control Fig. 2, that enable autonomous decision-making based on the integration of computing (cyber), physical components (e.g. machines) and real-time information collected by the IoT.

As shown in Fig. 1, CPS is designed to integrate sensor technology, data computing, and information networks into "smart" physical objects and infrastructure by connecting them to the IoT [5], [6], [7]. CPS can transform the way humans interact with physical systems (e.g., machines) and drive endless innovation [8]. The design process of a cybernetic system begins with modeling and necessarily ends with analysis and validation.

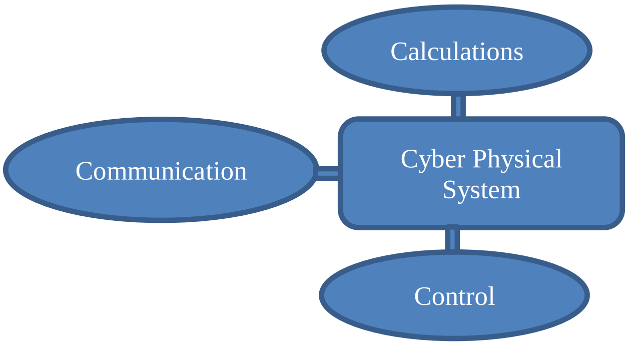

Fig. 2. Components of a Cyber Physical System components

IoT is a comprehensive concept designed to connect a network of computers, people, and physical objects to the Internet [5], [6], [9], [10]. Through improved traceability and ubiquitous connectivity, IoT facilitates data collection/sharing/ synchronization, machine-to-machine communication, interaction and integration of supply chain channels [5], [6], [11]. In this way, IoT can increase the flow of real-time data in an automated warehouse and provide constant monitoring and control of all moving parts in the warehouse through real-time information exchange and sharing. IoT improves the ability to quickly respond to changing storage conditions and take corrective action if necessary. Sensors play a crucial role in the successful implementation of smart warehouse technologies. In a broad sense, sensors can measure pressure, temperature, humidity, and other values of parameters important for warehouse processes, while allowing a statistical evaluation to be made for a set of measurements [5], [6]. They can help detect any anomaly and failure in the warehouse infrastructure and process. The data obtained from sensors allows a faster response to any problems and helps to eliminate potential problems. IoT can be used to manage and optimize warehouse activities [12], [13].

Cloud computing services are on-demand computing resources, such as data, software, platform and infrastructure, through hosted Internet services, thereby improving computing power while saving costs and making intelligent storage technologies more accessible and scalable [14].

Peripheral computing (Grid) is provided by an infrastructure of computing and telecommunications devices to solve problems with autonomous distributed computers that communicate with each other in a network. Grid computing is a next-generation computing technology with a focus on combining several weak and smaller networks to make a strong processing power and storage resource [15], [16].

A warehouse management system (WMS) is designed to comprehensively consolidate all warehouse data into one easily accessible platform to provide a complete view of warehouse operations and material flows and thereby improve visibility into warehouse operations. It is also designed to speed up order processing times, provide immediate order status information, and increase warehouse space utilization and labor productivity [17]. A WMS is an essential part of a smart warehouse. These systems are used to track warehouse performance on a daily basis. Every single task and process can be tracked with this piece of technology and they can also help identify problem areas.

A collaborative robot ("cobot") is an industrial robotic technology designed and programmed to work safely alongside workers. It allows machines and humans to work side by side on the same task at the same time and in the same area. Cobots can be assisted by automated guided vehicles (AGVs) that can augment warehousing, loading and unloading activities by following digital paths through the warehouse. AGVs can reduce the risk of material damage during material movement, and increase the efficiency of material handling. AGVs are a must for building a smart warehouse.

These vehicles are responsible for the handling of materials and the transport of goods and are gradually replacing the currently known loading and unloading machines and equipment. The advantages of having an AGV are higher speed, determining the optimal route for movement in the warehouse, which saves time.

Cobots (or robots) are machines that work alongside humans to automate work. Drones are used for a safe and easy way to reach hard-to-reach places in warehouses.

Automated control platform is an essential prerequisite for intelligent warehousing. It plans the placement of the production in the warehouse, storage space, etc., while simultaneously providing information, synthesizing and updating production-related data in real time. This platform can be supported by an automated storage and retrieval system (AS/RS), which aims to create synergies between many different types of technology, software, hardware, vehicles and robotics to streamline and automate handling, storage, the storage and extraction of the production in a warehouse [18]. Incorporating automated picking platforms can increase picking efficiency and accuracy by using a variety of innovative picking tools, such as voice activation, which reduce processing time and reduce the risk of human error.

Artificial intelligence AI for process automation is part of the Smart warehouse systems. Its inclusion improves performance and minimizes errors. AI can also help robots.

III. BARRIERS TO BUILDING A SMART WAREHOUSE

The review of the literature on the construction of smart warehouses and the current practice show a wide variety of barriers that are characteristic both for the introduction of innovative solutions and barriers related to the specifics of smart warehouses. They can be divided into external (which arise outside the warehouse) or internal (characteristic of the internal environment of the warehouse).

External barriers:

E1. Regulatory policy: presence of too many laws and regulations that are often subject to change and ambiguous in their interpretation; outdated legislation that is not adapted to the development of innovations; lack of a long-term concept for economic development of innovation activities, lack of a system for promoting the development of knowledge about innovation in companies; lack of state and regional political support for regional innovation systems; too bureaucratic support mechanisms; insufficiently developed regional innovation systems in Bulgaria;

E2. A frequent recurrence of widespread inflation and a growing pattern of cautious investing;

E3. Lack of consistent state policy for financial support;

E4. Difficulty or impossibility of raising funds for innovative activities due to the reluctance of banks to grant loans for such investments; lack of a system for financing innovative activities; complex credit procedures; bureaucracy; focusing investors on short-term investments.

E5. Insufficient development of public innovative infrastructure, insufficient technology transfer;

E6. Competence of the administration: limited support from the public administration due to unfamiliarity and vagueness of regulations; lack of business experience of people working in innovation centers; misunderstanding the strategic importance of innovation;

E7. Technological barriers. These include the lack of reliable infrastructure or difficulties in integrating with the legacy systems running in the warehouse.

For example, the use of cutting-edge engineering applications requires developing algorithms that must be supported by robust middleware systems and programming models [19]. Overall, as Smart warehouses are still in their infancy, immature technologies along with non-standardized functional modules are also identified as key barriers to their adoption [20].

Internal barriers:

I1. Lack of familiarity with smart warehouse systems and capabilities as this is a relatively new field.

I2. Significant initial investment for automation, sensor technology, technology infrastructure. When a complete redesign of a warehouse is required, the investment is usually very high [21], [22], [23], [24]. In some cases, a step-by-step implementation strategy is preferred [25], [26].

I3. The long period of time required for the implementation of an innovative project is related to the workload of the company.

I4: The long payback period is related not only to investment costs but also to implementation and training. To deal with this, companies need to analyze the costs and return on investment before deciding to implement the technologies. This makes it difficult for them as it is difficult for them to assess the beneficial effect of the implementation in advance.

I5. The need for a radical transformation of the traditional warehousing paradigm and changes in protocols (such as remote monitoring and control of warehouse activities, predictive remote maintenance and repairs, human-robot collaboration throughout the warehouse, virtual managed self-service, automatic closed-loop feedback mechanisms and automatic service failure recovery).

19/I12. Cultural barriers

I6. Need to work with vendors to assess, plan, implement, learn and scale, in an end-to-end implementation, to capture the chances of digital transformation success.

I7. The complex integration of multiple technologies to build, transmit, store, retrieve and protect data.

I8. The new warehouse design must be adapted to the specific conditions, as there are no standardized implementations.

I9. Lack of a unit responsible for research and development and implementation of innovations.

I10. Lack of prepared personnel with technological and digital education;

I11. Security and safety (e.g. cyber attacks and hacking) related to the IoT platform and other subsystems of logistics and warehouse systems is vital for technology adopters. This includes several concerns related to cyber attacks [27], [28]. The greater the number of devices connected to the IoT network, the greater the potential for security and privacy issues [29]. As an example, privacy violations related to tracking the locations of certain items could compromise a firm's competitive advantages [30]. In this context, blockchain-based systems are often proposed. However, blockchains are not able to avoid and neutralize cyber-attacks [20] but are focused on ensuring that information cannot be subsequently modified [31]. Furthermore, there are additional physical safety challenges raised for automated devices such as robots, drones or AGVs that may cause harm to operators [32].

I12. Cultural barriers are associated with a number of challenges. The implementation of smart warehouses requires the integration of a wide range of technologies, and companies need additional knowledge and skills that can be achieved through investment and training [33]. Digital maturity level is still low and resistance to change can be another barrier to adoption. The most frequently repeated factor hindering the implementation of innovations is the human factor, i.e. the resistance/reluctance of employees to change and the related need to adapt to new working conditions [34].

The lack of managerial competence regarding innovative solutions is also a significant obstacle. A change in terms of technical skills and collaboration with smart equipment and technology must be accompanied by a change in mentality within the firms themselves [35]. Lack of appropriate communication, for example the use of complex terminology or terminology known only within a particular unit that is not understood by all employees. Failure to comply with the levels present in the company in communication.

The Delphi method was used in the present study. The opinion of 7 experts was studied (j=1, 2, ...7). They gave each barrier their score xi (i=1,2,…,19) on a scale of 1 to 100 (100 being the highest). The answers form a matrix $[X]_{ij}$, i =1,2,...19, j =1,2, 7. For the study, we define a matrix $[X]^*_{ij}$, TABLE II, each element of which is obtained from (1) (ie lowest value is most significant)

$$x^*_{ij} = 100 - x_{ij} \tag{1}$$

The resulting values for arithmetic mean $x_{iaverrage}=\sum_{j=1}^{7} x_j/j$, i=1,2,….,19 and for the median M_{ei} rank the barriers equally in importance, with the top 5 barriers in descending order being as follows: I12-Cultural; I2-A significant initial investment is required; E3-Lack of consistent state policy for financial support; E4-Difficulty or impossibility of raising funds for innovative activities due to banks' reluctance to grant loans for such investments; E7-Technological barriers.

Distribution of barriers by importance by the concordance coefficient is in the following order: x19; x9; x12; x3; x7; x4; x18; x17; x11; x10; x1; x5; x2; x15; x8; x14; x6; x13 and x16. Here, in the third place, barrier I5-Need for a radical transformation of the traditional warehousing paradigm and changes in work protocols appears in third place, instead of E3.

The concordance coefficient w=0.94, i.e. a high degree of agreement of expert opinion is available. We estimate the significance of w by Pearson's test $\chi 2$=118.79. At $\propto = 0.05$ и 18 degrees of freedom, the table value is $\chi_{tabl}2$=20.8623. As $\chi 2 > \chi_{tabl}2$, it follows that w is not a random variable, i.e. it is statistically significant and the results obtained are meaningful and usable.

TABLE II. MATRIX $[X]^*$, AVERAGE AND MEDIAN

N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	$x_{average}$	M_e
1	9	11	10	12	8	13	10	10.57	10
2	18	16	19	20	18	17	20	18.57	18
3	5	4	7	6	4	5	5	5.57	5
4	5	7	7	4	5	5	4	5.86	5
5	17	20	18	17	19	18	16	18.57	18
6	38	40	40	42	43	39	39	41.00	40
7	5	4	5	8	5	6	3	6.14	5
8	28	30	28	29	25	27	28	29.00	28
9	2	4	5	1	5	6	3	5.00	4
10	9	11	9	12	8	7	10	10.86	9
11	7	4	6	5	8	11	13	9.29	7
12	5	4	5	6	5	6	3	6.57	5
13	40	40	42	43	39	43	40	42.86	40
14	31	30	33	29	34	28	27	32.29	30
15	27	20	18	27	25	28	27	26.71	27
16	45	50	44	46	47	45	49	48.86	46
17	5	7	5	6	10	8	9	9.57	7
18	5	4	6	8	5	6	7	8.43	6
19	1	0	2	1	3	2	2	4.29	2

The weighting factors of the barriers are as follows: E1=0.06211; E2=0.04978; E3=0.0704; E4=0.07018; E5=0.05045; E6=0.01547; E7=0.0704; I1=0.03475; I2=0.07265; I3=0.06368; I4=0.06637; I5=0.07085; I6=0.01413; I7=0.03094; I8=0.03991; I9=0.00538; I10=0.06726; I11=0.06928; I12=0.07601.

IV. CONCLUSION

The offered grain in Bulgaria is 11 180 820t, of which 663 970t for domestic consumption and 263 720t for feed. The long-term storage of grain depends on two main factors that change during storage - temperature and humidity. Compliance with grain protection standards during storage requires constant monitoring and implementation of a number of measures. Traditional warehouses have a number of disadvantages, such as inefficient space management, damaged material, inefficient operations, inefficient material handling equipment, etc. The modern development of technologies, digitization, Industries 4.0 and 5.0 allow to provide significant improvements in this area. Today we are witnessing the development of technological innovations, one of the most notable technological transformations being the growing popularity of intelligent storage concepts. The main components of a smart warehouse are: cyber physical system (CPS); cloud and peripheral computing services; Internet of Things (IoT); automated management platforms; warehouse management systems (WMS); and collaborative robots (“cobots”) and drones. The review of the literature on the construction of smart warehouses and the current practice shows a wide variety of barriers that are characteristic for the introduction of innovative solutions, as well as barriers related to the specifics of smart warehouses. They can be divided into external or internal. The assessment of the defined 19 external and internal barriers was made by 7 experts using the Delphi method.

The resulting values for the arithmetic mean $x_{iaverrage} = \sum_{j=1}^{7} x_j / j$, i=1,2,….,19 and for the median M_{ei} equally rank the barriers in order of importance, with the first 5 barriers in descending order being as follows: I12-Cultural; I2-A significant initial investment is required; E3-Lack of consistent state policy for financial support; E4- Difficulty or impossibility of raising funds for innovative activities due to banks' reluctance to grant loans for such investments; E7-Technological barriers.

When using the concordance coefficient in the third place, instead of barrier E3-Lack of a consistent state policy for financial support, barrier I5- Need for a radical transformation of the traditional storage paradigm and changes in work protocols appears.

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