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Process Control Systems Meeting

INFORMATION

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PCS conference has a history of more than two decades. Its goal is to bring together modern methods, tools, innovative applications, and experiences related to the design, investment, control, optimization, management, and IT tasks associated with process industry systems. The two-and-a-half-day event offers not only presentations but also professional workshops, panel discussions, and exhibitions, providing numerous opportunities for networking. The conference take place at Palotaszálló in Lillafüred, Miskolc. (2-4.10.2023.). Website of the conference can be found at the following link: http://pcsmeeting.hu/

The Organizing Committee of the Process Control Systems Conference highly values the convergence and collaboration between industry and the scientific community. In this regard, we would like to provide an opportunity for PhD students, postdocs, and young researchers working in the related field to present their work free of charge on the zeroth day of the conference.

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ELECTRIC FORMULA STUDENT RACECAR DEVELOPMENT AT THE UNIVERSITY OF MISKOLC

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Abstract

Formula Student is not only a worldwide competition form, known as the highest in its league, but also a student movement giving a solid ground for the professional development of talented university students. The competition itself combines the practical application of first-grade solutions with students' theoretical skills. In the context of the competition, the participating teams are tasked to design, construct, manage, then race a real, open wheeled formula type race car. Until 2023 there were 4 main categories, combustion vehicles, electric vehicles, hybrid vehicles and driverless vehicles. Following the modern industrial trends, since the year 2024, the combustion category is out of the competition, but a new, hydrogen conception category came into play. Electric Racing Miskolc or ERM in short, is the Formula Student Team of the University of Miskolc. The ERM team, founded in 2022 August, has the objective to take part in their first ever competition in the 2024 summer season. If they achieve their goal, they will become the second fully electric formula student car building team in Hungary.

Keywords: *Formula Student, Education, University of Miskolc, Student teams, Practice-oriented education*

1. Formula Student [1]

The goal of Formula Student is to design, construct and introduce a formula racing car to a conceptual market and to race that car on several international racing events with the help of all members who have a legal student status. The organization ensures the team members gain valuable insights in their field of expertise and have the opportunity to build channels which enable smooth communication between the students of Formula Student and the supporter companies of the movement. These competitions are held in several countries across Europe, the most notable ones are Germany, England, Austria, and Spain.

An average Formula Student competition takes up to four days, which consists of two days of scrutineering and assuring that the car complies with various security rules. If it meets all these regulations, the vehicle will be allowed to take apart in the next two days of events. These can be sorted into two main groups: static and dynamic.

Static events are presentations which include defending the engineering design, presenting business plan and cost analysis. These give 40% of the total scores.

Dynamic events include the “Acceleration”, the so called “Skid Pad” which tests the suspension dynamics of the car on an “8” shaped track, and the “Autocross” which examines the car’s performance on a specific section of the racetrack during measured lap time. Finally, the “Endurance” event where the overall time performance and fuel efficiency of the vehicle are taken under scope on a 22 km long track.

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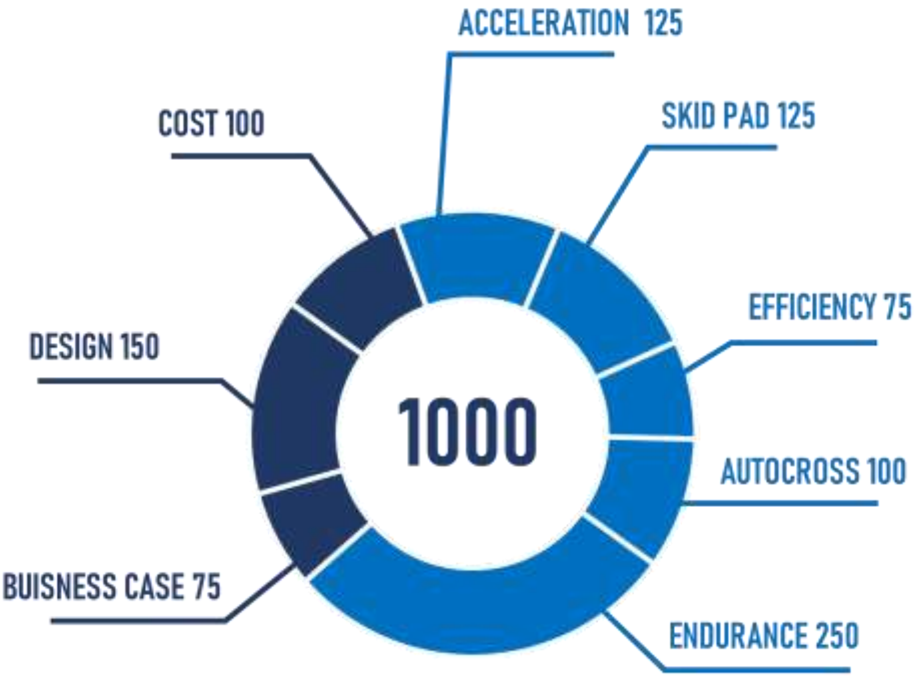

Figure 1 *The point distribution chart of the competition.*

2. Our Team [1]

Electric Racing Miskolc is an initiative group of volunteering students located in Hungary, Miskolc, where team members can gather extensive understanding and experience in the automotive industry and various fields of motorsport. They can learn the true meaning of teamwork, as well as use their knowledge in practice.

The project provides opportunity to become familiar with the usage of the most advanced technologies, as well as offering an indirect way to the industrial companies for the students who are involved.

The team members are students of the Faculty of Mechanical Engineering and Informatics, Economics and Materials Sciences, who participate in the basic and master's degree program of the region's most significant institution of higher education and several professors and PhD students help our work.

Besides providing the human resources, the University of Miskolc also provides the operation for the Formula Racing Miskolc with significant professional, infrastructural, financial support, and personal relations.

The interests and extra activities of the team members include the automotive industry and there are several the national and regional scientific students' competitions as well as thesis works to prove it. It is natural that the members of the Formula Racing Miskolc are willing to invest their free time into research and development of the project, proving their dedication to and success for the Formula Student movement.

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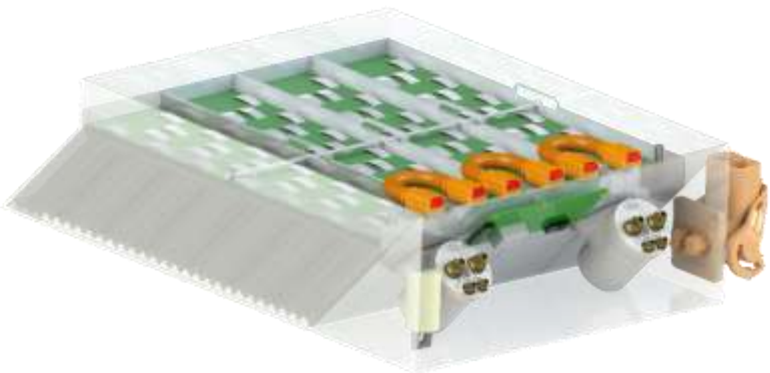
3. Developments

Like the Formula Student international competition series, our community has a duty to follow trends in the development of the automotive industry. The advancement and legitimacy of electric powertrains is unquestionable on both public roads and racetracks.

Our first electric project car, the ERM-01 is a concept with a central electric motor, powered by an EMRAX 228 water-cooled BLDC motor and controlled by a UniTek BAMOCAR D3 control unit.

1. Figure EMRAX 228 - the electric motor powering our racecar.

Our engine is powered by a self-developed battery pack made up of lithium polymer cells. A battery monitoring system developed by our members is responsible for the safety of the battery pack used to supply the low voltage system.



2. Figure 3D rendered image of the designed battery pack.

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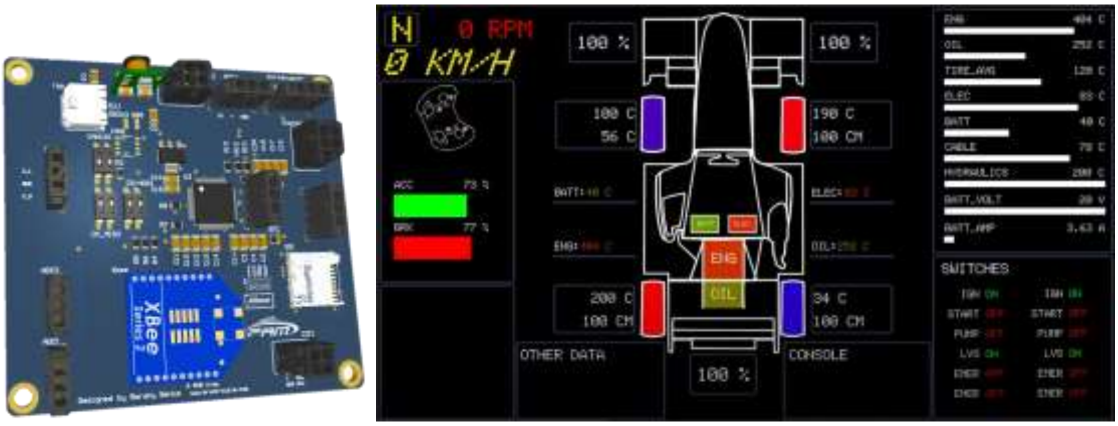
In addition, a complex telemetry system is provided in the car, thanks to which we can implement continuous data collection in a racing environment, which provides a detailed picture of each moment of the pilot in addition to the basic data.



3. Figure The back- and frontend of our telemetry system.

4. Our Goals

As we are a first-year team, our main goal is to attend our first ever race in the electric category, in 2024. As our long-term plan, we would like to implement our own self-driving system on our car, to attend the autonomous contests as well.

5. Team Structure

Our team consists of 3 main departments. The Mechanical, the Electrical and the Economy departments. Students from different faculties can join each department and gain experience in the relevant fields.

The mechanical department is made up of 4 sub-departments, the Powertrain, Suspension, Chassy and Aerodynamics. They are responsible for designing and manufacturing all the mechanical parts of the vehicle.

The Electrical Department is responsible for the motor controls, the battery design and manufacturing, as well as the supporting management electronics. They are also responsible for all the safety systems on the car and for the inside and outside communicational interfaces.

The Economy department also has 2 sub-department, the marketing, and the financial ones. The Marketing subdepartment is responsible for creating such environment on the social and other media platforms, where sponsors can be promoted, creating the income possibilities for the whole team through these sponsorations. They are also responsible for managing the recruitment process and making the team attractive for the students. The financial sub-department is responsible for managing all the incomes, expenses, they assist the different departments in the procurement process.

The Economy department as a whole is responsible for 2 of the static events on the competitions, the cost event, and the business case event, the other two departments have the responsibility to compete in the engineering design static event, as well as all the dynamic events.

The team management is not a dedicated department in our case. Each and every department or sub-department leader takes part in the team management, bringing the management processes really close to the actual workflows.

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6. Impact on the industries

As the team must work on a real-life project, similar to the real motorsport teams, they gain experience way sooner than other students. Most students only start gathering these skills and the knowledge required in the real world after they leave the university, but our students who are part of the team, are actively gathering these experiences, while creating an extraordinary thing in their student years.

Our job, as team managers are not only making sure, that we build the best possible vehicle for the competitions, but also to educate them and have them experience what they will in the industrial environment.

Our workflows and team structure are built around real industrial standards and systems, creating the most realistic "training" environment for every student.

This way we help accelerate the learning process in which they join the different industries.

7. Conclusion

Students. taking part in the Formula Student movement. Are way more capable and ready for taking part in the different industries. They gather a lot more experience and develop better soft, and technical skills than most of the students leaving the universities with their new degree. Formula Student is the biggest and most advanced competition series between universities in the world, that every student should experience in their lifetime.

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UNDERWATER ROBOTIZED MEASUREMENT DEVELOPMENTS

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Abstract

UNEXUP, an EIT RawMaterials upscaling project funded by the EU, has yielded a highly sophisticated underwater robotic platform. This technology, being commercialized by UNEXMIN Georobotics Ltd., demonstrates the capability to conduct precise measurements and gather samples within submerged mines and caves. It stands as a valuable solution for comprehensive surveys, essential for collecting geological and spatial data before commencing maintenance or dewatering operations in mines. With the use of specialized sensor technology, the robotic platform is capable of performing underwater measurements such as magnetic field measurement, water sampling, water parameter measurements and radiation measurements down to 1 500 m water depths. This effort could help the sourcing methods and exploration of raw materials by examining flooded mines where material extraction could be restarted, and repair works could be conducted on old mineworking. Besides operating in mines, this technology is also useful in underwater cave systems to gather useful information about such ecosystems. Besides the available technology there are new developments currently in progress by the company for surveying water reservoirs with non-invasive methods to estimate the structural integrity of freshwater reservoirs. The article introduces the technology developed during the UNEXMIN and UNEXUP projects and introduces some results gained on missions completed with the systems.

Keywords: *underwater, robotics, photogrammetry, water parameter, measurements*

1. UNEXMIN project

UNEXMIN is a Horizon 2020 project funded by the European Union that commenced in February 2016. The project unites partners from Hungary, Portugal, Spain, Finland, Slovenia, and the United Kingdom. The Hungarian team had the focus on the geoscientific instrumentation. The Finnish partner oversaw developing the mechanical components of the robot, whereas the Portuguese and Spanish participants managed navigation and autonomy. The data's post-processing was executed by the English team led by Hungary. The initial build, UX-1a, performed on must missions while another two robots, UX-1b and UX-1c, were also implemented during the project. All robots conformed to pre-determined dimensions, taking the form of a 60cm diameter sphere, and weighing 110 kg approximately. This size and shape were selected as the robot is less likely to become damaged or stuck in narrow mine shafts during dives. Additionally, the robot is able to avoid potential hazards such as dangling wires and other obstacles throughout its path in the field. Figure 1 shows the robot with the laser positioning units and a sonar on the outside. The robot consists of 3 main parts, a grey, specially moulded, and machined aluminium pressure shell and two removable side plates covered with a black painted hard foam coating. The robot is designed and built to be able to dive stably to a depth of about 500 m during deployments and to operate autonomously for 5 hours and return to the launch site [1]. The robot also had a tethered communication with the surface over an underwater cable to monitor its movement from the control room on the surface. The cable was only handling communication, the robot had its own internal battery system.

The UNEXMIN project developed an autonomous robotic system to map water-flooded mines at depths of up to 500 metres. The project encompassed an international partnership with Hungarian, Finnish (engineering), English, Slovenian (geological data processing), Spanish, Portuguese (navigation and autonomy), and Belgian (dissemination) collaborators. The aim of the project was to design 3 self-governing robots, each capable of conducting distinct, non-destructive geoscientific investigations. During 2018-19, the robots were assessed in various locations across Europe, including Finland, Slovenia, Portugal, England, and Hungary. The test sites consisted of inundated, disused mines, with the exception of Hungary, where the robots were trialled in the tunnels of Molnár János cave in Budapest. During the project, 2 robots have been assembled, with minimal differences in design, and only the geological instrumentation were completely different.

Figure 1. *UX-1a*

The instrumentation of UX-1a:

- 1 multispectral (UV-VIS-NIR) unit,
- 1 pH measuring head (and associated reference electrode),
- 1 electrical conductivity meter,
- 1 dual frequency sonar.

Instrumentation of the UX-1b:

- 1 gamma ray meter,
- 1 water sampling unit.

UX-1c instrumentation:

- flux-gate magnetometer system consisting of 6 sensors.

The instruments of the UX-1a robot have already been installed in the robot in 2018, and after calibration, further laboratory and field tests have been performed with them.

2. UNEXUP project

The UNEXUP project was and upscaling project of the UNEXMIN technology to increase its technology readiness level to the maximum, allowing the establishment of a spinoff company named UNEXMIN Georobotics Ltd. with the scope on utilising the available technology for carrying out partners for industrial surveys. The project conducted successful surveys in Hungary, United Kingdom, Germany and in the Czech Republic. The robotic technology in this project was developed by a Portuguese partner and the physical system based on a modular arrangement of all instrumentation allowing quick change of parts and adopt to customer requirements more efficiently.

3. Underwater technologies

During the UNEXMIN and UNEXUP projects several systems were developed aiming to collect useful geological information. Main tasks were studying mineralisation and collecting water parameters.

3.1. Multispectral and hyperspectral systems for mineralisation detection

For identifying mineralisation an optical system was developed end then optimised. The system consists of a lighting module and a camera module, both in a separated housing to avoid reflections. The first version seen on Figure 2, based on a principle of having a grey-scale camera with an extended detection range and a light source with transmitting different wavelengths and triggering each of them in a given time to have an overall of 14 images of the target within a given time limit. The unit had the light sources and the controller unit in a shared pressure-proof housing on the side of the robot, next to the camera unit.

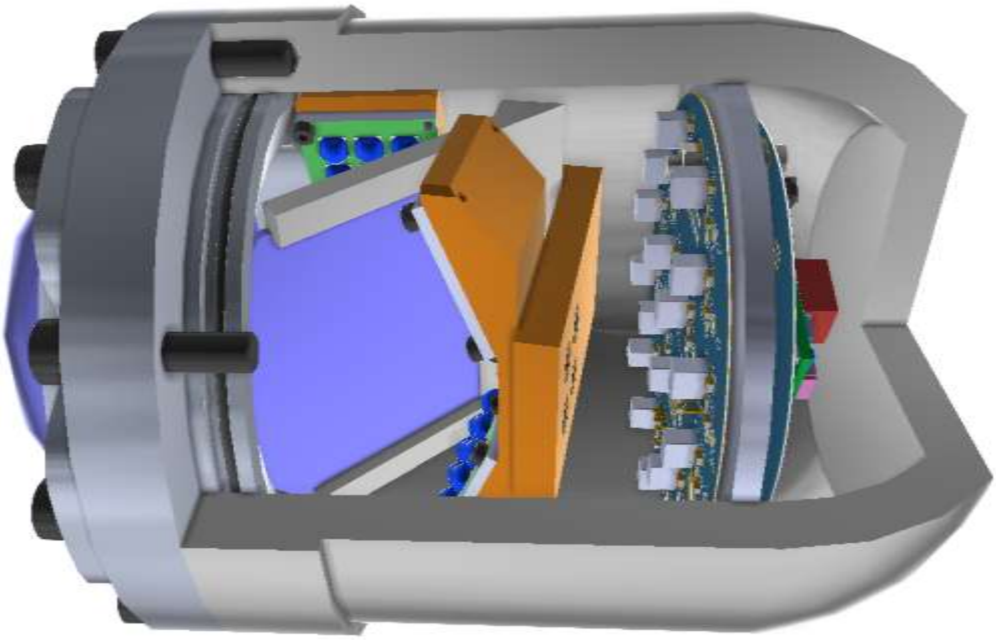

Figure 2. *Multispectral light source*

The drawback of this solution was the time what an image needed to be taken. An average shutter time was 5-10 ms for each wavelength which adds up to 70-140 ms of shutter time total. For the optical navigation system each light emitting unit had to work in a proper sequence which was predefined by the main controller to ensure only one kind of light source is active at any time during operation. Changing the shutter time of this unit changed the overall timing of the sequence not to mention that between each multispectral flash there were additional light source activations extending the shutter time. During this time the robot could move and on the sequence the target was not in the same location which resulted in the increase of post-procession time. The new system overcome this problem with the use of a full-spectrum light source with hyperspectral cameras sharing one optical channel. With this solution the required time for making a spectral image was reduced to the exposition time of the cameras which can be as small as 5 ms or even less with the proper light source.

3.2. Water parameters measurements

Collected data from water parameters is an important indicator of water quality which is amongst other data a crucial factor when a mine is considering dewatering procedures. A multi-purpose water parameter measurement unit was developed which can measure temperature, electrical conductivity, O_2 concentration and pH in a range of 4-9. The unit has a depth rating for 1 500 m with a safety margin of 20%. The modular buildup of this unit has an advantage to fit different sensors to measure pH with .1 precision. The unit also has self-diagnostic features which monitors the internal pressure, humidity, and leakage condition.

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3.3. Fluxgate magnetometer system

During UNEXMIN project a fluxgate magnetometer system was developed which was further developed in UNEXUP project. The magnetometer unit's primary aim is to measure magnetic flux density within the three-dimensional space surrounding the robot. It can be utilised to gauge the magnetic field strength in each direction separately, but measuring the gradient of field strength offers a more comprehensive understanding. During operation, the magnetic field is also measured. The UX-1 robot was equipped with a unit that comprises six separate fluxgate magnetometer sensors. These sensors are standard and housed in identical plastic shells to ensure proper alignment. The sensor and the cylinder axis should be collinear to reduce deviation in any angle [2]. In the UNEXUP project the size and placement of this unit was optimised.

4. Summary

Between 2021 and 2023 there were several field trials and industrial surveys performed with the robotic platform, one of the greatest achievements is the cooperation with the Czech Speleological Society to inspect the Hranice Abyss which resulted in a record of reaching 450 m depth in a natural freshwater cave which is estimated to have a depth more than 100 m which is measured to 519.5 meters for now. The introduced methods for magnetic measurements and water parameter measurements were not only tested in laboratory conditions and in real environment but also were validated and used in real case scenarios. Besides the further development of the mineralisation identification system, the optimisation of the water parameter unit is also part of the future plans to develop an even more reliable unit.

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IMPROVING MICRO-LOGISTICS PROCESSES BY INDOOR POSITIONING SYSTEM AND THE TOOLS OF DATA SCIENCE

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Abstract

The advancement of logistics processes is a pivotal aspect of Lean philosophy. However, accurately determining the potential opportunities for improvement and the actual effects of individual changes on the system can be challenging. The integration of indoor positioning systems can help in this matter by enabling real-time visualisation of system states based on a model representation, allowing us to track our resources. This, in turn, facilitates the creation of real-time value stream mapping. It is important to note that the measured position data may be imprecise due to environmental noise. Therefore, it is worthwhile to examine and refine them to maintain accuracy in state estimation. By utilising the toolkit of data science, we can easily uncover activities that deviate from established processes and identify bottlenecks. Furthermore, we can evaluate the real impacts of different changes on the processes by using model-based simulations. Real-time value stream mapping can be used for process control, optimising the processes based on known current states, and predicting potential issues. The proposed methodology was inspired by addressing an industrial challenge, which will be showcased in a demonstrative manner as a case study.

Keywords: Indoor Positioning System, Markov Decision Process, Production control, Logistics process optimisation

8. Introduction

The optimisation of logistics processes and the spread of automation, particularly the use of Automated Guided Vehicles (AGVs), are key elements within the lean philosophy and in the context of Industry 4.0. AGVs efficiently handle material tasks, but their optimal scheduling - task timing are crucial for effective and seamless logistics processes. The Markov Decision Process [1,2,3] (MDP) model serves as a mathematical tool to achieve optimal task scheduling for AGVs [4]. Its components include states, actions, state transitions, and rewards. The use of data from indoor positioning systems (IPS) is becoming increasingly prevalent in industrial practice [5]. This technology plays a crucial role in achieving full traceability by enabling us to define states using precise position information provided by the system. This enables us to accurately track the current position and state of AGVs. Leveraging this information, the MDP model facilitates the optimisation of task execution, predicts potential scheduling problems, and ensures the efficiency of logistics processes [6,7,8]. The research methodology presented focuses on addressing the challenges associated with AGV scheduling. It is inspired by real-world industrial practice. In the following sections, we provide a detailed account of a demonstrative case study describing the application of the MDP model in an industrial setting. This case study illustrates the practical implementation of the MDP model for optimising AGV scheduling and highlights it is importance in improving overall logistics efficiency. Understanding the intricacies of AGV scheduling is critical, especially as logistics processes become more complex and data-intensive. As Industry 4.0 continues to reshape manufacturing landscapes, the MDP model emerges as a valuable asset for ensuring optimal task execution, resource utilisation, and predictive capabilities in logistics environments. In the following sections, we will explore the theoretical foundations of the MDP model, its practical implementation challenges, and the outcomes observed through its application in real-world scenarios. The evolving role of AGVs in the logistics domain highlights the necessity for advanced scheduling mechanisms, and the MDP model emerges as a promising approach to meet these demands.

9. Materials and methods

A Markov Decision Process (MDP) is a mathematical framework used to model decision-making in scenarios where an agent interacts with an environment over a sequence of discrete time steps. The key characteristic of an MDP is the Markov property, which states that the future state of the system depends solely on the current state and the action taken, making the process memoryless. In an MDP, the system comprises states, actions, transition probabilities, and rewards. States represent the potential situations of the system, actions are the decisions that can be made, transition probabilities describe the likelihood of transitioning from one state to another after taking a specific action, and rewards quantify the immediate benefit or cost associated with a state-action pair (see in Figure 1). The IPS plays a crucial role in monitoring the states and state transitions of the MDP, particularly in applications like AGV tracking. IPS provides full traceability, enabling precise and continuous tracking of states. As a result, tracking enables states to be recognised more quickly and efficiently, ensuring their accurate monitoring for process optimisation and improvement.

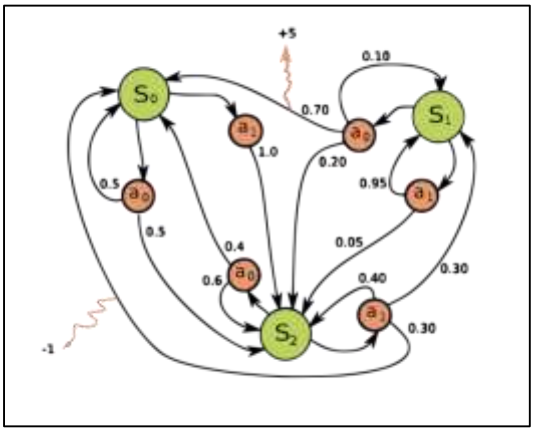

Figure 1. *Example of a simple MDP with three states (green circles) and two actions (orange circles), with two rewards (orange arrows) [Source: Wikipedia]*

MDP is a mathematical framework that encapsulates the decision-making process within a dynamic system. Leveraging reinforcement learning [9] within the MDP framework enables an agent to learn an optimal policy by interacting with the environment, taking into account states, actions, transitions, and rewards. The optimisation process begins with defining the states, actions, and rewards that are relevant to the specific problem domain. States represent the various situations or configurations the system can be in, actions are the decisions that can be taken, and rewards quantify the immediate benefit or cost associated with a state-action pair. Through continuous interaction of the agent with the environment, the reinforcement learning algorithm learns to associate specific actions with maximising cumulative rewards over time. This learning process involves iteratively updating the agent's policy based on observed rewards and experiences. The MDP model enables the reinforcement learning algorithm to make informed decisions by considering the probabilistic transitions between states and the expected rewards associated with each action. The optimisation objective is to converge to an optimal policy that maximises the expected cumulative reward over time. In summary, the MDP model serves as the underlying framework that directs the reinforcement learning algorithm in the optimisation process. It provides a formal representation of the decision-making environment, enabling the algorithm to learn and adapt its policy to achieve optimal outcomes based on the defined states and their associated rewards.

10. Results and discussion

Logistic process optimisation based on the MDP is demonstrated using a real production problem, where micro-logistic tasks are carried out by an AGV. The Figure 2 shows a production line consisting of three automated production cells: welding, molding, and assembly. In the welding production cell, there is an inbound section (*Wi1*) and an outbound section (*Wo1*) where empty boxes are stored, and welding semi-finished parts are retrieved. Similarly, in the molding production cell, there is an input area (*Mi1*) and an output area (*Mo1*) where welded semi-finished products are stored and molded semi-finished products are retrieved. In the assembly production cell, there are two input areas and two output areas where semi-finished molded products are stored (*Ai1*) and finished products are retrieved (*Ao1*). In addition, the assembly cell cannot handle the storage of empty boxes within the production cell. Therefore, the AGV must transfer them from the second output position (*Ao2*) to the second input position (*Ai2*). The empty boxes consist of 10 trays that are universal and suitable for storing semi-finished and finished products in any state. In each production cell, there is a buffer at both the infeed and outfeed, each consisting of a single unit, which in this case corresponds to 10 trays. From a process optimisation perspective, it is crucial to prioritise task assignments to the AGV in order to prevent stoppages in any of the production cells due to the unbalanced production process (where working times in individual automatic production cells vary). In addition, there is a continuous process with a buffer serving as an automated warehouse for storing empty boxes (*Pe*) and semi-finished welding and molding products (*Pw*, *Pm*). Furthermore, there is a packaging area where the finished products (*Pa*) need to be transported. When the AGV is not engaged in a task, it is going back to the charging station and waits in the charging state. If the state of charge (*SOC*) falls below a specified limit, the AGV will initiate movement to the charging station.

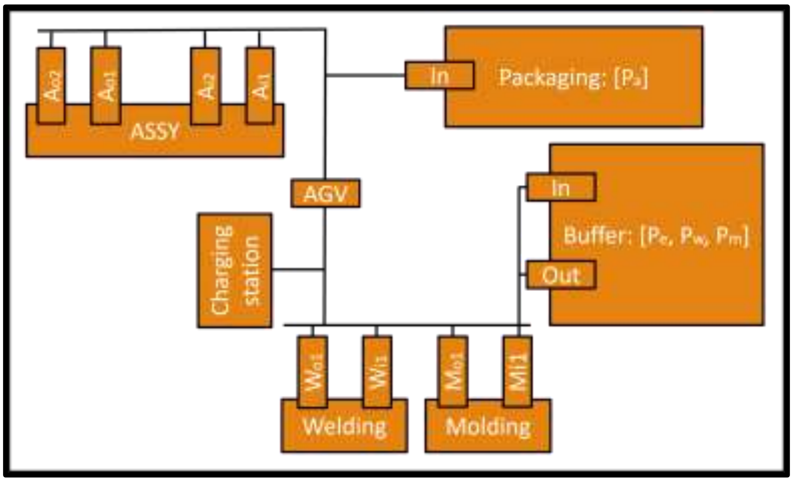

Figure 2. *Schematic of the layout with automatic production cells, filling station, packer and buffer included in the logistics optimisation*

Given our production and logistics processes, we can determine the states of the system, which is essential for the construction of the MDP model. In this case, it is recommended to assess the state of each production cell according to the state of the input and output zones, as these conditions determine whether the production cell will cease operation (due to lack of raw materials or if the storage area is full). It is recommended to refine these states according to the specifics of the current problem. The states for the input and output of each production cell can be defined in a similar manner, as summarised in Table 1 and Table 2.

Table 1. *The states of the automatic production cells based on the availability of the raw material and the completion of the semi-finished or finished product with the corresponding rewards*

State	Description	Reward
0	t = 0; production halted, no raw materials available / picking out zone is not empty	extra negative
1	0 < t <= 10; production stops within 10 minutes	negative
2	10 < t <= takt time; production is in the initial phase	positive
3	takt time < t <= 2 ∗ takt time; production is ongoing, buffer / picking out zone is empty	extra positive

In addition, it is necessary to monitor the buffer inventory, the quantity of manufactured products, and the charge level of the AGVs (see Table 2). These states are necessary to determine the tasks (actions) that can be performed at the moment. For example, if there is no semi-finished welding product in the buffer, the action of taking out the welding semi-finished product from the buffer will not be available. Similarly, if the AGV's battery charge is low, then going to the charging station will be the only selectable action.

Table 2. *The states of other elements*

State	Description
Pa	number of finished product
Pw	number of welding semi-finished product in the buffer
Pm	number of molding semi-finished product in the buffer
Pe	number of empty crates in the buffer
Agv	AGV SOC

Based on these factors, a SV state vector can be formulated to characterise the current state of the system:

$$SV = [W_{i1}, W_{o1}, M_{i1}, M_{o1}, A_{i1}, A_{i2}, A_{o1}, A_{o2}, P_a, P_w\ P_m, P_e, AGV] \quad (1)$$

Based on the $SV(t)$ state vector, we can also determine the $R(t)$ rewards obtained at time instant t based on the Table 1:

$$R(t) = [RW_{i1}, RW_{o1}, RM_{i1}, RM_{o1}, RA_{i1}, RA_{i2}, RA_{o1}, RA_{o2}] \quad (2)$$

Once the states have been identified, it is important to analyse the potential state transitions and how they can be accomplished through various actions. The list of possible actions is given in the Table 3. With the indoor positioning system, we can accurately determine the precise timing of the selected state transition closure. Once the action is completed, we will know the location of the AGV and the tasks it can theoretically perform there. To determine the network of actions, refer to Figure 3.

Table 3. *Actions*

State	Description
AGV_Action_1	Picks up an empty crate from the buffer storage
AGV_Action_2	Picks up a welding semi-finished product from the buffer storage
AGV_Action_3	Picks up a molding semi-finished product from the buffer storage
AGV_Action_4	Picks up a welding semi-finished product from the welding machine
AGV_Action_5	Picks up a molding semi-finished product from the molding machine
AGV_Action_6	Picks up an empty crate from the assembly machine
AGV_Action_7	Picks up a finished product from the assembly machine
AGV_Action_8	The AGV stands empty, ready for loading
AGV_Action_9	Stores an empty crate in the buffer storage
AGV_Action_10	Stores a welding semi-finished product in the buffer storage
AGV_Action_11	Stores a molding semi-finished product in the buffer storage
AGV_Action_12	Stores an empty crate in the welding machine
AGV_Action_13	Stores a welding semi-finished product in the molding machine
AGV_Action_14	Stores an empty crate in the assembly machine
AGV_Action_15	Stores a molding semi-finished product in the assembly machine
AGV_Action_16	Stores a finished product in the packaging station

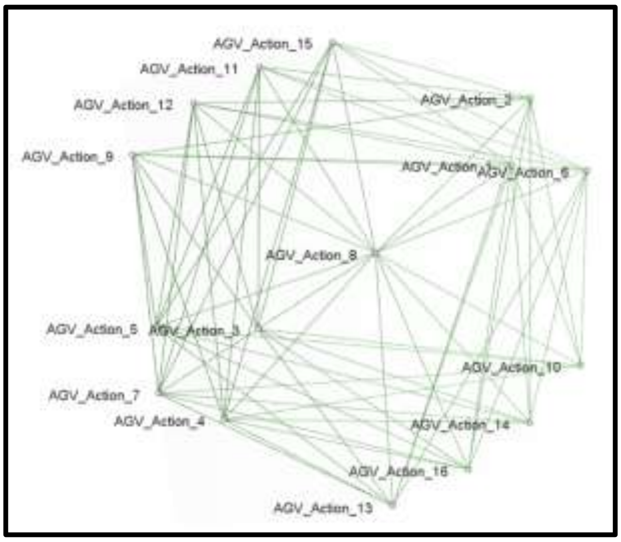

Figure 3. *Actions connection diagram, which shows which action can theoretically be performed after a given action has been performed*

In the realm of optimisation, a deep understanding of the system's states, their associated rewards, and the potential actions that lead to state transitions is crucial. This fundamental knowledge enables the formulation of a state vector that represents the system at a specific time *t*, along with its corresponding reward. This is a crucial aspect in characterising the system's dynamics. The intersection of feasible actions for AGVs based on particular states defines a set of choices in a given scenario (see in Figure 4).

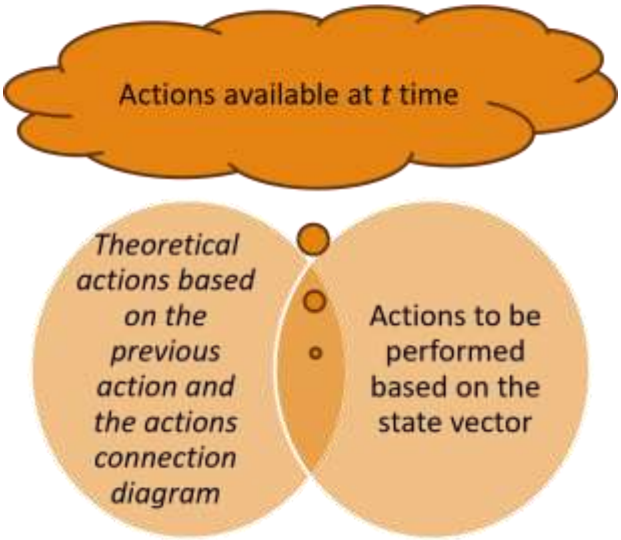

Figure 4. *Determination of the actions available at time t*

The selected action initiates a transition to a new state vector, enabling the recalculation of the system's state and reward. This process lies at the core of the reinforcement learning model within the MDP framework. Through iterative decision-making, reward observation, and policy updates, the reinforcement learning model systematically navigates through various scenarios. The ultimate objective is to converge on an optimal policy that maximises the cumulative rewards over successive time steps. In addition, the integration of real-time indoor positioning data enhances this optimisation paradigm. By accurately tracking the AGV, state transitions become predictable, enabling prompt decision-making based on preexisting information. This functionality is particularly beneficial in optimisation processes as it enables more efficient resource allocation and precise scheduling. As part of full traceability, this data enables continuous monitoring of production processes, allowing for dynamic adjustments and improvements in response to evolving conditions. The adaptability of the model, which is based on the MDP structure, enables it to optimize tasks according to specific criteria, such as distance metrics. The synergistic interplay between the MDP model and reinforcement learning shows promise for addressing complex optimisation challenges. It establishes a framework in which intelligent decision-making, guided by acquired experience, contributes to the continuous improvement and efficiency of logistics and manufacturing processes. In summary, the fusion of the MDP model and reinforcement learning not only provides a theoretical foundation for decision-making but also offers practical insights into real-time optimisation, emphasising adaptability and continuous improvement in dynamic environments.

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11. Conclusions

During the optimization process, the combined application of the MDP model and reinforcement learning algorithm provides an effective framework for improving logistics and manufacturing processes. A comprehensive comprehension of system states and rewards enables modeling, which in turn allows for the maximisation of cumulative rewards over time by optimizing AGV operations. The symbiotic relationship between MDP and reinforcement learning enables dynamic decision-making to adapt to variable conditions. Integration of real-time indoor positioning data enables continuous monitoring of processes and optimal task selection based on criteria such as distance. The combination of these methodologies not only offers theoretical benefits but also leads to practical, achievable intelligent decision-making in the areas of logistics efficiency and manufacturing processes.

ACKNOWLEDGMENTS

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BLENDING HYDROGEN INTO NATURAL GAS; TECHNICAL AND OPERATIONAL CHALENGES

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Abstract

Blending hydrogen into existing natural gas pipeline networks has gained increased attention as a potential pathway to facilitate the integration and transport of renewable hydrogen at scale. By leveraging the substantial gas network infrastructure already in place, hydrogen blending could help decarbonize end uses currently dependent on natural gas while avoiding the high costs of dedicated hydrogen pipelines. However, integrating even small volumes of hydrogen introduces complex changes to the transport properties and thermodynamic behavior of the blended gases.

This paper presents a review of the literature on technical challenges arising from hydrogen blending into natural gas systems. The impact of hydrogen addition on key gas properties like viscosity, density, compressibility and heating value is examined. Consideration is also given to implications for pipeline material integrity, compression requirements, measurement systems and leak detection. The results indicate that while blending offers opportunities to advance low-carbon energy goals, fundamental alterations occur to fluid dynamics and gas characteristics. Addressing issues around component compatibility, flow assurance, safety and performance will be crucial to accommodating higher hydrogen ratios.

Opportunities and barriers involved with leveraging existing infrastructure are discussed based on analyses from past blending projects and laboratory studies. Knowledge gaps around long-term material effects, field-scale demonstrations and economic viability are also identified. The review aims to provide insight into technical feasibility considerations for hydrogen blending as a means of integrating renewable gas while utilizing pipeline networks.

Keywords: hydrogen blending; natural gas properties; gas measurement; volume conversion; gas meters; gas chromatographs

1. Introduction

Hydrogen's versatility in energy applications has led to global exploration of blending it into existing natural gas pipelines, offering benefits such as carbon footprint reduction (Ruth et al. 2020). However, challenges emerge with this approach (Melaina, Antonia, and Penev 2013).

Blending hydrogen from low-carbon sources into natural gas infrastructure can cut the carbon footprint, offering benefits in energy penetration, cost reduction, and emissions reduction (Topolski et al. 2022; Melaina, Antonia, and Penev 2013). Despite advantages, concerns arise regarding compatibility and safety risks (Gondal 2019). Hydrogen's distinct properties necessitate a careful assessment based on the most limiting pipeline component (Diez et al. 2020).

Transporting hydrogen in pipelines, whether blended or pure, presents challenges, impacting pipeline materials and regulatory compliance (Canadian Energy Research Institute, 2021; GPA Engineering 2019). This review aims to outline technical challenges, considering varying perspectives on blending hydrogen. It emphasizes network-specific assessments, analyzing past blending demonstrations and effects on gas properties, thermodynamics, measurement

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systems, and pipeline materials. The paper guides future research by highlighting opportunities and obstacles in integrating hydrogen into existing natural gas systems, addressing transportation considerations, material susceptibility, and safety concerns. Ultimately, the goal of hydrogen blending is to mitigate greenhouse gas emissions.

2. Literature Review

2.1 Impact on gas Transport Properties

The integration of hydrogen into natural gas has profound effects on fluid properties, influencing energy transmission dynamics. This section explores these changes, encompassing viscosity, density, calorific value, and critical properties.

2.1.1 Viscosity

Viscosity, crucial for assessing pressure losses in pipelines, undergoes changes with the introduction of hydrogen. Diez et al. (2020) observed a minor reduction in dynamic viscosity in natural gas-hydrogen blends. This decrease influences flow dynamics, impacting heat transfer, flow patterns, and turbulence (Heidaryan et al. 2013). Viscosity's importance lies in its role in transportation assessments, where accurate predictions depend on factors like the Reynolds number, influenced by fluid viscosity (Heidaryan et al. 2013).

Figure 1 depicts the outcomes of a study by Abd et al. (2019) on the variation in viscosity with varying hydrogen concentrations at constant temperature and pressure. From Figure 1 the highest natural gas viscosity records at 0.2% hydrogen with 0.7% deviation from the viscosity of the typical natural gas while the lowest viscosity is at 10% hydrogen content with 1.353% deviation. To the end, high viscosity leads to higher losses in pressure, therefore, the hydrogen with concertation lower than 2% has a negative effect on the natural gas flow assurance.

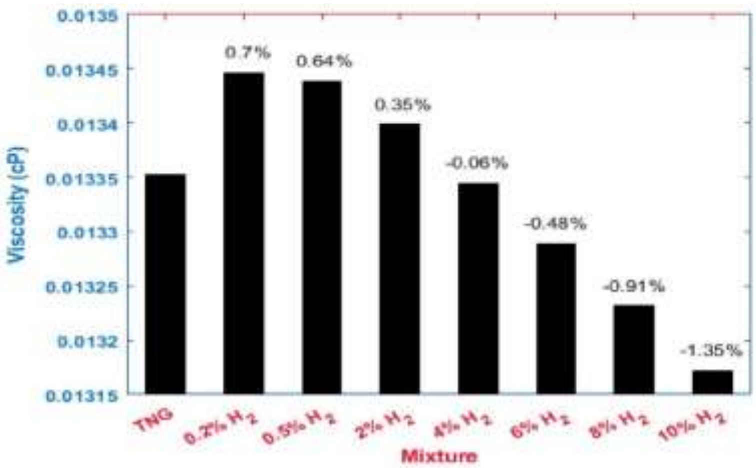

Figure 4 *Variation in Viscosity with Different Hydrogen Concentrations as per Abd et al. (2019) Study.*

2.1.2 Density

Hydrogen's incorporation reduces the density of the gas mixture due to its lower molecular weight. This has implications for pipeline flow behavior, gas flow rates, and pressure drop considerations. Gas density, influenced by temperature and pressure changes, is crucial for design, optimization, and transmission assessments. Abd et al.'s (2019) study illustrates density reduction with increasing hydrogen content, impacting flow assurance. Figure 2 visually represents the density variations.

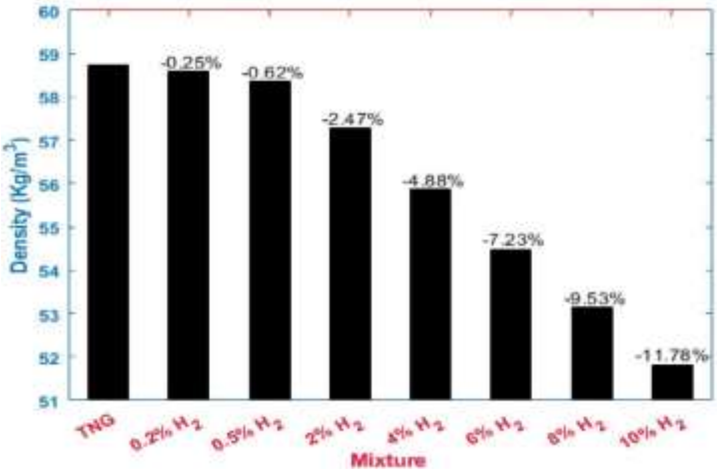

Figure 5 *The impact of hydrogen content on the mixture density (Abd et al 2019).*

2.1.3 Calorific Value

The introduction of hydrogen results in a decline in the calorific value of the gas mixture due to hydrogen's lower energy content compared to methane. This reduction affects heating capacity, combustion behavior, and energy yield upon combustion. The impact on gas flow rates, compressor power, and energy consumption per compression stage is significant. Studies, such as those by Witkowski et al. (2018) and Quintino et al. (2021), highlight the lower energy delivered through pipelines when transporting hydrogen or hydrogen-methane blends compared to natural gas alone. Gondal's (2019) case study in Sui Northern Gas Pipelines Ltd (SNGPL) further emphasizes the need for comprehensive simulation studies to establish efficient hydrogen-dependent energy systems.

2.1.4 Critical Properties and phase envelop

The technical implications of blending hydrogen extend to thermophysical properties, phase equilibrium, and pressure-temperature conditions throughout the gas network. Abd et al. (2019) demonstrated that hydrogen content modifies critical properties and the phase envelope of natural gas mixtures (see Figure 3).

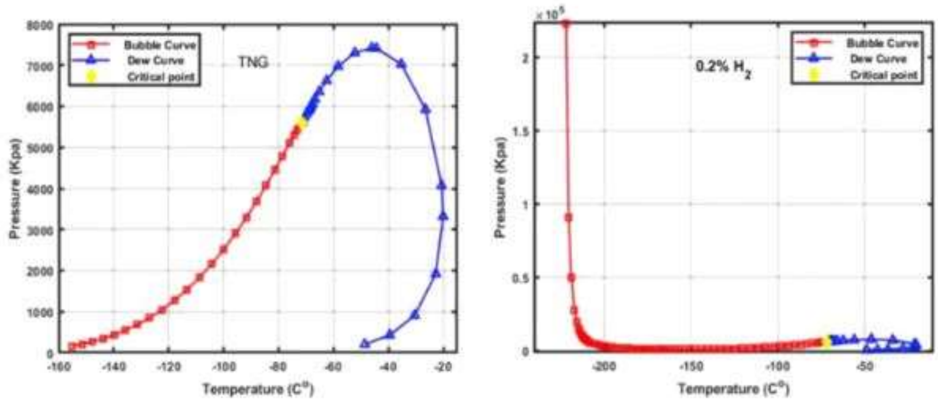

Figure 6 *Phase diagram of the typical natural gas mixture and the hydrogen at various concentration (Abd et al. 2020)*

Even low hydrogen concentrations significantly alter the phase envelope, impacting flow behavior, pipeline design, and operational parameters. Investigations reveal hydrogen's effects on flow dynamics, pressure distribution, and heat transfer within pipelines. Hydrogen's introduction alters thermophysical properties, influencing critical pressures and temperatures, flow behavior, pressure drop characteristics, and temperature distribution across the network (see Figure 4). These complex implications require careful consideration for the safe and efficient transmission of natural gas-hydrogen mixtures.

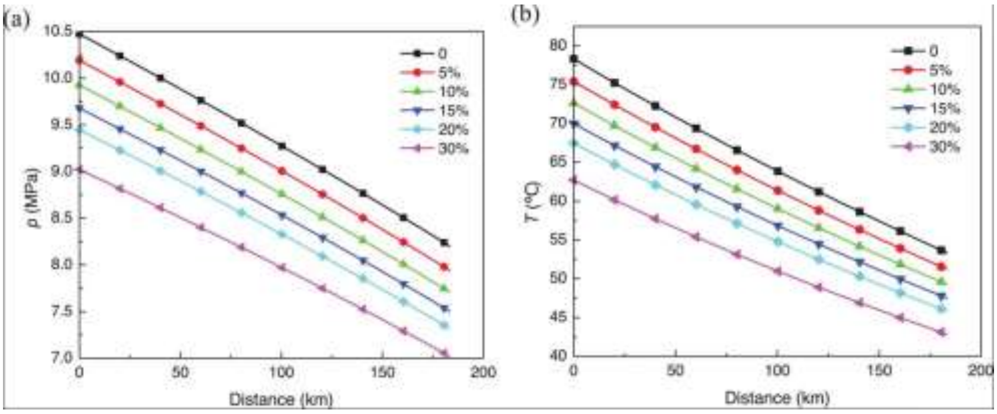

***Figure 7** Pressure and temperature drop for joint operation of pipeline and compressor at 15 °C. (a) pressure drop; (b) temperature drop (Zhang et al. 2021).*

2.1.5 Other Transport Properties

Velocity of Sound: The addition of hydrogen leads to an escalation in the velocity of sound within the gas blend due to hydrogen's unique molecular properties (Dell'Isola et al. 2021). This acceleration is significant for acoustic phenomena, compression wave propagation, and sonic velocities within pipelines and equipment. Abbas et al. (2021) illustrated in Figure 5 that pressure losses and subsequent density reduction result in increased velocity, surpassing the erosional velocity limit for hydrogen contents greater or equal to 60% in the blend.

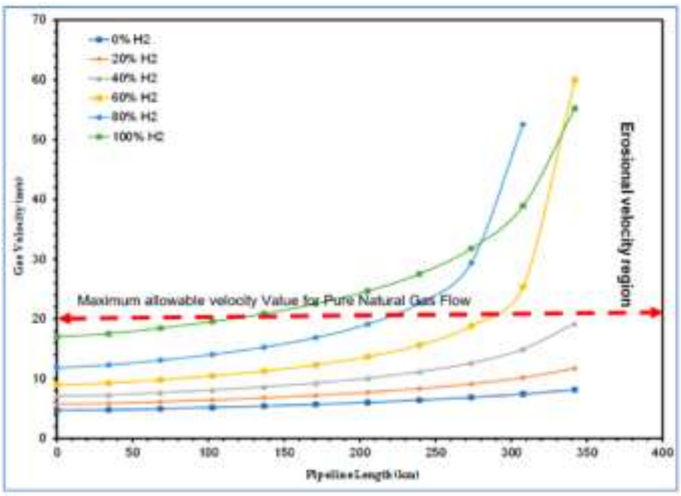

***Figure 8** Velocity profile for gas pipeline flow of hydrogen blends (60 bar, 303.15 K) (Abbas et al 2021)*

Reynolds Number: The dimensionless Reynolds number, representing the fluid flow regime, undergoes a reduction as hydrogen integrates into the gas mixture (Chaczykowski et al. 2017). This reduction is attributed to hydrogen's low viscosity and density, influencing the transition from laminar to turbulent flow regimes. These changes impact heat transfer dynamics and pressure drop characteristics.

2.2 Implications for pipeline infrastructure Compressibility, Energy Transmission, and Compression Technology

The introduction of hydrogen into natural gas pipelines has significant implications for pipeline infrastructure, impacting compressibility, energy transmission capacity, and compression technology selection.

2.2.1 Compressibility Factor, Energy Transmission, and Pressure Drop

Compressibility Factor and Algorithms:

Hydrogen injection influences the compressibility factor (Z), vital for volume conversion at standard conditions. Łach et al. (2016) and Dell'Isola et al. (2021) studied Z with varying hydrogen content, emphasizing the influence of pressure and calculation algorithms. Kuczynski et al. (2019) illustrated Z changes as a function of hydrogen content and pipeline length (see Figure 6).

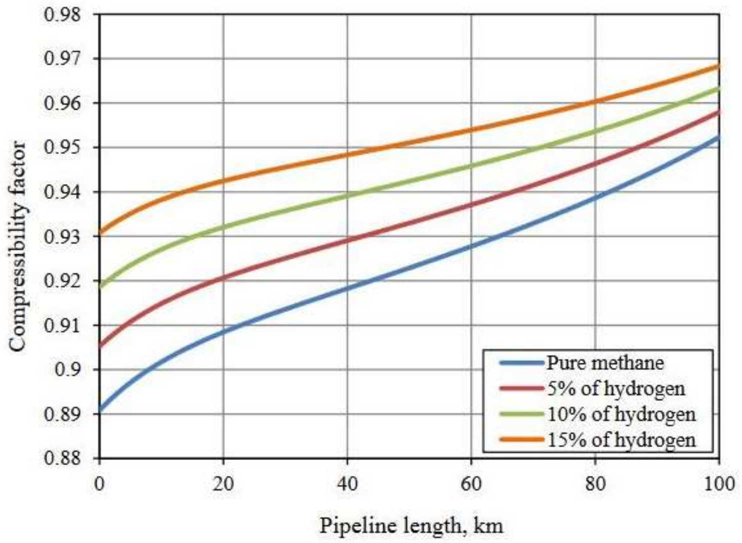

Figure 9 *Compressibility factor changes as a function of hydrogen content and pipeline length (Kuczynski et al 2019)*

<u>Energy Transmission Capacity:</u>

Despite natural gas being denser than hydrogen, at a fixed pressure drop, the energy transmission capacity at 100% hydrogen concentration is only 15%–20% lower than pure natural gas (Bainier and Kurz 2019). Higher hydrogen blend ratios result in increased flow velocity, potentially necessitating raised pipeline operating pressures.

<u>Pipeline Pressure Drop:</u>

Hydrogen's impact on pipeline pressure drop depends on blending compositions. With a constant volumetric flow rate, increasing hydrogen content reduces pressure drop due to lower mixture density and higher compressibility factor (Blacharski et al. 2016; Witkowski et al. 2018). However, for a constant energy flow rate, pressure drop initially increases,

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peaking at 70%–85% hydrogen, before decreasing (Allison et al. 2021). These findings underscore the importance of considering both pressure drop and energy flow rate.

2.2.2 Compression Technology Selection

Centrifugal Compressors: Centrifugal compressors, crucial in the energy sector, face challenges with hydrogen due to its low density and molecular weight. Existing natural gas compressors are considered unsuitable for hydrogen transport due to the associated risks of hydrogen embrittlement. Ongoing efforts are directed toward adapting centrifugal compressors to meet the demands of hydrogen transport, focusing on material compatibility, operational adjustments, and lubricant concerns (Di Bella 2015). These adaptations are crucial as the industry seeks reliable and efficient solutions for large-scale hydrogen transport (Castello et al. 2005; Altfeld and Pinchbeck 2013).

Reciprocating Compressors: Reciprocating piston compressors, well-established for hydrogen compression, offer flexibility in handling gases with varying molecular weights. Non-lubricated versions are preferred for high-purity applications, preventing oil contamination in hydrogen intended for end-use, such as fuel cells. While reciprocating compressors demonstrate effectiveness, concerns arise regarding maintenance costs, particularly with components like valves, rider bands, and piston rings that undergo wear over time (Witkowski et al. 2017). Expertise in piston sealing and packing rings can mitigate these concerns, ensuring that reciprocating compressors outperform other technologies in terms of operational expenses.

When considering the adaptation of reciprocating compressors for hydrogen service, a thorough analysis is essential. This analysis should encompass material compatibility, performance impact, adjustments to the operational envelope, concerns related to lubricant contamination, and issues related to seals. Although specific studies on hydrogen tolerance for reciprocating compressors are limited, concentrations up to 10%vol have been deemed non-critical (Altfeld and Pinchbeck 2013). As the industry aims to accommodate higher hydrogen concentrations and purity levels, optimizing and adapting reciprocating compressors for hydrogen becomes a critical aspect of ensuring efficient hydrogen compression.

2.3 Effect on Gas measurement systems

2.3.1 Impact on flow meters

The introduction of hydrogen into natural gas mixtures brings substantial changes in properties, impacting measurement accuracy and system compatibility. While hydrogen content up to 5-15% poses minimal issues, uncertainties rise at higher concentrations, necessitating further research (Stetsenko et al. 2020, Müller et al. 2013, Iskov et al. 2006, Dehaeseleer et al. 2018). Dell'Isola et al. (2021) found significant alterations in specific gravity, calorific value, and speed of sound with hydrogen blending up to 25%. These changes pose challenges for inferential flow meters like orifice plates, commonly used in gas transportation, affecting billing accuracy with rising hydrogen concentrations (Diez et al. 2020).

Evaluation of Meter Types: Three main meter types (turbine, ultrasonic, and Coriolis flow meters) were assessed for hydrogen service. Turbine flow meters have limitations in gas velocities and minimum flow requirements, with most manufacturers specifying compatibility up to 10% H_2 (Diez et al. 2020). Ultrasonic flow meters face limitations in flow rates and uncertainties with higher H2 concentrations, with ongoing technology development aiming to enable measurement up to 10% H2 (Diez et al. 2020). Coriolis meters, while fully compatible with 100% H2 flow, face challenges with lower densities and erosion risk (Diez et al. 2020). PA Consulting's 2020 study investigated the applicability of various gas metering systems for hydrogen-natural gas blends, encapsulated in Tables 2 and 3 (European Commission 2020).

Technology Suitability: Different gas metering technologies vary in suitability for measuring blended hydrogen-natural gas streams. Factors like whether they directly measure mass flow or require known gas properties for accurate volumetric flow measurement influence their applicability. Mass flow meters like ultrasonic, thermal mass, and Coriolis may compensate for variations in gas blend composition. The operating principles, such as moving parts in diaphragm and rotary meters, may be less suited for high-pressure hydrogen applications. Meter placement considerations also impact suitability, with orifice plates better for large pipelines than distribution systems. No single technology is clearly superior, and suitability depends on specific application parameters like flow rates, pressures, and temperatures.

In summary, hydrogen blending introduces challenges to existing metering systems, limiting compatibility to around 10% H2. Ongoing technology advances aim to address these limitations, but further research is needed to validate performance for blended gas streams and realize the full potential of hydrogen in natural gas grids.

Table 1
Comparison of meter types

Technology	Typical Application	Pros	Challenges
Diaphragm	Residential / Commercial NG Metering	Incumbent technology for domestic / commercial metering ofNG. Low cost, reliable, widely available	Measures volumetric flow: gas composition, temperature and pressure need to be known for accurate metering. Moving parts (mechanical actuation), with wear over time. Not suitable forhigh pressures.
Rotary	Commercial / Industrial NG Metering	Mature technology, low cost, reliable, widely available	Measures volumetric flow: gas composition, temperature and pressure need to be known for accurate metering. Moving parts (mechanical actuation)
Turbine	Industrial, Utilities(water monitoring)	Mature technology, low cost, widely used	Flow rate can be calculated using k-factor for known fluid; gas composition, temperature and pressure needs to be known for accurate metering. Moving parts (mechanical actuation).
Ultrasonic	Industrial / Hydrogen custody transfer Domestic natural gas	Non-contact measurement: Suitable for low temperature / high pressures (liquid hydrogen / corrosives e.g. ammonia). Directly measures mass-flow, additional diagnostic information can be used to infer changes in fluid density (potential to compensate for variations in blend). Cangive detailed diagnostic information (pipe condition, flow conditions, fluid density). No moving parts	Flow rate needs to be computed from acoustic information (introduces complexity and cost)

Thermal mass	Industrial, Precision metering (labs)	Directly measures mass flow (not volumetric). High accuracy,no moving parts	Gas composition needs to be known for accurate metering (will not compensate for variations in gas blend). Not suitable for very high pressures or larger pipework. Flow rate needs to be computed from thermal information (adds complexity and cost)
Coriolis	Hydrogen refuelling	Non-contact sensor: Suitable for very low temperature / very high pressures (liquid hydrogen / corrosives e.g. ammonia). Directly measures both mass-flow and fluid density (potential to compensate for variations in blend). Highaccuracy. Gaining wide acceptance for FCEV refuelling	Relatively new technology. Flow rate needs to be computed from vibrational information (introduces complexity and cost). Cheaper alternatives to Coriolis available for large-portfolio applications, such as residential
Differential Pressure (Orifice Plate)	Petrol / Diesel Re- fuelling, Industrial & Petro-chemical, Watertreatment plants	Mature technology, simple, low maintenance, low-cost	Gas composition needs to be known / well blended for accuratemetering (will not compensate for variations in gas blend). Relatively stable flow required. Low rangeability. Significant loss in fluid pressure may occur whilsttransiting the meter

Table 2

Consideration of meter suitability for use cases

Use case (Hydrogen as a replacementfuel)	Fuel type	Meter technology							Commentary
		Diaphragm	Rotary	Turbine	Ultrasonic	Thermal Mass	Coriolis	Orifice	
Domestic	Legacy	(green)	(red)	(red)	(green)	(green)	(red)	(red)	The diaphragm and rotary meters work mechanically and activate the counter directly making them easy to use and not requiring further interpretation. They willlikely be fine with hydrogen blends up to 20%. And rotary beyond that.
	Hydrogen	(amber)	(red)	(red)	(green)	(green)	(red)	(red)	
Industrial	Legacy	(green)	(green)	(green)	(green)	(amber)	(amber)	(green)	Industrial settings typically operate at higher volumes and pressure. So, while themeters above can still perform, turbines, ultrasonic (good diagnostic data) and orifice meters currently perform well and are expected to be a good option for hydrogen.
	Hydrogen	(red)	(amber)	(green)	(green)	(amber)	(amber)	(green)	
Transport	Legacy	(green)	(red)	(amber)	(red)	(red)	(amber)	(red)	Coriolis and diaphragm meters are well known and accepted for flow metering ofhydrocarbons in a transport setting. Coriolis meters are being increasingly used for hydrogen refuelling, having good rangeability and the ability to work under the350 and 700 bar pressures currently being used.
	Hydrogen	(red)	(red)	(amber)	(green)	(amber)	(green)	(red)	

Key
Recommended
Potentially suitable / less cost-effective
Poor suitability

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2.3.2 Impact on gas quality measurements

Gas quality measurement of H_2NG mixtures presents challenges due to the limitations of conventional process chromatographs designed for natural gas analysis. The use of helium as a carrier gas in process chromatographs impedes the detection of hydrogen due to their similar thermal conductivities (151 and 180 Wm−1K−1 for helium and hydrogen, respectively, (Inficon 2021)). To address this, alternative devices dedicated to other gaseous fuels or constructed based on specific guidelines are necessary. One such solution involves a four-channel chromatograph equipped with thermal conductivity detectors (TCD) that utilize argon and helium as carrier gases. This chromatograph can determine components in natural gas-hydrogen mixtures, including hydrogen content up to 37% mol / mol, with an analysis cycle duration of 3 to 5 minutes (Inficon 202). Another approach in the refinery sector employs three-channel analyzers with TCD and a flame ionization detector (FID) to determine hydrogen content and other basic components in natural gas-hydrogen mixtures up to 100%. This analysis takes around 15 minutes but requires additional technical gases, increasing operational costs (perkinelmer 2021a, perkinelmer 2021b). Although hydrogen's explosive nature restricts its use as a carrier gas in gas chromatography, chromatographs with TCD detectors using hydrogen as a carrier gas can reduce analysis time to 7.5 minutes (perkinelmer 2021a, perkinelmer 2021b). Furthermore, single and double-channel chromatographs with TCD are available, facilitating analysis of components such as pseudo-component C6+, hydrogen, helium, oxygen, and more (thermofisher 2021a, thermofisher 2021b). Another chromatograph dedicated to natural gas analyses offers a wide range of determinable components, including hydrogen content up to 10%, with analysis times ranging from 10 to 40 minutes (agilent 2021). While chromatographs designed for refinery gas analysis possess a broad analytical range for hydrogen determination, they are unsuitable for certain H_2NG mixtures due to limitations in methane analysis. Consequently, the choice of appropriate chromatographs depends on the specific application, with considerations for the hydrogen concentration and the mix of gases involved (inficon 2021).

3. Enabling hydrogen blending: key recommendations and strategies

The following are some additional suggestions from The California Public Utilities Commission FINAL REPORT (Raju and Martinez-Morales 2022):

1. **Address Specific Leak Mechanisms**: In-depth research is needed to understand and predict leak flow rates with varying hydrogen concentrations through joints, threads, cracks, and pinhole defects.
2. **Study Hydrogen Diffusion and Embrittlement**: Investigate hydrogen diffusion and embrittlement processes in metals, alloys, and materials used in the natural gas infrastructure.
3. **Examine Elastomers**: Assess elastomers under real operational conditions to evaluate long-term performance and devise appropriate management strategies.
4. **Evaluate Polyethylene Pipes**: Investigate the impact of hydrogen on polyethylene pipes to guide the revision of performance standards.
5. **Research Metallic Pipes and Components**: Examine metallic pipes and components under varying hydrogen concentrations to determine safe operating pressures and factors of safety.

6. **Electrochemical Charging Study**: Conduct an in-depth electrochemical charging study to develop an alternative, more effective method to pressurized gaseous hydrogen charging.
7. **Gaseous vs. Electrochemical Charging**: Establish a relationship between gaseous and electrochemical charging to improve simulation accuracy with different hydrogen blend concentrations.
8. **Uniform Blending Technologies**: Evaluate blending technologies and strategies to ensure uniform gas compositions throughout the system.
9. **Strategies and Technologies Assessment**: Assess strategies and technologies such as coatings for mitigating hydrogen diffusion and propane blending to meet Wobbe index requirements.
10. **Case-by-Case Studies**: Conduct comprehensive studies of key components, equipment, and facilities to identify suitable blend percentages that ensure operational safety, network durability, and appliance integrity.
11. **Safety and Dispersion Studies**: Investigate leak detection, odorization, gas build-up, dispersion dynamics, and safety zones to account for changes in flammability, ignition, and explosivity due to varying hydrogen blending percentages.
12. **Mitigation Strategies**: Develop strategies to mitigate or avoid known hydrogen impacts, including addressing underground storage facilities and end-use equipment with specific restrictions.
13. **Accelerating Hydrogen Use**: Explore strategies to accelerate hydrogen use and blending into the natural gas infrastructure, including above-ground storage, distributed production, and integration with the electric grid.
14. **Procedural Updates**: Update existing inspection, leak detection, maintenance, and repair procedures to address potential risk factors associated with hydrogen's broader flammability range, low ignition energy, and high flame velocity.
15. **Gas Compression and Metering**: Evaluate impacts on gas compression, quality, and metering accuracy using experimental and modeling analysis, considering relevant international standards.
16. **Demonstration of Hydrogen Blending**: Recommend conducting real-world demonstrations of hydrogen blending, ranging from 5% to 20%, in a representative section of the infrastructure to assess the effects of various parameters.
17. **Laboratory Research**: Conduct laboratory-scale research to address critical technological and scientific issues, focusing on higher hydrogen blend percentages.
18. **Proposed Timeline**: Propose a three-year timeline for completing these activities and adopting a hydrogen blending standard.

4. Conclusion

This literature review explores the complexities and challenges associated with blending hydrogen into natural gas pipelines, highlighting potential benefits and technical intricacies. The integration offers advantages such as utilizing existing infrastructure and incorporating low-carbon energy sources, but careful consideration is necessary due to the alterations in transport properties.

Hydrogen blending significantly affects flow dynamics, pressure losses, and heat transfer rates in pipelines (Diez et al., 2020; Abd et al., 2019), requiring operational and infrastructural adjustments, especially in compression equipment. The impact on measurement systems and leak detection technologies necessitates innovation to ensure accurate metering and safe pipeline monitoring (Ozturk, 2021).

Studies indicate varying pressure drop trends and modifications in compression requirements at higher blend levels (Witkowski et al., 2018; Allison et al., 2021), posing challenges for centrifugal compressors in natural gas transmission. The review underscores how hydrogen blending alters the thermophysical properties of natural gas, affecting combustion, pipeline design, and end-use characteristics.

The review concludes that integrating hydrogen into natural gas pipelines poses technical challenges, particularly in accurate gas measurement and control infrastructure. Existing instrumentation may not be inherently suitable for blended gas compositions. Flow metering technologies and gas chromatography systems need further research and modifications for accuracy at varying hydrogen concentrations (Melaina et al., 2013; GPA Engineering, 2019), highlighting complexities in calibration ranges, mass flow calculations, and sensitivity upgrades.

Hydrogen blending impacts critical aspects like pipeline pressure drop, flow rates, energy transmission capacity, and compression requirements. Material compatibility issues and infrastructure modifications add to the complexity. Despite challenges, blending hydrogen offers opportunities for renewable hydrogen transportation and decarbonization, emphasizing the need for careful analysis, regional considerations, and ongoing research.

Collaboration among industry stakeholders, academia, and policymakers is crucial to overcoming challenges and unlocking the full potential of blending within existing gas infrastructure. Comprehensive testing and continued progress are imperative for evaluating compression requirements, ensuring safety, and assessing economic feasibility at different hydrogen concentrations, contributing to successful low-carbon energy transitions.

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THE CONTROL AND DATA ACQUISITION SYSTEM OF A CONTINUOUS GASIFICATION EXPERIMENTAL TECHNOLOGY

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Abstract

The growing demand for energy relies largely on the use of fossil fuels today. To reduce this, the use of Clean Coal Technologies (CCT) is a solution that focuses on gasification. A gasification system developed at the University of Miskolc was a single-charge gasification system that was not suitable for continuous experiments. The continuous operation of the gasification system required the implementation of several control tasks. The storage of relevant measurement data from sensors and operating units is a fundamental task for processing and analyzing experimental results. Data archiving has been implemented by various data acquisition solutions in the control system, which have different advantages and operating conditions. This paper presents the main components and archiving technologies of the control- and data acquisition system in the built gasification experimental equipment.

Keywords: *gasification, pyrolysis, automation, data acquisition, PLC*

List of Abbreviations

CCT – Clean Coal Technologies
CSV – Comma-Separated Values
FTP – File Transfer Protocol
HMI – Human Machine Interface
I/O – Input/Output
IPS – In-Plane Switching
PLC – Programmable Logic Controller
RDF – Refuse Derived Fuel
RTU – Remote Terminal Unit
SCADA – Supervisory Control and Data Acquisition
TCP – Transmission Control Protocol
UDP – User Datagram Protocol

1. Introduction

Based on a survey by the International Energy Agency, energy demand shows an increasing trend these days. CO_2 emissions in 2018 reached 33.1 Gt, which represents an increase of 1.7% compared to the previous year, which is caused by the rapid increase of energy demand in developed and developing countries [1]. Although the world is increasingly striving to use renewable energy sources, it still largely relies on the use of fossil fuels to meet its energy demands. To reduce this, one of the solutions is the application of Clean Coal Technologies (CCT) [2]. A central element of this is gasification [3].

Gasification is a thermal decomposition process carried out in an oxygen-poor environment, during which the starting material (coal, biomass, municipal waste, including RDF, etc.) is converted into synthesis gas, achieving the highest possible calorific value and the gas composition required by the technology [4 – 6]. Most of the research that investigates this process are only performed in mg or g-scale experiments in small lab-scale systems.

The gasification system used previously in this research was a single-charge gasification system, which provided significant progress in the size increase, but could not be applied in continuous experiments. At the same time, for increasing the technology to an industrial scale, it is necessary to develop an experimental system that is suitable for conducting experiments in conditions similar to the industrial environment. The article presents the development of the control- and data acquisition system of the continuous gasification experimental technology built at the University of Miskolc.

2. The Gasification Experimental Technology

The gasification equipment has a multi-stage design, as opposed to the commonly used single stage, as this allows for better control of the processes in the system. Gasification also takes place in several stages. In the first step, the material is heated in an oxygen-poor environment (pyrolysis), during which moisture is first removed from the material, followed by volatiles (longer chain hydrocarbons). This is followed by the gasification process, during which a gasifying medium of oxygen, air, water vapor or combinations thereof is introduced into the system, which reacts with the carbon in the material to be gasified. The gasification technology is shown in Figure 1.

Figure 1 *The experimental gasification technology*

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If the temperature and the mass flow of the material are controlled separately in these steps, the composition of the produced synthesis gas can be significantly influenced with a suitable composition for further use [7, 8]. A two-stage gasifier was designed for this purpose, with the requirement for special control over the mass flow. This is solved by 4 motors in the system, which rotate the material moving screws, based on a pre-set recipe. The synthesis gas leaving the system passes through a heat exchanger then a Venturi scrubber. In the system, it is essential to continuously monitor the amount of gas produced and the amount of tar and water condensed in the washer.

The composition of the exiting synthesis gas is measured by a gas analyser, the data of which must be recorded simultaneously with all other data (pressure, temperature, mass flow) from the system. Recording these parameters and regulating the gasification system is the responsibility of the control and data acquisition system presented in this article.

3. The Control System

The main control tasks of the experimental technology are performed by a Programmable Logic Controller (PLC). A PLC is a special-purpose industrial computer designed to control various machines and equipment. They are available in different mechanical designs, micro, compact and modular versions [9]. The modular configuration contains separate modules that can be divided into slots, which increases the flexibility of the unit [10].

3.1. Structure of the Control System

The central element of the gasifier's control system is a modular PLC manufactured by WAGO. The controller has a built-in web server, which enables configuration via the web (e.g., network and cloud settings, software installations) and the running of web visualizations according to the HTML5 standard. The advantage of web display is that the visualization can be accessed on any device that can run a browser, it is not necessary to purchase expensive industrial HMI panels. One disadvantage of web-based visualizations compared to local industrial HMI panels is the potential for slower response times and delays in data updates. This is due to the processing power of the server hosting the web application. Industrial HMI panels are often viewed as more secure from a security perspective, since they do not have direct network accessibility like web-based visualizations. The controller supports several communication technologies, it has two configurable Ethernet ports and one serial port. With these, the PLC can implement data communication according to various Modbus protocols (TCP/UDP/RTU) and RS-232/485 serial standards.

The condition for automated operation is the continuous measurement of quantities characterizing the state of the system. Based on these, the necessary interventions can be carried out. Accordingly, the technology contains several sensor and intervention units whose signals are received, and control signals are provided by the communication- and Input/Output (I/O) modules of the PLC system. Digital I/O modules work with 24 V voltage signal as usual in PLC systems, and analogue I/O modules work with various standard signals common in the industry (e.g., 0-10 V, 4-20 mA).

A digital input module receives status feedback of the valves, the temperature-dependent stop signals of the four material handling motors, as well as the pulses of the gas flow and consumption meter. Digital output modules are required to control material handling motors, valves, furnaces, and pumps. Thermocouples, level sensors and pressure transmitters are connected to analogue input modules. The frequency converters controlling the material handling motors and the control signals of the stepper motor are provided by analogue output modules. The configuration also includes an RS-

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232/485 communication module, which connects seven temperature controllers to the control system, communicating via RS-485 interface.

Monitoring of the technology and intervention in the process is possible through a web visualization from devices capable of running a browser and connected to the common network with the PLC. As a local solution to this, an industrial computer with a 7-inch IPS display was installed in the control cabinet of the technology. Figure 2 summarizes the main components of the control system and the data transmission technologies implemented between them.

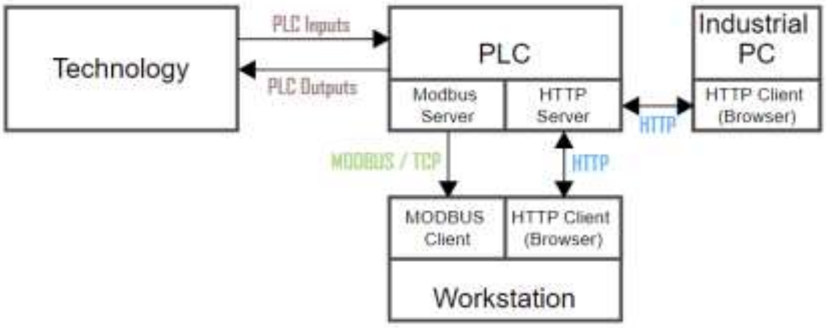

Figure 2 *Main components and data transfer solutions in the control system*

In addition to running the web visualization, the workstation shown in Figure 2 has a role in data acquisition. The operation of this is detailed in chapter 4.3.

3.2. Components of the Control Software

The control software running on a PLC consists of many program organization units, including programs, function blocks and functions. Each of the programs running in the PLC is assigned to a task, which starts the execution of the programs in a cyclical or interruptive manner [10]. In the following, the most important software elements and functions are presented without claiming to be complete.

The developed programs are typically called on separate tasks and executed cyclically. The main program runs on the highest priority task, which is responsible for reading the sensors, writing the control signals of the intervenors, and performing manual and automated operations. Automated operation is implemented according to a state machine control pattern. In the first step, the furnaces are switched on. After reaching the appropriate temperature, the speed and control mode of the steam generator and material handling motors are set, and the steam generator is switched on. In the third step, the material handling motors are also switched on. In the fourth state, the system waits for user intervention, until this happens, the venturi pump operates at half speed. After user intervention, the venturi pump operates in a regulated manner based on the monitored pressure value, and the technology is in continuous operation. The automatic mode can be stopped by the user at any time. Figure 3 summarizes the operation of the state machine.

The consumption and gas flow meter signals are processed in separate programs and tasks. The PLC project also contains additional programs that are responsible for the operation of the Modbus TCP server, the Modbus RTU client, the dynamic functions of visualization and data archiving.

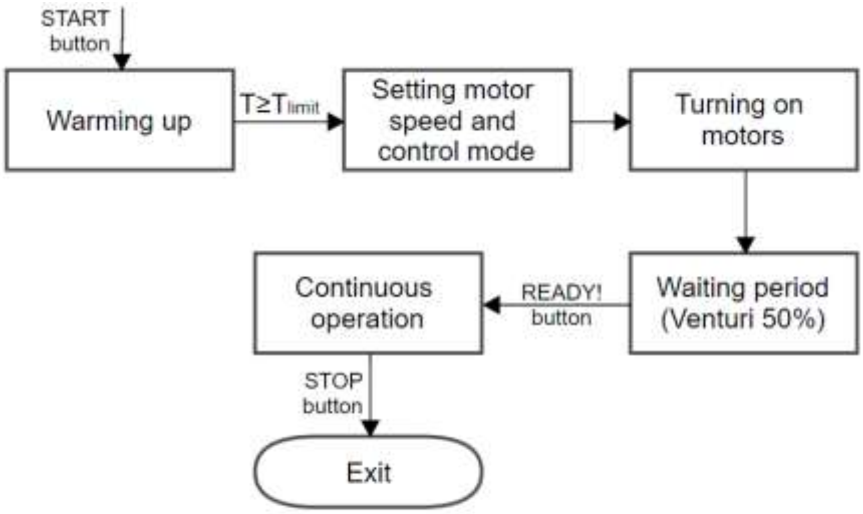

Figure 3 *The process of automatic mode*

With the use of function blocks, well-structured, modular programs can be created, but their advantage for the developer is noticeable when one algorithm can be used to operate many devices, as in this case, to manage the four material handling motors, the four valves or the seven temperature controllers. The implemented function blocks in the PLC project are responsible for the scheduling of the writing and reading tasks of the Modbus RTU client, the different modes of control of the valves and material handling motors, the recipe management, and the scheduling of the automated operation. The control software contains functions declared within programs, i.e., methods, which perform various data conversions and support visualization dynamization tasks.

3.3. The Supervision of the System

There are many processing tasks for the signals and measurement data from the technology, which is implemented in the monitoring system. Such tasks include managing event messages, generating processable data, archiving data, or managing user rights [11]. All of the listed functions have been implemented in the monitoring system of the experimental technology. Figure 4 shows the main screen of the developed visualization.

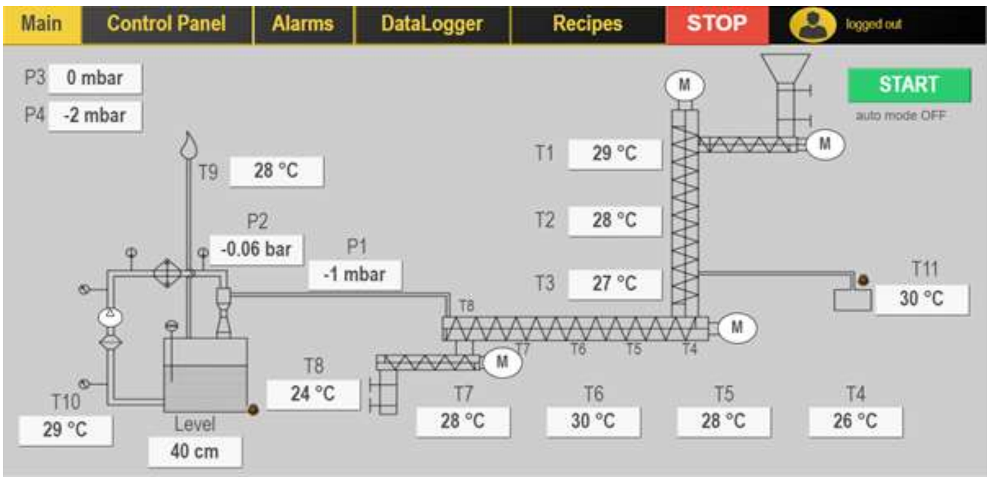

Figure 4 *Main Screen of the web-visualization*

On the developed web visualization, it is possible to monitor the technology; intervene in the process; create and apply different recipes according to the properties of the material to be loaded; save and display the relevant measurement data; furthermore, it sends messages and signals to the user as a result of predefined events (for example, when limit values are reached).

4. Data Acquisition in the Experimental System

Acquisition systems play a crucial role in monitoring and collecting data in various scientific experiments and industrial processes. These systems enable real-time monitoring of important parameters such as temperature, pressure, flow rate, and composition, allowing researchers and operators to have a comprehensive understanding of the process and make informed decisions. Different types of acquisition systems can be used depending on the specific requirements of the experiment or process, such as PLC, HMI, data loggers, or SCADA (Supervisory Control and Data Acquisition) systems.

Data loggers are electronic devices that are commonly used in data acquisition systems. They are designed to measure and record various data points at set intervals, providing a log of information that can be analyzed and used for further analysis. SCADA systems are more advanced acquisition systems that provide real-time monitoring and control of industrial processes. They have the capability to collect data from multiple sensors and devices, present it on a central interface (such as an HMI or web-visualization).

In the control system of the gasifier, different data acquisition methods ensure the archiving of measurement data, signals, and events. These procedures save relevant data to different destinations with different schedules and usage methods.

4.1. Trend View

The graphic view available from the web visualization interface, displayed in dialog windows, can be used to easily track the change of analog measurement data over time. The trend view is displayed after selecting different temperature, level or pressure quantities and provides the possibility to display different time intervals and to search between the measurement data according to Figure 5.

Figure 5 *Trend View in a dialog*

The program that operates trend view and data archiving runs on a separate task and saves the measurement data to a dedicated location in the PLC file system. The advantage of the solution is that the data is continuously archived while the PLC is running, but they can only be accessed through an FTP connection. It was a requirement that only one quantity could be seen on a graph. This requires graphics settings that slow down and stutter the display.

4.2. Data Logger and Data Plotter Application

The WAGO Data Logger function block was used to save the level, temperature and pressure data in CSV files and the Data Plotter application installed on the PLC to display them graphically on the web. The function block saves the measurement data to the device's SD card while the PLC is running, and the Data Plotter application allows opening the files created in this way and graphically displaying the data of the selected channels.

This solution also ensures the continuous archiving of measurement data while the PLC is running, moreover, instead of trend files, CSV files can be opened with a traditional spreadsheet manager. The disadvantage is also the difficulty of accessing the data, and the fact that the SD card is not functional in case of failure, or when the storage space is full, so the data carrier must be constantly maintained.

4.3. Self-Developed Data Acquisition Application

During the design of the data acquisition system, the need has arisen to develop a procedure that archives continuous and discrete data in files that can be opened with a traditional spreadsheet and does not require an additional data storage device in the controller. This task was solved with a desktop application developed in Python, which receives data from the control system via Modbus TCP as indicated in Figure 2.

The first task of the application is therefore to control the Modbus client and to convert the received data into a processable form. The data is first recorded in a MySQL database, so the related database manager and the functions responsible for maintaining the connection with the database has been implemented. Another task of the application is to save the data to a CSV file. In case of continuous operation, it generates a new file every day, but the user has the option to create it at the end of the given experiment, and to monitor the measurement data during the experiment. To control the data acquisition application, a simplified user interface is available, shown on the left of Figure 6, which allows opening the folder of the data measured during the current experiment, the web visualization running in the PLC and the saved CSV files, and provides feedback in a pop-up window shown on the right of Figure 6 about the connection established with the Modbus server and MySQL database.

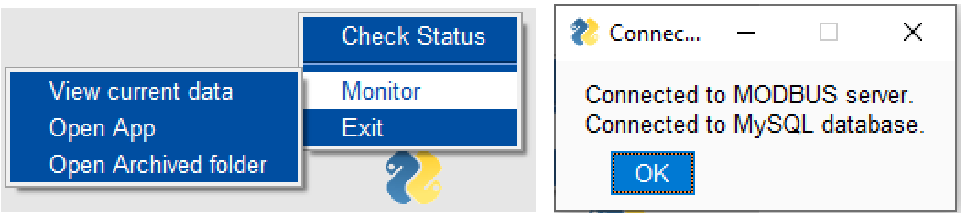

Figure 6 *Simplified user interface of the data acquisition application*

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For the application to function properly, the program units controlling the Modbus server had to be implemented on the PLC side. The advantage of the application is that it stores data in an easy-to-process format and its operation does not depend on the data storage device in the controller. However, archiving requires an additional workstation, and it only starts after a proper connection with the PLC and after starting the application.

5. Conclusion

The continuous operation of the gasification system required the implementation of several control tasks. In addition to PLC-based control, archiving relevant measurement data from sensors and operating units is a fundamental task for processing and analyzing experimental results. This is implemented by different data acquisition solutions in the control system, which have different advantages and operating conditions.

The control- and data acquisition system has functioned properly during the tests, and any operational errors have been corrected. Just like the experimental technology, the control system is also under continuous development, a task to be solved next is the transmission of the measurement data of the gas analyzer to the PLC via a serial interface. The results of the research contribute to the environmentally friendly utilization of fossil fuels.

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IMPACT OF INDUSTRY 4.0 ELEMENTS ON LOGISTICS FLEXIBILITY

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Abstract

Despite the increasing adoption of Industry 4.0 technologies in various industries, there is still a lack of understanding of their impact on logistics flexibility. This can lead to incorrect assumptions and suboptimal implementation strategies. The integration of Industry 4.0 technologies into logistics operations can be complex and challenging, requiring significant investment and expertise. By understanding the impact of Industry 4.0 on logistics flexibility is a competitive advantage. Companies can gain a competitive advantage by optimizing their supply chain operations and responding to changes in demand and supply disruptions more effectively. The aims of this research are to understand the current state of Industry 4.0 adoption and implementation in the logistics, to analyze the relationship between Industry 4.0 and logistics flexibility in case of uncertainty, and to identify the factors that drive or hinder the adoption of Industry 4.0 technologies in logistics operations.

Keywords: *Industry 4.0, Logistics, Logistics flexibility*

1. Introduction

Flexibility reflects the ability of a system to change or respond with little reduction in time, effort, cost, or performance [1]. Flexibility is often seen as a capability that prepares you to meet new, different, unexpected or changing requirements [2]. According to Tummala et al. [3], flexibility is one of the fundamental key factors for the successful implementation of supply chain management (SCM).

Logistics flexibility has missing link in the literature about flexibility, often used interchangeably or confused with supply chain flexibility. Therefore, its sub-components lost their fit within the framework of logistics flexibility. This may be due to the different understanding of logistics and supply chains among scholars from different backgrounds. However, Zhang et al. [4] focused on capabilities in a logistics model in a competence/capability framework, deliberately including speed.

In recent years, logistics-related technologies have fundamentally changed and become more affordable. By this, logistics management research and practical applications have isolated a number of success factors that can be used for the planning and development of logistics systems. In addition to the basic principles, such as improved design heuristics, flow orientation, process coordination, and automation are the main opportunities to improve the overall performance and flexibility of logistics.

In this article, we will first discuss the various terminologies often used in relation to logistics flexibility, then the definition of logistics flexibility and the methodological considerations of the current literature. Then, after a brief description of automation, we will examine how automation affects logistics systems and through this we interpret its impact on logistics flexibility.

Then, we will focus on the effect of real-time process monitoring and finally, impact of predictive analytics applied during the digitization of logistics processes on logistics flexibility.

2. Logistics flexibility

Zhang et al. [4] concentrated on capabilities in a logistics model, focusing on speed. In their proposed framework, physical supply and procurement flexibilities are supply-side competencies that support customer satisfaction through physical distribution and demand management flexibility. This point of view seems to be more comprehensive as it can also extend to manufacturing. Although scholars generally draw a line between the related concepts of flexibility, agility, and responsiveness, there is still some confusion about their concepts and overlap. Logistics flexibility is one of the most important dimensions of supply chain flexibility, corresponding to the ability to respond quickly and efficiently to changing customer needs, in terms of inbound and outbound deliveries and services [4]. Today's business environment requires time-based competition, so logistics flexibility can be a significant performance-enhancing capability [5].

If logistics flexibility were to be defined, then it is the ability with which the company's logistics system can adapt to changing needs, circumstances and challenges that are not at all foreseeable or can only be seen with great uncertainty, without significantly affecting business processes or service quality. Based on this ability, logistics flexibility enables companies to quickly and efficiently modify their logistics processes according to external or internal environmental demands, production capacity and material movement.

10. Figure *Components of logistics flexibility, based on [4], own editing.*

If we compare the main differences, supply chain flexibility is the ability of companies to adapt quickly and efficiently to changing needs and market conditions by connecting the activities of all supply chain participants (from suppliers to production, from warehousing to the consumer). Whereas logistics flexibility is the ability of the company's logistics system to adapt quickly and efficiently to changing needs and market conditions during logistics activities (warehousing, transportation, production, etc.). So, while supply chain flexibility spans the entire supply chain, logistics flexibility is limited to a company's logistics system. However, the two concepts are closely related because the logistics system is part of the company's supply chain and logistics flexibility can help the company to improve the flexibility of the supply chain.

3. The importance of automation for logistics flexibility

According to certain approach, automation is part of the 3rd industrial revolution, however automation is a key component of Industry 4.0 as well. Industry 4.0 enables machines and systems to communicate with each other and exchange data in real-time which improves automation, connectivity, and achieving higher productivity, quality, and efficiency.

Automation is a process in which human work is performed by automatic systems, machines, or software. The goal of automation is to utilize human resources more efficiently, by saving time, reducing errors, and increasing efficiency. Through automation, processes that were originally manual processes become automated processes, which gives industrial processes greater independence.

Logistics automation means the automatic control and verification of logistics processes. The aim of automation is to improve the efficiency, accuracy, and speed of logistics processes. Automated logistics systems make it possible to track the movement of products, optimize storage and delivery, and automate procurement and distribution processes.

Automated logistics systems use a combination of automatized material and warehouse handling systems, computer systems, barcode scanners, warehouse systems, freight tracking systems, mobile devices, and Internet to control and automate logistics processes. In general, there are many specific opportunities for implementing automation concepts in logistics systems to improve overall efficiency and flexibility. In this context, based on a systematic literature review [6], the applications and types of mechanized logistics automation can be grouped and summarized as follows:

- Automated loading and unloading systems
- Automated Guided Vehicles (AGVs)
- Automated storage and retrieval systems (AS/RS)
- Automatic forklifts for mechanized movement
- Mechanized palletizing
- Industrial robots/robotics
- Various types of carousels, conveyors and conveyor-based sorting systems
- Lift and turntables/accessories

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- Linear actuators
- Moving decks and screening and/or sorting systems
- Item picking devices.

In the following, we will highlight the three most frequently used logistics automation options, which can be implemented most efficiently and with the shortest lead time.

AGVs are one of the effective means of automating material handling processes in logistics, they can be used to handle the automated movement of goods. They have sensors and navigation systems that allow automated vehicles to navigate warehouses and production lines precisely and safely. AGVs offer a high degree of flexibility in logistics processes as they can adapt to different warehouse and production environments. They are highly scalable, allowing you to increase logistics processes and production in manufacturing and warehouse processes. AGVs can be integrated with automated warehouse systems, further increasing automation efficiency. Their use offers significant advantages in logistics processes, in addition to lower costs and the minimization of human errors.

However, the use of robotics in logistics processes is not limited to AGVs. There is a wide range of robots used in logistics, including small and medium-sized mobile robots capable of performing various tasks such as moving, labelling or packaging boxes or products. In addition to the robots used in industry, another important area of logistics robotics is the use of collaborative robots (cobots). Collaborative robots are robots that can work together with humans and enable human-robot cooperation [7].

Nowadays, a modern conveyor belt systems are quite easy to implement. The selection of a conveyor belt system depends on the material to be moved, the space available and the space required for further operations. Conveyor belts can be placed on the ground and/or overhead, integrated with sensors and actuators. As a result, machines, devices, systems, and products are able to automatically connect to each other without human intervention [8, 9]. Conveyor systems are not as flexible as AGVs, but for frequent transportation tasks, conveyor systems are a good solution for automation due to their mechanical simplicity, reliability, and very efficient material transfer capability and flexibility.

It can be declared that the impact of automation on physical logistics is significant, as it provides the following important benefits:

- More efficient warehousing: With the help of automated warehousing systems, companies can manage their warehouse stock more efficiently and find the products they are looking for more quickly.
- More accurate tracking and inventory management: With the help of automated tracking systems, companies can track the movement of products in real time, which improves the precision of warehousing and delivery. Automated warehouse systems also enable more accurate inventory management, as automated warehouse systems are capable of accurate inventory determination, tracking of warehouse goods, and optimizing the movement of goods.
- Reduced possibility of error: Automated systems minimize the possibility of human error, which improves the accuracy and safety of logistics processes.

- Increased efficiency: With the help of automated systems, companies can increase the efficiency of logistics processes, as the systems can perform tasks faster and more accurately. Automated processes can reduce delays and errors, which can significantly reduce losses.
- Advanced security: Automated systems provide greater security as they minimize the involvement of manual work. Due to automated equipment and systems, the risk of accidents and injuries is lower, since they work instead of employees, so the loss of downtime resulting from such events is also minimal.

The above mainly affects the flexibility of physical supply and the flexibility of physical distribution among the components of logistics flexibility.

The effect of automation on logistics flexibility can be described in the form of a formula as follows:

$$LF=f(t,Q,A,C) \tag{1}$$

where LF represents logistics flexibility, t is lead time, Q is stock of goods, A is automation level, and C are the factors limiting flexibility. The function takes into account the level of automation and the impact of the factors listed above on logistics flexibility. Increasing automation generally increases logistics flexibility, but the impact of automation may vary for different factors. For example, if automation reduces the size of the handling area in a warehouse, then the capacity of the warehouse can increase and logistics flexibility can improve as companies can hold more inventory, which in turn increases the number of goods available. At the same time, if automation reduces lead time (t), then flexibility can improve by allowing companies to respond more quickly to changing needs. However, the impact of automation may be limited due to factors affecting flexibility, such as limitations on the infrastructure available to transport goods. Automation has a positive effect on the flexibility of the supply chain, including logistics, and using this function, companies can calculate the extent to which automation increases this flexibility.

Automation, like everything, has its pros and cons. With the advent of automated machines, the industry experienced a revolution that launched a new methodology. Among the advantages of automation, we can highlight increased productivity, cost savings, better quality of life and improved working conditions. On the other hand, automation has disadvantages and difficulties. Among the risks, the following should be highlighted: technological dependence and obsolescence, increased investment and maintenance costs, and dependence on more qualified personnel.

Despite the above, it is undeniable that with the help of automation, companies are able to manage logistics processes more effectively, which improves their efficiency, reduces their costs and improves quality. In addition, automation allows companies to respond more quickly and adapt more efficiently to constantly changing market demands, i.e., increase the flexibility of logistics systems.

4. How does real-time process monitoring affect logistics flexibility

Real-time logistics process monitoring is the practice of monitoring and analyzing the different stages and activities of the movement of goods or services from their places of origin to their final destinations. The purpose of logistics process monitoring is to ensure that everything is going according to plan and to identify any problems or delays in the logistics process so that they can be addressed and resolved in a timely manner.

It was previously unthinkable to monitor logistics processes in real time, but now low-cost, low-power sensors and digital solutions enable more accurate monitoring, planning and management of business processes and supply chains. This has implications for logistics resilience by providing greater visibility and control over logistics operations.

Logistics sensors are devices or equipment that collect and transmit data about logistics processes, such as transportation, goods movement, inventory, and the condition of logistics assets. Below are some examples of the types of logistics sensors used for these purposes:

- GPS/IPS tracking devices: these are devices that use Global Positioning System (GPS) technology to track the location of goods or vehicles in real time. GPS devices are used to track the movement of goods throughout the supply chain, including in transit. In the warehouse, a similar purpose is served by the Indoor Positioning System (IPS), which works in a very similar way, but typically uses Bluetooth, WiFi or infrared technology to detect and collect data from sensors.
- IIoT Barcode scanners: these are handheld devices that are used to scan the barcodes of products, and allow for the tracking of stock levels and the movement of goods through the supply chain.
- RFID reader and tags: these are small electronic tags that can be attached to products, pallets or containers to track their movement through the supply chain. RFID tags can be read remotely, allowing real-time tracking and monitoring of goods.
- Packaging detection sensors - these sensors monitor the condition of the packaging, for example for fragile goods, and sound or send an alarm if the packaging is damaged, subject to acceleration/deceleration greater than a pre-set value or temperature of goods during transport lower or higher than limit.

Real-time logistics process monitoring is particularly useful for businesses that need to operate in a fast-paced and dynamic environment, such as e-commerce companies that need to deliver goods to customers quickly.

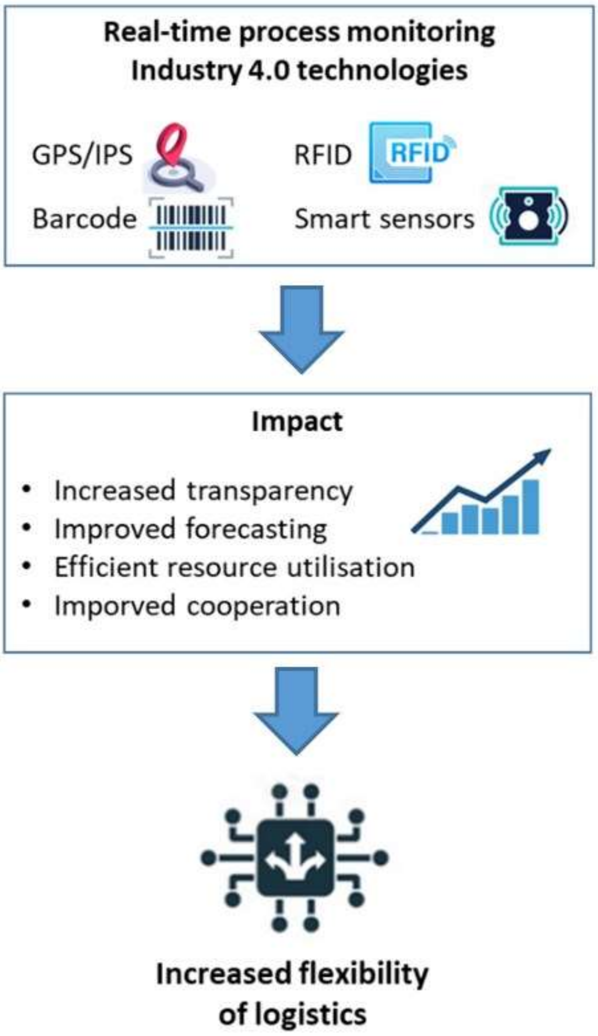
By providing instant updates and alerts, real-time logistics process monitoring helps businesses identify and resolve any issues that arise, ensuring deliveries are made on time. Data collected in real time and transmitted to a central database can be used as input for our simulations and machine learning data analysis. Let’s see how does it affect logistics flexibility.

Real-time data collection has a significant impact on logistics flexibility, by collecting and analyzing data on logistics operations, businesses can gain insight into their operations and make data-driven decisions to improve their flexibility. But let us see how it can affect logistics flexibility.

Real-time monitoring provides a clear and accurate picture of the status of logistics activities, allowing problems to be quickly identified and corrective action to be taken.

Data collection allows for monitoring stock levels, delivery times and delivery status in real time. This increased visibility can help businesses respond quickly to changes in demand or unexpected disruptions, making their logistics operations more flexible.

Improved forecasting allows more accurate forecasting of future demand by analyzing past data and trends. This renders it possible to adapt inventory levels and logistics operations to changing demand, improving flexibility.



11. Figure *Impact of real-time process monitoring, own editing*

By collecting data on their logistics activities, areas of inefficiency and areas for improvement can be identified. This helps allocate resources more efficiently, reducing costs and improving their ability to respond to changing demand.

By providing real-time data on stock levels and shipment status, there is a possibility to optimize logistics processes and reduce the risk of delays or disruptions, while reducing lead times.

Data collection can facilitate better collaboration between different departments and stakeholders within a company. By sharing data and insights, businesses can work together to identify opportunities for improvement and make data-driven decisions to improve their logistics flexibility.

By optimizing logistics processes and reducing the risk of delays or disruptions, real-time monitoring of logistics processes helps businesses reduce costs and losses and improve their profitability.

Overall, data collection is essential for improving logistics flexibility, transparency, and better use of data to make more informed decisions. Real-time data collection has a significant impact on logistics flexibility by enabling faster decision making and faster real-time fine-tuning of processes. Data collection processes and various sensors can be used to continuously monitor the movement of goods and transport processes. This enables logistics professionals to instantly fine-tune schedules, adjust transport routes, solve problems in transit and, by analyzing the relevant data, businesses can identify areas for improvement.

The positive impact of real-time data analysis through sensors is enhanced by Industry 4.0 technologies, which allow machines and equipment to communicate with one another and with people, further improving the flexibility and efficiency of logistics processes. Industry 4.0 technologies are based on the constant monitoring and analysis of data and information, allowing even faster and more efficient decision-making and the fine-tuning of processes.

Logistics flexibility is the ability to respond to changes, and it is extremely important in today's uncertain environment. Changes may occur in the modification of product or service features in relation to the design and development of product or service, the customer requirements, or the marketing mix that an organization offers. Real time monitoring of supply chains, as facilitated by the use of Analytics, can contribute towards real-time monitoring and uncertainty reduction, flexibility and speed in addressing changing customer demands and short lead times related to the transformation of supply chains if needed. Companies, hence, need to develop agile analytics capabilities to cope with high uncertainties in supply chain operations and gain competitive advantage. [10]

5. Impact of predictive analytics on logistics flexibility

Predictive analytics is the art of using historical and current data to make projections about what might happen in the future. By looking at what's happening in the present and what has happened historically, and then applying statistical analysis techniques to the data, researchers can make predictions about what the future might hold.

12. Figure *Value chain of predictive analytics, own editing*

As introduced earlier, logistics flexibility can be divided into 4 main areas: Physical supply flexibility, Physical distribution flexibility, Purchasing flexibility and Demand management flexibility. Already at the time of the appearance of machine

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learning, logistics experts predicted a serious positive effect on logistics systems, including an increase in efficiency and flexibility. Let's see what effects machine learning can have on logistics processes.

Machine learning can help logistics predict demand patterns with greater accuracy, enabling to optimize inventory levels, transportation routes and costs, distribution centers optimizing storage capacity, and reducing waste. This means improved demand forecasting and warehouse management.

One of the benefits gained from machine learning is enhanced route planning and optimization as machine learning can help logistics to optimize delivery routes based on a wide range of variables, such as traffic patterns and customer preferences. This can reduce transportation costs, increase on-time delivery rates, and improve customer satisfaction.

A second factor to be named is better supply chain visibility. To this extent, machine learning can provide logistics companies with real-time visibility into their supply chain, allowing them to track shipments, monitor inventory levels, and identify potential bottlenecks. This can help logistics companies respond more quickly to disruptions and reduce the risk of stockouts.

Improved risk management is another factor that should be highlighted when talking about predictive analytical processes. Machine learning can help identify potential risks and take proactive measures to mitigate them. For example, machine learning can be used to detect anomalies in shipment data, allowing logistics companies to take steps to prevent theft or other security breaches.

It is well-known that predictive maintenance is a key factor to be taken into account in case of any type of industrial activity. Machine learning can help logistics companies predict equipment failures before they occur, allowing them to schedule maintenance proactively and reduce downtime. This can increase the flexibility of logistics operations by minimizing the impact of equipment failures on delivery schedules.

Furthermore, machine learning support logistics processes in real-time adaptation, rapid response to disruptions, agile resource allocation.

The feature of real-time adaptation is yet another feature that is worth mentioning when talking about machine learning as it can help logistics companies adapt their operations in real-time based on changing conditions. For example, if a shipment is delayed due to traffic or weather conditions, machine learning algorithms can suggest alternative routes or transportation modes to ensure timely delivery.

Machine learning allows for agile resource allocation as it can help logistics companies allocate resources more effectively by predicting demand patterns and optimizing inventory levels. This can improve the flexibility of logistics operations by ensuring that the right resources are available when and where they are needed.

Machine learning also provides a new method for rapid response to disruptions as it facilitates more efficient response to disruptions by providing real-time visibility into their supply chain and predicting the impact of disruptions on delivery schedules. This can help logistics companies minimize the impact of disruptions on customer satisfaction and reduce the risk of stockouts.

6. Conclusion and summary

Above all, logistics remains a vital condition for companies to provide flexible, excellent service standards at affordable costs. In today's rapidly changing business environment, logistics flexibility is an essential component of a company's ability to manage supply chain uncertainties and meet customer demands. Automation, robotics, real-time process monitoring, and predictive analytics mean clear improvements in efficiency and flexibility of logistics. By integrating these elements has significant impact on logistics flexibility by enabling efficient control and reliable planning of supply chain operations, reducing the need for manual intervention. By increasing the efficiency and responsiveness of logistics processes, resources can be free up for more strategic tasks. In addition to automation, real-time process monitoring, and predictive analytics many other areas also have an impact on logistics flexibility, so the investigation of the following areas is also the subject of research and through these, further correlations can be revealed.

First, effect of increased visibility. Industry 4.0 technologies provide greater insight into the supply chain, allowing companies to identify inefficiencies and areas for improvement and make more informed decisions. And secondarily effect of flexible, and agile operations, by leveraging the latest technologies, companies can create a more flexible and agile supply chain that can respond more effectively to changes in demand and supply disruptions and minimize waste and inefficiencies.

Thirdly connection between logistics flexibility and sustainability. How logistics systems can be designed to balance flexibility and sustainability can be investigated. This research can consider environmental impacts, waste reduction, minimizing carbon emissions, and the potential for recycling as well.

And finally, the impact of technological developments on logistics flexibility. Smart technologies, such as artificial intelligence, self-driving vehicles, drones, or enhanced IoT devices, offer many opportunities to improve logistics flexibility. The impact of these technologies on logistics systems and how to maximize their potential can be also studied.

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PI, PID ALGORITMUS PARAMÉTEREINEK ADAPTÁLÁSÁNAK VIZSGÁLATA GENETIKUS ALGORITMUSSAL

INVESTIGATION OF ADAPTATION OF PI, PID ALGORITHM PARAMETERS WITH GENETIC ALGORITHM

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Absztrakt

A cikk Proportionális-Integráló (PI) szabályozó adaptálásának lehetőségeit vizsgálja. Az iparban Proportionális-Integráló vezérlésre Programmable Logic Controller-eket (PLC) és Distributed Control System (DCS)-alapú folyamatirányító rendszereket használnak. A gépek, folyamatok üzembe helyezésekor a PI vagy PID algoritmusok paramétereit hangolják a rendszerrel szemben támasztott követelményeknek megfelelően. Az üzemeltetés során előfordulhat, hogy a vezérlő rendszereket cserélni kell. Ez a kutatás bemutatja, milyen eseteketben foruldhat elő kizárlólag az irányító rendszer cseréje. A PI vezérlési algoritmus paraméterei nem adaptálhatók, ezért a rendszert újra kell hangolni, de ez veszélyes és időigényes folyamat. A kutatás bemutatja a FingerPrint (FP) lehetőségeit és a genetikus algoritmusok alkalmazását a PI algoritmus paramétereinek adaptálásához.

Kulcsszavak: PLC, DCS, fingerprint, genetikus algoritmus, adaptálás, PI szabályozó

Abstract

The article examines the possibilities of adapting a Proportional-Integral (PI) controller. In industry, Programmable Logic Controllers (PLCs) and Distributed Control System (DCS)-based process control systems are used for PI control. When machines and processes are put into operation, the parameters of the PI or PID algorithms are tuned according to the requirements of the system. During operation, it happens that the control systems must be replaced. This research demonstrates the cases in which the control system can only be replaced. The parameters of the PI control algorithm cannot be adapted, so the system must be retuned, but this is a dangerous and time-consuming process. The research presents the possibilities of FingerPrint (FP) and the application of genetic algorithms to adapt the parameters of the PI algorithm.

Keywords: PLC, DCS, Fingerprint, genetic algorithm, adaptation, PI controller

7. Bevezetés

Az iparban különböző vezérlő rendszereket használnak. Ezek a rendszerek lehetnek PLC-k, DCS-alapú folyamatirányító rendszerek vagy kártyás vezérlők. Számos esetben használjuk ezeket a rendszereket szabályozásra, mint például PI, PID, MPC (Modell Predictive Controll), vagy fuzzy logika. Mindegyik esetben szükséges a szabályozást megvalósító algoritmusok hangolása. A hangolásra több módszert is alkalmaznak, mint például ZN (Zeigler-Nichols) vagy a rendszer átviteli függvényének meghatározása néhány esetben adaptív PID hangolást is lehet alkalmazni. Azonban ezeket a módszerek nem minden esetben lehet alkalmazni és vannak olyan esetek, amikor egyáltalán nem.

A kutatás megvizsgálja, milyen esetekben kell cserélni a rendszer vezérlőjét. A csere után a PI szabályozó algoritmus paramétereit adaptáljuk az új vezérlőbe. Megvizsgáljuk, hogy milyen hatással van ez az eljárás a szabályozásunkra.

Bemutatásra kerülnek régebbi kísérletek, amelyek azt szemléltetik, hogy milyen hatásai voltak a PI szabályozó paramétereinek adaptálása, más folyamatirányító rendszerbe. A hatások vizsgálata a szabályozó minőségi jellemzőire terjednek. Meg kell jegyezni, hogy a kísérlethez egy gyártó független algoritmus lett felhasználva.

A cikk bemutatja az FP magyarul ujjlenyomatolvasó módszerét és működését. Ezzel a módszerrel a rendszerről lenyomatok készíthetőek. Ezek a lenyomatok a rendszer állapot jellemzői. Lenyomatokat készítünk a cserélendő és az új rendszerről is, és összehasonlítjuk őket. A cél, hogy ugyan olyan rendszert hozzunk létre.

Bemutatásra kerül a genetikus algoritmusok működése. Ezeket az algoritmusokat, akkor használjuk, amikor egy olyan problémával állunk szembe, ahol nem ismerjük megoldást, de az optimumot igen. Mivel a PID szabályozó algoritmus paramétereinek adaptálása egy ilyen eset, ezért megoldást nyújthat a problémára.

8. Az ipari vezérlők cseréjének oka és hatásai

Az iparban számos olyan eset van, amikor valami miatt a vezérlőket cserélni kell. Ebben a fejezetben ezeket az eseteket tárgyaljuk és vizsgáljuk a hatásaikat.

Ilyen eset az, amikor megszűnik a termék támogatás. Ebben az esetben a vezérlő kritikus pontja a vezérlési stratégiánknak, mert meghibásodás esetén nem érthetőek el az alkatrészek és a termék támogatás. Ilyenkor általában ugyan attól a gyártótól vesszük az új vezérlőt, akitől vettük a cserélendő vezérlőt és egy újra cseréljük. Azonban az új vezérlőnek nem csak a hardver architektúrája lesz más, de még a firmware is. Azonban a chip hiány miatt számos gyártó nagy szállítási határidőkkel dolgozik. Ez azt is jelentheti, hogy más gyártótól kell beszerezni a vezérlőt.

A vezérlőt meghibásodás miatt is cserélnünk kell. Abban az esetben, ha moduláris a rendszer, akkor a meghibásodott modult érdemes cserélni. Ez lehet a CPU vagy az I/O kártya. Korábbi vizsgálatok kimutatták, hogy a CPU és az I/O csere is okoz megváltozott szabályozást. A CPU esetében a firmware különbségek okozhatják a problémát. Az I/O esetében pedig az ADC (Analog Digital Converter) és a DAC (Digital Analog Converter) különbsége fogja befolyásolni a működést.

Vannak azonban olyan esetek is, amikor a funkcionális bővítés miatt kell új vezérlőt alkalmazni. A funkcionális bővítések miatt valószínűleg nagyobb terhelés lesz a vezérlőn. Ez megfogja változtatni annak a ciklus idejét és ez okozhat problémát a szabályozásoknál.

A vezérlők cseréjének számos hatása van. Ilyen a szabályozás viselkedésének megváltozása, ezért a rendszert újra kell hangolni. Azonban ez nem egyszerű, mert egy működő rendszerről beszélünk. Emiatt számos hangolási módszert nem lehet használni, vagy csak valamilyen tolerancia kereteken belül.

Karbantartásra is nagy hatással van a vezérlő cseréje. Igazából ebben a szakaszban történik a vezérlőcseréje és üzembe helyezése. Azonban a nem várt szabályozási hatások és a megnövekedett karbantartási idő miatt több ideig áll a gyártás. Ez nem csak megnövekedett karbantartási költségeket, mint például programozási költségeket jelent, hanem kötbérek költségét is jelentheti.

Energiahatékonyság korunk egyik meghatározó része. Egy jól beállított szabályozó energiahatékony. Ez azt jelenti, hogy optimális a szabályozási energia és a működési energia. Mivel a szabályozó viselkedése megváltozik, ezért az energiahatékonyságunk mértéke is csökkenhet.

Nem utolsó sorban az új szabályozó időigényes hangolása rengeteg selejt legyártását eredményezi, ami megnövekedett hulladékgazdálkodási költségeket is jelent. Számos esetben környezet védelmi bírságok megfizetését is eredményezi.

9. Kutatási előzmények

A múltban több kísérletet is folytattunk PI algoritmus paramétereinek adaptálásának vizsgálatára. A kutatások megkezdése előtt, készíteni kellet egy gyártó független PID algoritmust. Erre azért volt szükség, mert a gyártó által biztosított algoritmusok nem felnyithatóak, tehát a pontos működésüket nem tudjuk vizsgálni. Az azonban nagyon fontos a kutatás szempontjából, hogy az algoritmus paramétereinek adaptálásánál milyen változások történnek és megértsük őket.

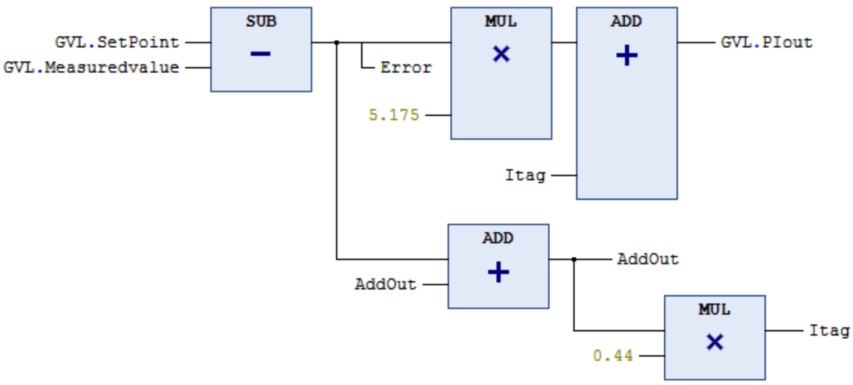
Az algoritmus elkészítéséhez szükségünk van a PID képletére. Azonban, a PID szabályozás a vezérlőn belül történik, ezért nem használhatunk analóg képletet. Azért lett alkalmazva digitális PID képlet, mert a vezérlő belső működése digitális. Az (1) képlet mutatja a szabályozó digitalizált képletét.

$$x_i = K_P * e_n + \frac{T}{T_I} \sum_{i=0}^{n} e_i \qquad (1)$$

-Ahol,

- x_i: a PI kontroller kimenete az i. időpontban
- K_P: arányos tag erősítési tényezője
- en: hibajel az adott időpontban
- T: mintavétel idő
- T_I: integrálási idő
- e_i: hibajel az i. időpontban [1]

Az algoritmust FBD PLC programozási nyelven lett algoritmizálva. Azért lett ez a nyelv kiválasztva, mert az iparban használt vezérlők támogatják ezt a programozási nyelvet. A *1. Ábra* a PI algoritmust szemlélteti.

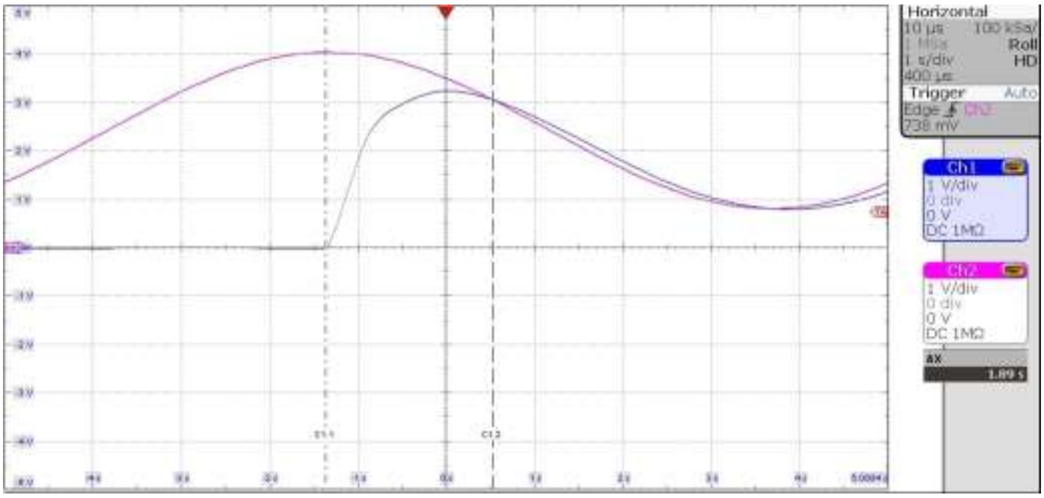


1. Ábra Gyártó független PID algoritmus

Az algoritmus megalkotásánál figyelembe kell venni az adatkonverziót. A PLC analóg kártyáinak értéke Word típusú változóként jelenik meg. Ezt az értéket Real értékre kell átkonvertálni és skálázni. Ez azért fontos, hogy a hangolást ne csak egész számokkal tudjuk megvalósítani. Az algoritmizálás bemutatáshoz a *1. Ábra* szemlélteti a kész algoritmust. A GVL.SetPoint a függvény generátor értéke. A GVL. Measuredvalue az áramkör kimenete, azaz a visszacsatolt érték. A *1.*

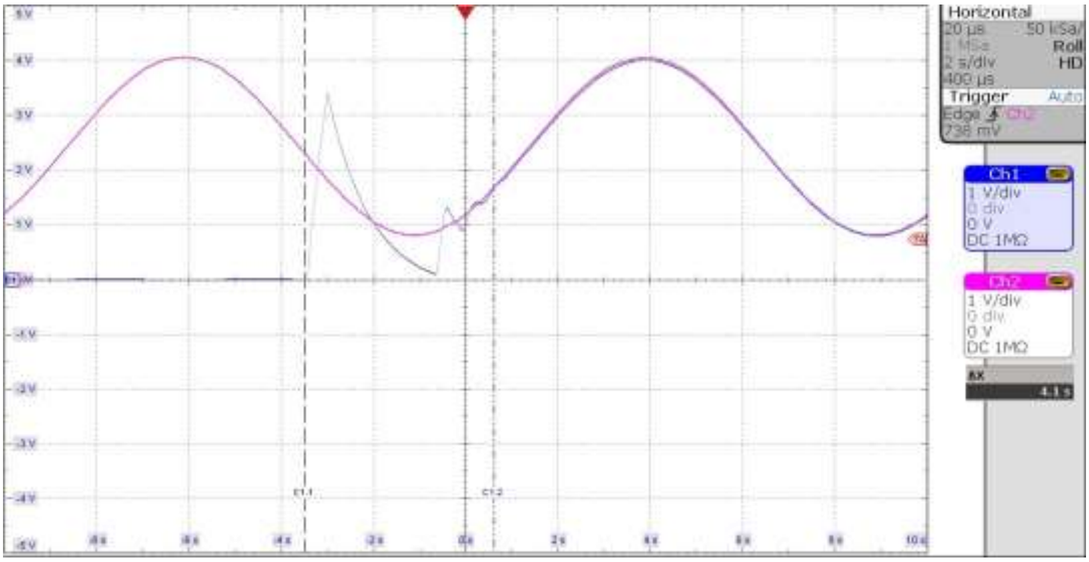
Ábrán látható Error, ami a különbségképző kimenete, azaz a hibajel. Az AddOut az algoritmus belső változója. A GVL.PIout egy Real érték, ami a I/O kártya csatornája írás előtt Word típusú változóra kell alakítani és vissza kell skálázni a kártya kimeneti skálájára.

Az algoritmus első eleme egy kivonó blokk, ami a különbség képző (SUB). A kivonó blokk bemenetére elsőnek setpointot (GVL.SetPoint) kell csatlakoztatni második helyre a mértértéket (GVL.Measuredvalue). Azért kell a setpointot elsőnek felírni, mert a hiba a setpoint (GVL.SetPoint) és a mértérték (GVL.Measuredvalue) különbsége. Ez egy párhuzamos PI vezérlő, ezért el kell ágaztatni a kapott hiba értékét és elsőnek a P (Proportional) blokkba kell bevezetni, ami egy szorzás. A jelenlegi hibát meg kell szorozni a beállított P paraméterrel, így kapjuk meg a P hatást. Az I tag a fentebb látható (1) képletből a következő: $\frac{T}{T_I}\sum_{i=0}^{n} e_i$. Tehát ezt az integrálást kell megvalósítani. Ezt úgy lehet megtenni, hogy egy visszacsatolt összeadó blokk végez egy összegzést, majd ezt össze kell szorozni a képletből adódó T/T_I taggal, és a szorzó kimenetét a PI összegzőjére kötni. Tehát a hibajel az összegző bemenetére csatlakozik, amelynek a kimenetét visszacsatoljuk a blokkunk másik bemenetére (ADDOut), majd ezt a blokkot a szorzó blokk bemenetére kötjük. A szorzó blokk másik bemenetét T paraméterrel szorozzuk, ami az 1. Ábrán 0.44. A P és I tagot egy összeadó blokk bemenetére csatlakoztatjuk. Az összegző blokk kimenete adja a PI vezérlő kimeneti jelét. A kimeneti jelet konvertálni kell Word változóra és skálázni kell a kimeneti kártya értékére, mert Real érték nem írható a kártya csatornájára. Az algoritmus ugyanazokkal a blokkokkal lett megírva a Mitsubishi vezérlőn is. Ugyanazok az adatkonverziók és skálázási műveletek lettek végrehajtva. Tehát az egész algoritmus át lett „másolva” adoptálva a másik PLC vezérlő fejlesztő környezetére.



2. Ábra WAGO PLC hidegindítás

A vizsgálat alatt a függvény generátor paraméterei rögzítettek és idővel sem lett változtatva. Szinusz jel alaknál 100 mHz, HL (High Level) 2 V, LL (Low Level) 400 mV a fázis 0°. A 2. Ábrán látható, hogy a beállási idő 1.84 s Wago PLC esetében és nem látható túllendülés. A Mitsubishi PLC-n futatott algoritmus hideg indítási eredménye a 3. Ábrán látható. A vezérlő beállási ideje 4.1 s, ebből az adatból láthatjuk, hogy 2.21 s-al lassabban érte el a vezérlésünket. Azonban fontos megjegyezni, hogy igen magas túllendülés figyelhető meg. Egy túlvezérlés beláthatatlan következményekkel járhat az iparban. A vizsgálat megvalósult rámpa jel típusra és értéktartó szabályozásra is. A vizsgálat alatt a függvény generátor paraméterei rögzítettek és idővel sem lett változtatva. Szinusz jel alaknál 100 mHz, HL (High Level) 2 V, LL (Low Level) 400 mV a fázis 0°. A 2. Ábrán látható, hogy a beállási idő 1.84 s Wago PLC esetében és nem látható túllendülés. A Mitsubishi PLC-n futatott algoritmus hideg indítási eredménye a 3. Ábrán látható. A vezérlő beállási ideje 4.1 s, ebből az adatból láthatjuk, hogy 2.21 s-al lassabban érte el a vezérlésünket. Azonban fontos megjegyezni, hogy igen magas túllendülés figyelhető meg. Egy túlvezérlés beláthatatlan következményekkel járhat az iparban. A vizsgálat megvalósult rámpa jel típusra és értéktartó szabályozásra is.



3. Ábra: Mitsubishi PLC hidegindítás

A 2. és 3. Ábra alapján elmondható, hogy a PI algoritmus adoptálása utána a következőket figyelhettük meg. A Wago PLC-n elvégzett hangolás alkalmával semelyik esetben sem okozott túllendülést. A Mitsubishi PLC-re adoptált algoritmus minden hidegindítás során túllendülést okozott. A vizsgálat azt is feltárta, hogy a Wago PLC-n az értékkövető PI vezérlés beállási ideje sokkal alacsonyabb, mint a Mitsubishi PLC-re adoptált PI vezérlő beállási ideje. Azonban a kísérlet bebizonyította, hogy értékkövető szabályozásnál, tehát konstans DC típusú jelnél az adoptált Mitsubishi PLC beállási ideje alacsonyabb, mint a WAGO PLC beállási ideje.

1. Táblázat Adoptálás eredményei más jelalakra

Szempontok	Rámpa jel típus	
	Wago PLC	Mitsubishi PLC
Vezérlés beállási ideje	1.92 s	3.95 s
Túllendülés	Nem	Igen
	Constans DC jeltípus	
Vezérlés beállási ideje	3.92 s	3.34 s
Túllendülés	Nem	Igen

A vizsgálat folytonos üzemmód vizsgálattal lett folytatva. A vizsgálat az alapjel (setpoint) követését vette figyelembe. A kérdés az volt, hogy a PI adoptálást elvégzendő algoritmus mekkora hibával tudja követni az alap jelet a hangolt PLC-vel szemben. A következő eredmények születtek, amit a 3. Táblázat szemléltet.

2. Táblázat: Folytonos üzemű adoptálás eredménye

Szempont	Rámpa jel típus	
	Wago PLC	Mitsubishi PLC
Jel követési hiba értéke	278.22 mV	73.339 mV
	Konstans DC jeltípus	
Jel követési hiba értéke	11.889 mV	10.345 mV

Folytonos üzemű működésnél nem volt megfigyelhető túllendülés. Sőt a Mitsubishi PLC jobb szabályozási minőséggel valósította meg a szabályozást. [2]

10. Ujjlenyomat olvasó módszer

Az ujjlenyomat olvasó módszer egy olyan biometrikus azonosítási technológia, amely a személy egyedi ujjlenyomatát használja az azonosításhoz. Az ujjlenyomatokat általában digitális formában tárolják, és az algoritmusokat az ujjlenyomatok elemzésére használják. [3]

Pontosság: Az ujjlenyomat olvasó pontossága az egyik legfontosabb tulajdonsága. A rendszernek pontosan kell azonosítania az ujjlenyomatot, hogy biztonságos és hatékony legyen.

Rugalmasság: Az ujjlenyomat olvasó rugalmassága azt jelenti, hogy a rendszernek képesnek kell lennie azonosítani az ujjlenyomatokat különböző környezeti feltételek mellett, például nedvesség vagy hőmérséklet változásai esetén.

Kompatibilitás: Az ujjlenyomat olvasó kompatibilitása fontos tulajdonság, mivel a rendszernek képesnek kell lennie integrálódni más rendszerekkel, például az adatbázisokkal, vagy a beléptető rendszerekkel. [4]

Egy ugyan ilyen módszert szeretnénk kidolgozni, ahol elkészítjük a még működő rendszer ujjlenyomatát. Ez valójában azt jelenti, hogy amíg működik a rendszer méréseket hajtunk végre, amivel a rendszer jellemzőit tudjuk kimérni. Megvizsgáljuk, hogy különböző zavarokra hogyan reagál a rendszer. Ezekből az adatokból eltudjuk készíteni a rendszer modelljét. A modell segít megérteni, hogy mely paraméterek módosítása van hatással a rendszerre. Ez után a cserélendő rendszerről is elkészítjük az lenyomatokat. Először a kétlenyomatot össze kell hasonlítani és matematikailag meg kell határozni, hogy mik a különbségek. Végül ugyan olyan modellt kell létre hozni. A modell segítségével a rendszer hasonló működésűvé tehető, mint a cserélt rendszer. A 4. Ábra bemutatja a rendszer topológiáját.

4. Ábra Ujjlenyomat olvasó topológiája

A topológiából látható, hogy szükségünk lesz egy adatgyűjtő kártyára, aminek a segítségével a mérések, az az ujjlenyomatok elkészíthetőek. A számítógépen fognak az adatok koncentrálódni. Az adatok feldolgozására és az új rendszer megvalósításához intelligens algoritmusokat használunk.

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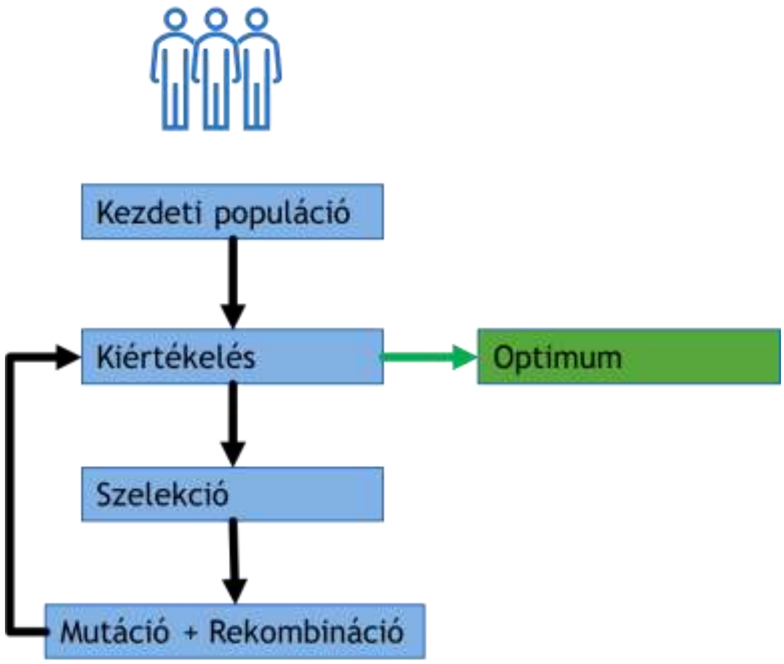
11. Genetikus algoritmusok alkalmazása adaptálási folyamatoknál

A genetikus algoritmusokat általában optimalizálásra vagy olyan esetekben alkalmaznak, amikor nem tudjuk, hogy mi a megoldás, de ismerjük az optimumot. Jelen esetben mind a két eset előfordul a kutatásunkba. Optimalizálni akarunk egy szabályozót úgy, hogy ismerjük a régi rendszer működését, tehát az optimumot. Továbbá nem tudjuk, hogyan oldható meg a probléma. Ezért lehet megoldás a genetikus algoritmus ebben az esetben. A genetikus algoritmus működését a 5. Ábra szemlélteti. [5]



5. Ábra genetikus algoritmus működése

A módszerhez szükségünk van populációra, ami egyedekből áll. A populáció a paramétereket jelenti és az egyed egy paraméter. Először is a kezdeti populáció megvalósítására szükségünk van egy működő rendszerre, ahol a szabályozó jól működik. Itt méréseket hajtunk végre, amelyekhez a PID paramétereit rögzítjük. Így állítjuk elő a „Kezdeti populációt". Ebből a populációból ki kell választanunk a legjobb paramétereket és a hozzájuk tartozó méréseket, tehát kiértékeljük őket. A kiértékeléssel megméretettjük az egyedeket, hogy ki áll legközelebb az optimumunkhoz. Ezt a megmertetést fitnesz függvénynek hívjuk. Ez a függvény az egyed attribútumai alapján kalkulált érték. A vizsgálat után kiszelektáljuk a legmegfelelőbb paramétereket és mérési eredményeket. A mutáció és a rekombinációs folyamat következik. A rekombináció során véletlenszerűen kiválasztunk két egyedet és keresztezzük őket. Ez azt jelenti például, hogy összegezzük őket és vesszük az átlagját. Ezzel az eljárással megszületik az új egyed, ami az új populáció tagja lesz. Ezt a többi egyeddel is elvégezhetjük véletlenszerűen. A mutáció során egy egyedre van szükségünk, például egy paraméterre és neki az értékét megváltoztatjuk. Például, ha 5 volt az értéke, akkor megváltoztatjuk 6-ra. A mutáció és rekombinációs eljárásból megalkotjuk az új populációt. Ez egy iterációja a genetikus algoritmusnak, tehát a kérdés, hányszor kell ezt megismételni és elvégezni? Ezt általánossággal kijelenthetjük, hogy addig, ameddig el nem érjük az optimumot. Tehát újra kiértékelés következik és nézzük mennyire vagyunk az optimumtól vagy már elértük-e. Azonban érdemes megjegyezni, hogy ha további iterációk nem hoznak jobb eredményeket, akár romlást is észre vehetünk, akkor meg kell állítani az algoritmust. [6]

12. Konklúzió

A kutatás a PI algoritmus adaptálását vizsgálta és a lehetséges módszereit. A vizsgálat során kijelenthető, hogy különböző gyártó által gyártott PLC-re a PI algoritmus paraméterei nem adaptálhatóak a rendszer vagy a PI algoritmus paraméterei változtatása nélkül. A cikk megvizsgálta az ujjlenyomat olvasó módszert és annak lehetőségeit. Ez a módszer megoldást jelenthet a PI algoritmus adaptálási folyamatára. A genetikus algoritmusok segítségével optimalizálhatunk és olyan megoldást nyújthatunk ott, ahol nem ismerjük a módszert, de ismerjük az optimumot. A genetikus algoritmus működése megfelelhet az adaptálási folyamatnak, továbbá alkalmas a PI algoritmus optimalizálására is. A jövőben az ujjlenyomat olvasó módszert kell részletesen kidolgozni és a háttérben működtetett algoritmusokat kell optimalizálni a folyamatra.

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CHANGES IN THE SAFETY LEVEL OF POTENTIALLY EXPLOSIVE INDUSTRIAL TECHNOLOGIES IN PRACTICE

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Abstract

Industrial production processes may often result in potentially explosive atmospheres, and therefore, in addition to the presence of potential ignition sources with respect to the technologies, such hazardous facilities carry the risk of possible explosions. The safety requirements on explosion protection are set out in binding directives for the Member States of the European Union (EU), but the means ensuring the achievement of the respective objectives are developed by national authorities. The establishment of the safety level of explosion protection is stipulated in Hungarian legislations by means of the regulations of the Labour Safety and Fire Protection Authorities.

In Hungary, since the country's accession to the European Union in 2004, there have been continuous changes in the system of requirements regulating the safety of explosive technologies; in recent years, such changes have entailed new, previously non-existing risks, the nature of which cannot be known yet. The previous legislations basically stipulated the use of technical solutions set out in national (mostly harmonised) standards as compulsory requirements in order that explosion protection for certain hazardous facilities could be provided.

A new economic trend occurring in the 2020s is that complete factories and plants arrive in Hungary from outside Europe, which also have explosive hazards. The world outside Europe does not fit our safety standards to such a comprehensive extent, and the need for improving the balance between safety and technological development can be identified as an economic trend. Changing regulations also related to explosion protection are intended to increase the freedom of investors and designers; as an alternative to the compulsory application of former national standards, there is an opportunity to be able to establish the same level of safety by prioritising the use of engineering methods.

In the new, more liberal framework, the prevailing of security against explosion protection has been decreasing, new risks have been identified regarding the adequacy of the solutions developed, and in order to balance such risks, the effectiveness of the operation of the new regulatory regime needs to be assessed and the assessment system on the compliance of alternative solutions needs to be regulated.

Keywords: *explosive atmosphere (ATEX), Explosion Protection, human and organizational factors (HOF)*

1. Introduction

Several different fields of safety sciences are known. In the majority of EU Member States, protection against explosions or explosion protection is regulated under two branches of safety engineering, Labour Safety and Fire Protection, for example in DIRECTIVE 2014/34/EU (hereinafter "ATEX114") [1], DIRECTIVE 1999/92/EC (hereinafter "ATEX 153") [2], Joint Ministerial Decree 3/2003 (III. 11.) of the Ministry of Employment and Labour as well as the Ministry of Health, Social and Family Affairs [3], and Decree 54/2014 (XII. 05.) of the Ministry of the Interior (hereinafter “OTSZ”)[5], but also in many other areas, mandatory requirements have to be fulfilled, such as Ministerial Decree 35/2016 (IX. 27.) on the testing and certification of equipment and protective systems intended for use in potentially explosive atmospheres [4].

This regulatory system, and thus the respective framework of harmonised standards [12], regulations [3][4][5][6], sectoral directives [9][10][11], which have been established in this regard, results in a complex mechanism of action that serves as a basis for developing protection solutions, and thus achieving proper explosion protection.

The effectiveness of Hungarian regulations on explosion protection and the adequacy of the application of the framework have been criticised in many forms, either from the professional side, as detailed by Király (2018)[6], or from the user side, as discussed by Parádi (2022)[7].

In our research, we seek to answer the question where the current evolution of the level of safety available is headed in terms of potentially explosive industrial technologies; for this purpose, we need to examine and assess the current status of the existing situation.

2. Changes in Explosion Protection

The main aim of our research is to determine the extent to which the requirements of the currently known regulations are applied in the general practices of explosion protection in Hungary, and how effective the safety solutions developed during the operational periods of hazardous facilities are. We will investigate and assess what level of safety could be achieved in practice by the results of the mechanism of action known to this point, which requires compliance with the technical standards.

Based on the foregoing, we seek to find how the level of safety achieved could be improved in order that it could be more sufficient in terms of the innovative and modern approach that is now being used with respect to the engineering community that develops solutions and the technical solutions that implement explosion protection.

We have observed two changes in the newly emerging potentially explosive industrial technologies:

- on the one hand, we are experiencing significant changes taking place in the framework regulating the operations of explosion protection
- on the other hand, in the course of our daily work, we see that the designing and construction activities of new plants in Hungary are increasingly carried out, in part or in whole, by foreign companies, moreover, by companies from outside Europe

2.1. Changes in the National Legislative Framework

In the process of Hungary's accession to the European Union, the regulations on safety requirements related to potentially explosive technologies have been changed; the most of the relevant standards have been replaced, new ones have been adopted and nationalized [12]. The mandatory use of standards has been abolished and their application has been voluntary for basically 20 years under Act XXVIII of 1995 on National Standardization [13], although legislations with technical content may stipulate the use of a given standard mandatory; however, the requirements of the given legislation are fulfilled if the solution described by the standard is used without change.

Review on the Application of Standards

Regarding the topic of standardisation, we have consulted the own publication of MSZT (the Hungarian Standards Organisation) [16], which provides a valuable overview in general terms, not specifically in the speciality of explosion protection.

"The only legal, official solution for the publication of a Hungarian version of a foreign language* standard is the Hungarian national standard issued by the Hungarian Standards Organisation, which guarantees conformity with the foreign language source standard. This is the only possible authentic Hungarian equivalent of the source standard.

*Based on Act XXVIII of 1995 on National Standardisation, Act LXXVI of 1999 on Copyrights, as well as on the exclusive mandate and rules of the international (ISO, IEC) and European (CEN, CENELEC) standards organisations.".

MSZT also provides another very important interpretation in terms of international orientations, as quoted precisely below:

"Non-conformity with standards may result in serious economic and legal consequences, because standards offer voluntarily applicable solutions to meet the essential requirements set out in the relevant legislations, in line with one of the most significant principles of the technical legislations of the European Union. **In case these are taken into account, conformity with the legislations has to presumed - in accordance with another EU principle, which is, however, about legal compliance - and it is forbidden to check such conformity by means inspections.** Voluntary standards, whether or not they are related to legislations, are agreed upon by consensus. All economic operators and legislators can participate in their development, according to their interests and the need to assert their interests. Their contents reflect the technical requirements, technologies, testing/inspection methods known at the time of their publication, i.e. the current status of technologies, which are accepted (sometimes with certain compromises) by the parties involved in the consensus.

Standards provide generic and repeatedly applicable procedures and technical solutions, which have been adopted by common consensus and which offer optimal solutions for the different stakeholders. In the case of products or services compliant with valid standards, it can be assumed that the party applying those standards has acted with due care, in accordance with the accepted level of technological development.

Consequently, based on the foregoing, in case standards are not complied with:

- the placement of the given product/service on the market may take an indefinitely long time and it may require an unforeseeable amount of costs, as their conformity with the legislations cannot be presumed, and **a separate procedure is required in order to demonstrate that the chosen solution meets the legal requirements (equivalent to or better than the standard**),

- the technical content and the method of inspection have to be specifically stipulated in detail (rather than just indicating a reference to a standard) in contractual legal relations and in tenders (especially in public procurement tender procedures), in order that they would be acknowledged and accepted by the parties involved in the performance of the contract and the respective controlling processes, as well as by those involved in any subsequent legal proceedings,

- **the protection ensured by the standard is lost in relation to incidents affecting life, health, environmental or property safety** (a separate procedure is required to demonstrate that the given non-standard solution is equivalent to the standard, and this is almost impossible in the case of an accident or damage that has already occurred)."

Review on Fire Safety Standards

In terms of Fire Safety Standards, Section 3 was included in the 2017 version of the OTSZ [5] and in the former versions as well, according to which compliance with national standards is mandatory in areas with explosive atmospheres, and deviation may be allowed in certain cases as stated in Section 3 Subsection (2) of the Regulation: "Deviation from the requirements of this Regulation may be allowed in case the given requestor demonstrates that the protection objectives set out in this Regulation are met and that at least the same level of safety is ensured.". Section 3 has been removed in its entirety from the version of the OTSZ [5] entering into effect as of 1 January 2018, and, consequently, the spirit of the standard-based obligation known until that time was also eliminated. As a new approach, Technical Guidelines for Fire Safety ("TvMI") have been developed to support the work of engineers and to establish potential technical solutions. As of 2013, TvMI guidelines are now available for 14 areas to help meet the requirements of the OTSZ [5], 3 of which are related to solutions for potentially explosive atmospheres: TvMI 13.3:2022.06.13 Explosion Protection [9], TvMI 12.5:2022.06.13. Control, inspection and maintenance [10], and TvMI 7.5:2022.06.13. Electrical installations, lightning protection and protection against electrostatic discharge [11]. TvMI is not mandatory to be complied with, but it is intended to describe technical solutions that meet the legal requirements of the relevant field. Even Section 3/A Subsection (3) of Act XXXI of 1996 on Fire Protection (hereinafter: the Fire Protection Act) [14] states that "The safety level specified in the National Fire Safety Code can be attained by the following means:

a) by complying with a national standard on fire safety.

b) by applying the technical solutions and calculation methods developed in the technical fire safety directives, or

c) **by a solution that partially or completely differs from the technical fire safety directives or national standards, if the designer can certify the equivalent level of safety**." [14].

At the time of the introduction of the 2020 version of the OTSZ [5], the Ministry of the Interior's National Directorate General for Disaster Management published the following notice on its official website:

"The amended National Fire Safety Code has entered into force

The amendment takes place after more than five years, since the amended National Fire Safety Code regulating fire safety in Hungary was adopted in December 2014. The Ministerial Decree (of the Ministry of the Interior) came into force in 2015, and its fundamental novelty was the separation of mandatory requirements setting the expected level of safety and optional (voluntarily applicable) solutions and methods to meet the requirements. The technical solutions and methods highlighted in the legislation have been transferred to the Technical Guidelines for Fire Safety ("TvMI"), which were also newly introduced in 2015. The revision of the Code was based on experience gained over the period of five years of and its processing. In addition to the staff of the disaster management authorities, a number of professional organisations were also actively involved in assessing how effective the rules had been in the course of the practical application of the rules, while providing suggestions, feedback and drafting the text of the standards. Consequently, the National Fire Safety Code created as a result of the amendment is based on a broad-scale professional consensus. In parallel with the finalisation of the draft legislation, the revision and extension of the technical guidelines for fire safety also began. Twelve existing directives have been amended, and two brand new directives - on explosion protection and risk classification - have been added to help the activities of designers.

The amendment of the OTSZ **further increased the freedom of investors and designers, the possibility to apply engineering methods, and even more emphasis was placed on supporting investments of key priority in terms of national economy. In addition to the aim of further strengthening fire safety, conditions have been created for** designing buildings **based on even more flexible rules and in a more cost-effective way**."

Review on Occupational Safety and Health Requirements

According to Act XCIII of 1993 on Occupational Safety and Health [15], the conditions for safe working conditions must be defined within the framework of legislation and applicable standards, as stipulated in Section 2 Subsection (3). Until the end of 2018, according to the provisions of Section 11, "[...] Taking into account the legislation on National Standardisation, a national standard with occupational safety content shall be considered as a rule on occupational safety, with the consideration that, in the event of the application of a solution other than the national standard in Hungarian language, the employer shall be obligated - in the event of a dispute - to prove that the solution applied by the given employer is at least equivalent to the requirement or solution contained in the relevant standard from the occupational safety point of view." As of the 1 January 2019, the wording of has changed to "[...] Taking into account the Act on National Standardisation, a national standard with occupational safety content entirely in Hungarian shall be deemed to be a rule on occupational safety." In this case, the employer's obligation to deviate from the legislation has been removed. In terms of occupational health and safety regulations, we can conclude that only a Hungarian-language standard can be mandatory, while the majority of harmonised standards have not been published in Hungarian.

The Institution of Design Harmonisation

The institution of design harmonisation was established by Act LVIII of 1996 on the professional chambers of design and expert engineers and architects [17] by virtue of the HUNGARIAN CHAMBER OF ENGINEERS' REGULATIONS OF PROCEDURE FOR PLAN DOCUMENTATION HARMONISATION [18]. The introductory Preamble of the Regulations states the following:

"Act LVIII of 1996 on the professional chambers of design and expert engineers and architects clearly stipulates that only designers who are members of the Hungarian Chamber, hold a designer' licence and are registered in the Official Register of designers are allowed to design buildings requiring building permits licence in Hungary in a responsible manner. All design stages of the design documentation must be prepared by an authorised designer. The status of legality must be ensured for all designs. There is no specific legislation on the nationalisation of technical designs for constructions, and it is not required. By enforcing the provisions of these Rules of the Chamber, the nationalised plan becomes legally applicable in Hungary. The resolution covers all phases of the designing process (tender design, permit design, construction design, etc.).”

The institutional framework of this design harmonisation could even be a key solution provider to the problems we are facing in the course of this research, which we consider particularly important in terms of safety aspects due to the following definition:

„Design harmonisation shall mean the sequence of actions by means of which designers with a designer license in Hungary, with the full undertaking of designing responsibility, carry out a review and revision of a design document prepared by a non-Hungarian (or even a Hungarian) designer, which is based on a non-Hungarian system of regulations, and which is recognised by the client, through which the status of legality will be established and the design document becomes compliant with the Hungarian legal system and regulations." according to the definition stated in the HUNGARIAN CHAMBER OF ENGINEERS' REGULATIONS OF PROCEDURE FOR DESIGN DOCUMENTATION HARMONISATION [18].

The institution of design harmonisation is no longer applied in law; it has been abolished.

2.2. Impact of International Investments on Ensuring Proper Explosion Protection Regulations

Hungary applied for membership of the European Union in 1993, and in 2004, we successfully joined the member states of this community. It was during this period leading up to accession when the economic and regulatory changes that were a prerequisite for any Member State to be able to harmonise its legal and economic framework with the EU systems took place. This was no different in the area of the regulations governing technical industries. The provisions of technical standards and regulations were also harmonised. These harmonisation acts altogether have the capacity to ensure that the free flow of goods and services and the conditions of legal certainty can operate in a single unity of real value within the EU, and only in a highly regulated way can it join the rest of the world outside the EU. Explosion protection regulations mean the rules that have been developed and established throughout the area of the EU, whether they concern a product or a protection system intended for use in a potentially explosive atmosphere, or even a technical solution for occupational safety. However, we have identified that in other unions or economic communities of the world, there are approaches and regulations, product standards or technical solutions different in form and in perspectives, which regulate the requirements for potentially explosive atmospheres in a different way. Hungary is a member of the EU and we are harmonised with the legal, economic and technical regulatory systems applied in the EU.

In the course of our work, we can increasingly encounter complete explosive technologies not only from the countries of the European Community, but also, quite characteristically, complete investments or production equipment, technological production equipment and production lines from three distant countries, China, South Korea and America. We had to adapt Hungary's economic, legal and technical framework to the EU spheres of regulations at the time of Hungary’s accession. In recent years, the question of a novel technical problem has become increasingly pressing: how is it possible to ensure that complete factories reinstated from outside the EU could meet the safety requirements in terms of explosion protection?

We have raised this question on the basis of our own observations; however, the problem is also identified more generally in terms of technical safety in an article by German and South Korean authors. According to the finding of the authors, the intentions to use hydrogen, known for its explosive properties, is a global trend in terms of decarbonisation goals and the security of energy supply, making the industry a focus of interest for policy makers and societies. The authors conclude that German national regulations impose overly stringent safety requirements, and therefore the industry **identifies the need to balance safety and technological development when** discussing the harmonisation of German and South Korean technical regulations.[8]

3. Assessment of Explosion Protection Solutions in Practice

In order to establish some sort of status reports on the level of compliance that the current regulations aim to achieve, we will analyse cases of explosion protection activities carried out in the scope of our own work activities. The referenced cases took place in the last 15 years; we seek patterns and repetitions among inadequately designed explosion protection solutions.

3.1. Unlawful disabling of Gas Leakage Sensors

In the case of potentially explosive areas, it is common to use gas detectors for fire protection and labour safety purposes, both indoors and outdoors. In the cases presented below, a typical, we have found a typical, often occurring and very serious breach of the safety requirements for explosion protection in the course of the periodic conformation inspection of systems operating for 3 years or more.

Picture 1 gas detector inhibition with adhesive tape

Picture 2 gas detector inhibition with aluminium foil

Regarding Pictures 1 to 4 and 5a, we identify the similarity and repetitively occurring phenomenon that the operation of gas sensor systems with technologies running in the meantime is deliberately disabled by unlawful human intervention. The means such disabling are effective, despite the fact that their implementation uses undesignated solutions that are found on site, including self-adhesive tape, aluminium foil, plastic shoe coverings, latex gloves and clear plastic bags. In the fifth case, the acknowledgement button of the signal processing centre that can be seen on

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Picture 5b, which belongs to the ethanol sensor (shown on Picture 5a) disabled with a plastic bag, is also disabled with a specially carved piece of stick supported by a steel support beam. The fact that these disabling activities took place is a serious problem, and so is that fact that they were maintained.

Picture 3 inhibition with plastic disposable shoe cover

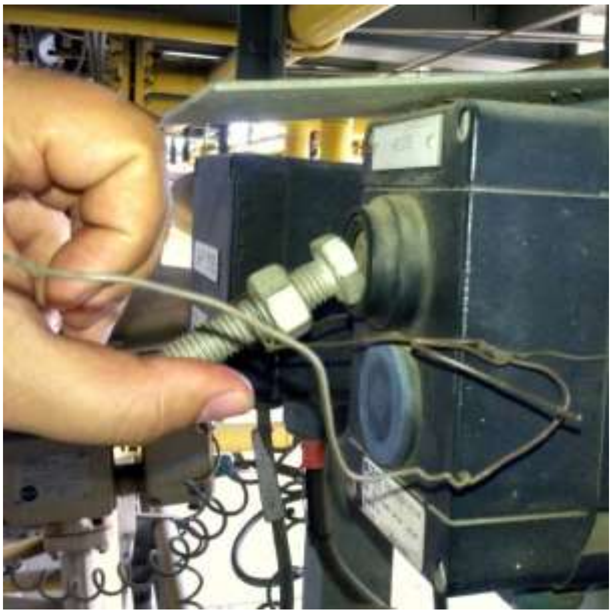
Picture 4 gas detector inhibition with latex gloves

Pictre 5a inhibition with transparent plastic bag

Picture 5b ack. button supported by a piece of wood

3.2. Unlawful Activation of Push Buttons

In addition to the previous solutions that disable the operation of gas sensors, another recurring violation of the rules is the solution of keeping push buttons pushed by "supporting" them. In all such cases, push buttons are used for starting or stopping operations requiring the presence of an operator in hazardous technologies, on the basis of fire and labour safety considerations. The issue is not about remote control not being potentially available in some cases, based on the technology level of our age. The issue in this case is that the presence of an operator is essential for operational safety and, ultimately, for explosion protection, and accordingly, the given process could only be carried out under the supervision of a responsible person being at the given location.



Picture 6 bolt supported pushbutton activation

Picture 7 spring steel wire fixing

Picture 8 flexible rubber hose insertion

Picture 9 shape-locking aluminium plate insert

Pictures 6 to 9 show a variety of ways by means of which parallel methods to gas detectors are intentionally and unlawfully used, i.e. after items found at the location have been made suitable for such purposes. These ways seriously violate the possibility of requirements of fire protection, occupational safety and health, and, accordingly, explosion protection, to be ensured and met.

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3.3. Consideration of Human and Organisational Factors Regarding the Mitigation of Risks

According to a problem statement and respective solutions developed by Chinese and Italian authors, the traditional risk management system for ATEX areas needs to take human and organisational factors into account, as they write in the article titled "ATEX-HOF Methodology: Innovation Driven by Human and Organizational Factors (HOF) in Explosive Atmosphere Risk Assessment" [20]. The basis for the activities associated with the disabling of a gas detector or pushbutton is not only due to faulty design or changed technological conditions; it is the fact that individuals within a given corporate safety culture can and do perform illegal actions leading to these dangerous conditions.

3.4. The Roles of Designers in the Applicability of Safety Considerations

In the past 2 years, we have been involved in the pre-installation design, permitting and then construction phases of two international projects in Hungary, where we have identified identical, pattern-like activities in engineering roles that are contrary to compliance with safety measures.

In one case, we were commissioned to work on a design harmonisation project for a biofuel technology. The technology was purchased by the end user from another European country, with the construction fully contracted to the technology license holder. The only thing the technology licensee was competent about is the technology procedures. However, that license holder had no experience in investments or even in meeting standard requirements, either in its country or in Hungary. The license holder contracts various foreign subcontractors in the scope of various partial tasks, the preparation of lightning protection plans in explosion hazardous areas, the classification of explosion hazardous areas, even also the preparation of the construction designs. The end user identified this source of risk, which is how we were commissioned to harmonise the designs in terms of explosion protection. As it has been reviewed in the framework of this article, the designer who harmonises and nationalises a design at the time of design harmonisation shall be deemed ultimately responsible for the harmonised design plan as if they were its own, and we have therefore started to request data to be supplied, in its entirety. We immediately encountered resistance when we asked for basic data on the ranges of the explosion hazardous zones, the pieces of information were hidden from us. Finally, upon having received the data, we concluded that the original designer was "incorrect" about the previously hidden baseline data, the quantity of hazardous materials, the gas properties and other technical values. After the correction of the respective data, the range of explosion hazardous zones increased significantly. When such errors are found, the need for a more effective regulation enforcement regime arises. In this particular case, a fundamental design content requirement was breached by the original designers when the input base data used for the design were not recorded in a way, and were deliberately hidden, so that a third party would not be able to calculate such data again. We wish to note that to the best of our current knowledge, design harmonisation is not required on the basis of legislations.

In another case, we identified problems in relation to the lightning protection designs for a chemical technology; in this case the first problem identified was the lack of a design. In relation to the primary containment system, type-based general practice solutions were applied at the design stage and the risk assessment was carried out in a simplified manner while hiding essential data. These are fundamentally inadequate conditions, construction can only be commenced based on detailed design drawings, and only detailed design drawings can be used by the electrical safety inspector to carry out their investigation. When assessing the basic data used for risk assessment, it was revealed that the original designer had concluded a more favourable arrangement, resulting in a low level of use of coordinated surge arrester devices. However, if correcting the previously hidden misinformation about the exact number of people spending a certain amount of time at the explosive technology area, and thus the designer takes into consideration the risk of loss of life in explosive areas, the most stringent protective measures to be applied and the mass use of coordinated surge arresters should be expected to be required.

In the cases presented as examples, the strong attempts to hide the basic data of the designs can be seen as a pattern, but in the given situation, the consideration of the basic data that were eventually revealed had to be corrected, resulting in the need to apply a less favourable technical solution in terms of installation costs. These corrections allowed the level of technical safety intended to be achieved to reach the appropriate level.

4. Conclusion

A recently published study (Jie et al., 2020)[20] as well as our own research activities lead to the conclusion that human and organisational factors have significant effects on the implementation and enforcement of the safety requirements of an explosive industrial technology.

Based on our case studies, we can conclude that, even within a framework of strict compliance with the traditional requirements of standards, we can find severely incorrect and repetitively occurring operating conditions in the practical implementations of potentially explosive atmospheres. The results of our more extensive research show that the root causes of the problems originate from the earlier and earlier stages of the life cycle of hazardous facilities. These can be related to the implementation nature of the investments coming from abroad on one hand, and, on the other hand, to the transforming system of increasingly permissive regulations. We have also concluded that the occurring hidden non-compliances will persist for longer and longer periods in the lifecycle of hazardous plants, they remain invisible in their hidden status, and will even entail new hazards and accumulate such problems and hazards in later lifecycle stages.

According to our assessment, the possibilities of applying non-standard technical solutions, either one-person solutions or solutions that are merely self-certified, should be assessed. There is a need for developing an institutionalised professional body that would legalise solutions that offer the same protection as the application of standards. For this purpose, we propose a committee of experts, set up from time to time by the Hungarian Chamber of Engineers, to assess technical solutions that are different from the standard but offer the same level of security. The this achieved result could be that a novel technical solution developed by a given designer would only be certified as suitable if the committee of experts also considers such solution as acceptable. If the assessment is positive, there should also be the same legal certainty as when a designer applies the standards without modification. According to the publication of the Hungarian Standards Organisation (2015) titled “Misconceptions and Facts” [16], this legal certainty is "presumed to be in conformity with the law when standards are applied voluntarily, and it is forbidden to be inspected by means of an investigation".

In the current changed regulatory framework, it is possible for a single designer to develop a solution that differs from the standard but provides the same level of safety as the standard. The use of a technical solution that is different from the standard does not currently give the designer of the explosion protection regime the same legal protection as the designer would get in the case of a standard solution, so the role of undertaking individual responsibility is significantly re-evaluated.

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