Autonomous Systems Landscape in Hungary: Model and the First Results of a Survey

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Abstract: The global economy increasingly responds to industrial digitization trends and develops its digitalization strategies, i.e., through application of Industry 4.0 concepts. Thereby, initiatives and developments are often carried out on a company-, industry- or country level. Hungary is one of the most industrialized countries in Europe since many leading car companies, together with their suppliers and related industries have production sites in this area. Witnessing the unprecedented scale and speed of industry transformation due to digitization in general and the emergence of autonomous solutions in all aspects of production and logistics in particular, it is well justified to deal with the question of what Autonomous Systems (ASys) will look like. How influential will it be when the changes' hard challenges and disruptive effects will be overcome, and what are the chances to meet the critical requirements of collaboration and cooperation? What are the technological and management tools to avoid being stuck in the so-called pilot purgatory? To analyse the ASys development status on a high level in the main part of this study, we introduce a conceptual model, including pillars and dimensions aiming to understand the Hungarian ecosystem in terms of ASys. The suggested framework follows a holistic approach in assessment by integrating the following pillars: ecosystem smart factory, human, product. In the second part a questionnaire's first results are presented: there is yet a lot to do to facilitate a definite turn in the mindset of the actors and to make them realize the relevance of simultaneous and continuous cultural and technological development. It's a newly developed, but already tested model to evaluate ASys ecosystems, which can be used in other countries, as well.

Keywords: Autonomous systems, Maturity model, Readiness assessment, Digitalization

1. Introduction

The term Industry 4.0 refers to the fourth industrial revolution, based on cyber-physical systems, i.e. the integration of real and virtual reality in a way that has never been done before, to achieve a new level of organisation and control of the entire value chain throughout the entire life cycle of products. This cycle follows increasingly individualised customer needs and extends from the conceptual design of the product, through its manufacture, to its delivery to the end user and finally to its recycling. ASys are an essential element of this.

ASys in manufacturing refer to the integration of advanced technologies and intelligent systems to enable self-governed and automated operations in the manufacturing industry. These systems utilize a combination of artificial intelligence (AI), machine learning (ML), robotics, and sensor technologies to perform tasks and make decisions without human intervention. According to Fottner et al (2021), Müller et al. (2021) and Ebert and Weyrich (2019), the key aspects of ASys in manufacturing are the following: Robotic Process Automation, Industrial Internet of Things, Machine Learning (ML) and Artificial Intelligence (AI), Autonomous Mobile Robots, Autonomous Quality Control Systems, and Autonomous Maintenance Systems. Based on the above-mentioned papers, the goal of ASys in manufacturing is to enhance productivity, improve product quality, increase operational efficiency, reduce costs, and provide a safer work environment. By automating repetitive tasks, optimizing processes, and leveraging data-driven insights, ASys enable manufacturers to achieve higher levels of performance and competitiveness in the global market.

Numerous maturity models can be found in the literature, most of which evaluate the overall readiness of a specific company for Industry 4.0. This study does not aim to extensively review existing models and readiness assessment methods, as others have already done so, such as Leyh, Schäffer, and Forstenhäusler (2016), Marheine, Gruber, and Back (2019), Leineweber et al. (2018), and Nick et al. (2019). Mittal et al. (2018) conducted a critical literature review on smart manufacturing and Industry 4.0 roadmaps, maturity models, frameworks, and readiness assessments currently available. They concluded that only a limited number of these models partially address the specific requirements and challenges faced by SMEs, as they primarily focus on solutions for large multinational enterprises.

In our research, as Synder (2019) emphasizes we conducted a literature review to understand the role of Asys methods, products, and services in relation to digital manufacturing and logistics. This review aimed to identify relevant application fields for inclusion in the maturity model's, as well as the application levels of Asys methods in research and industry. No papers or works directly assessing the ASys capabilities of manufacturing companies were found by the authors of this paper.

Regarding the evaluation method, some models rely on self-assessment, while others incorporate workshops or audits conducted by external experts. An alternative approach with minimal financial and labor-intensive efforts, time, and associated risks involves an online survey as input (with varying levels of result analysis for each model). For instance, the German Engineering Federation (VDMA) has developed two short self-assessment models specifically designed for small and medium-sized engineering companies (VDMA, 2015).

Following Teichert's (2019) six-step approach for developing a digital transformation maturity model, we utilized the same methodology for design this Asys model. The approach involved defining the scope, designing, populating, testing, deploying, and maintaining the model.

This paper also presents a model where the data collection was made by an online survey. The model focuses on industrial enterprises and their closely related service organisations. Research institutes, universities and professional associations are not included in the scope of the survey, as these organisations do not produce, manufacture specific products or provide logistics services, and many of the questions are therefore not meaningful in their case.

In this paper, adapted to the above points, a novel maturity model and a questionnaire is introduced, with the following aims 1) to assess the individual objective maturity level and capabilities of industrial firms 2) to assess the subjective needs and expectations of the actors of the domestic Industry 4.0 ecosystem.

2. The Definition System of the Model, the ASys and Industry 4.0

In this section the ASys aims (A1 - A4) have been summarized that are intended to serve as the foundation for the future fulfillment strategy, based on the model and the questionnaire we have developed. More precisely, the questionnaire is intended to assess the necessary steps contributing to their implementation, and here it should be deduced that we derived our model from the goals of Industry 4.0.

When evaluating the domestic situation of autonomous systems and aiming to create a model for that purpose, we essentially examine the direct or indirect fulfilment of the above statements and characteristics according to the established evaluation coordinate system.

In 2020, the Hungarian National Laboratory for Autonomous Systems has defined and set its own aims (see Table 1)

Table 1: Survey of the autonomous R+D sector related to ASys's goals

AIM	ANRL goals – full description	Decomposition of goals	The main question about the area of purpose	Connected Dimensions
A1	To solve R+D tasks demonstrating the functional and cooperative functioning of road and mobile robots mobility. To coordinate research, development and innovation activities.	Mobility-related R+D of road, aircraft and mobile robots demonstrating the functional and cooperative operation of systems, coordination activities.	Do you conduct mobility-related research? Which properties of the systems are being investigated?	Value chain Environmental criteria Organization and strategy Autonomous Systems dimension Knowledge transfer Sustainable product

AIM	ANRL goals – full description	Decomposition of goals	The main question about the area of purpose	Connected Dimensions
A2	Efficient and innovative solution of the above research tasks through the coordinated cooperation of the Hungarian professional and research community dealing with mobility.	Contact of research institute with industrial partner. Membership of professional organisations	Do you have connections to domestic mobile research institute? Are you a member of a professional organisation?	Organization and strategy Autonomous Systems dimension Knowledge transfer Sustainable product
A3	Compilation of relevant state tender materials and preparation of industrial projects.	Compilation of relevant state tender materials and preparation of industrial projects	Do you compile tender materials and prepare industrial projects?	Environmental criteria Organization and strategy Knowledge transfer
A4	Well-thought-out dissemination of knowledge necessary for the cultivation of research in the field through novel knowledge transfer mechanisms and traditional higher education channels.	Research knowledge in the special field, dissemination of this knowledge through all communication channels	What are the basic knowledge groups required for research in this field? Do you effectively disseminate your knowledge in this field?	Environmental criteria Organization and strategy Employment Dimension Knowledge transfer User Product and Service Demand

3. Model Description

The model is built on 4 pillars (Ecosystem, Smart Factory, Human, Product) which consist different dimensions. Table 2. visualizes the model structure. The realization of the following four objectives is expected as a result of the Industry 4.0 vision (Monostori et al. 2016; Bauernhansl et al. 2014):

- Horizontal integration: The smart factory constantly adapts to new circumstances in its environment (e.g., order backlog and availability of materials) and optimizes its production processes. This is achieved through integration with suppliers and customers within the value chain.
- Vertical integration: In the smart factory, people, machines, and other resources are represented in a digital model and communicate with each other through cyber-physical systems.
- Smart products: These products possess information about their own manufacturing processes and are capable of collecting and transmitting data about their manufacturing and usage phases throughout their lifecycle. This enables the digital modeling of the smart factory and the development of service offerings based on product data.
- The human being is the controller of value creation and is at the center.

By analyzing the above definitions of Industry 4.0 and aligning them with the stated objectives, we have developed our own model's framework and dimensions.

Table 2: Pillars and dimensions of the model

Industry 4.0 aim	Pillar	Topics	Dimensions
Horizontal integration	Ecosystem	Strategic characteristics of the company, overview of the local environment, methods to improve to reach the horizontal integration.	Value chain Environmental criteria

Industry 4.0 aim	Pillar	Topics	Dimensions
Vertical integration	Smart Factory	Physical realization of ASys, to achieve the *vertical integration* aim of Industry 4.0, application of cyber-physical systems, digital models.	Organization and strategy Autonomous Systems dimension
Human	Human	Highly skilled human resources are key to competitiveness, importance of education and training, targeted collaboration between industrial and academic sectors.	Employment Dimension Knowledge transfer
Smart product	Product	Smart products collect and transmit data about themselves during their usage phase. Services can be products as well.	Sustainable product User Product and Service Demand Dimension

3.1 Ecosystem Pillar

This pillar encompasses the strategic characteristics of the company, including management, statistical data and the overview of the local environment. The descriptions of local resources examine the company's immediate operating environment and the characteristics of the local market.

The model includes questions regarding the appearance of necessary services in the local market, focusing on their quantity, quality, and prices. The feasibility of environmental consciousness and sustainable development raises questions about the company's behavior regarding conscious energy and material utilization, as well as their applied manufacturing methods – which are necessary to improve to reach the *horizontal integration* aim of Industry 4.0.

3.1.1 Value chain dimension

The role of the company in the value chain and the knowledge it brings as added value provide insights into how a company can position itself in global markets. Conclusions can be drawn and based on the number of partner relationships, organizational structure, and operational philosophy.

The extent to which a company supports open innovation and how active innovation management is conducted are also relevant to this approach. The dimension includes questions about the **supplier network**, which encompasses all the actors in the supply chain who supply finished products, as well as those who provide the supply of raw materials, semi-finished products, commercial goods, and other manufacturing and logistics equipment.

External IT services also play an important role, and in the model, they refer to the IT and telecommunications services provided by external, independent companies that support or assist in day-to-day operations.

3.1.2 Environmental criteria dimension

This dimension refers to everything outside the factory gate that does not involve the government sector and includes all the partner relationships in which the company participates for economic reasons, including consumers of their products and services. Providing a national infrastructure that enables **horizontal integration** in the digital world is a fundamental prerequisite for realizing Industry 4.0 (see Table 2).

Implementation of ASys can only be successful in an environment that allows for **standardized communication** both within companies and between companies, and that actively and openly incorporates the results of technological innovations into everyday life, benefiting not only economic entities but also individuals, society, and communities. This requires an innovation-friendly legal and regulatory environment, in which the state must also play a role through the implementation of its financing and policy tools (see A3 in Table 1).

3.2 Smart Factory Pillar

The Smart Factory question group evaluates the physical realization ASys, to achieve the *vertical integration* aim of Industry 4.0. Logistics and manufacturing are now closely integrated, so it is advisable to examine the qualitative and quantitative characteristics of the available resources in both areas simultaneously, as well as the company's relevant development plans. In a smart factory, continuous data collection and digital model building takes place for production-specific information, so it is interesting to assess in which areas and to what extent this occurs, and what IT regulations are made to ensure security.

3.2.1 Organization and strategy dimension

In this dimension, the primary question is whether the company can align its competitiveness with growth towards a higher level of maturity. It is essential to identify the key areas and measures where the greatest value generation occurs. To become a true digital enterprise, a clear vision and a documented, evaluated strategy are also necessary: the primary question is whether the company sees the connection between competitiveness and ASys. It is essential for leaders to have a clear understanding of the concept of ASys and to have a shared vision for the company. In terms of mindset, it is relevant to assess how much support is given to open innovation and whether active innovation management is conducted in the company's key areas for ASys development. (see A2 in Table 1).

3.2.2 Autonomous systems dimension

The evaluation of a company's capabilities should take into account the physical resources required for value creation, the processes taking place in the virtual world, and the characteristics/traits of humans (who connect all system elements, interpret data, and manage the system). It is also necessary to analyze existing equipment, future development directions, challenges, and opportunities related to the suitability for using/applying cyber-physical systems.

In terms of logistics systems, today's technologies already hold significant potential. E.g., Autonomous Mobile Robots (AMRs) replace the position of AGVs with advanced, flexible, and cost-effective technology. The **IT infrastructure** of companies is also a key element of ASyS maturity. Appropriate network infrastructure is required for data collection, transmission, storage, and analysis. Appilcation of cyber-physical systems (Monostori, 2015) can also improve the ASys readiness of a company.

3.3 Human Pillar

Highly skilled human resources are key to competitiveness, and attracting, retaining, training and continuously motivating them can be a major challenge, especially for SMEs who are striving to achieve the human-related goals of Industry 4.0. Due to the high costs of in-house or company-funded adult learning, it is mainly large companies that can afford to train their employees on an ongoing basis. Enterprises often face a shortage of skilled labour, which can be partly explained by training gaps and lower digital competences of the ones leaving the education system. (see A4 in Table 1).

3.3.1 Employment dimension

No matter how technocratic our vision of the future may be, it is essential to place the human at its center. In this dimension, we examine the internal training programs, the human resource processes existing within a company, and how they evaluate the competencies of their employees in relation to the future expectations arising from ASys. The success of implementing ASys significantly depends on knowledge, expertise, and capabilities. Digitalized workplaces demand a new work culture, where the significance of traditional working hours decreases, and result-oriented performance evaluation takes the forefront.

3.3.2 Knowledge transfer dimension

Cooperative groups operating in the economy highlight the intensive and targeted collaboration between the industrial and academic sectors, known as triple helix relationships (Leydesdorff and Etzkowitz, 1998). This involves identifying common research topics, initiating joint activities that combine theoretical and practical knowledge, and concentrating the entities of the economic, academic, and governmental spheres spatially to support faster innovation creation and diffusion (see A4 in Table 1).

3.4 Product Pillar

It is essential to know to what extent respondents are active in terms of innovation regarding both products and services, as well as processes and methods, as Smart Products are likely not yet widely produced in domestic factories. A characteristic of smart products is that they collect and transmit data about themselves during their usage phase. The question is whether the manufacturer utilizes this data, and if so, where and in what specific areas, i.e., to what extent the company is characterized by services based on product data.

The evaluation of smart products, services, and their closely related stakeholders such as customers, suppliers, and business partners are carried out in this fourth pillar.

3.4.1 Sustainable product dimension

Lifecycle management refers to the tracking of products throughout their lifecycle in the spirit of sustainability. During this procedure, the possibilities for product development that can respond to constantly changing user needs are collected, and their feedback is integrated into the design and manufacturing phases. At the current level of digitalization, it is possible to incorporate essential elements of reusability, refurbishment, and recyclability into product development and manufacturing, thereby reducing their ecological footprint, but also considering economic perspectives. Nowadays, interoperability with other manufacturers' products and systems is also a crucial factor to consider. (see A1 in Table 1).

3.4.2 User product and service demand dimension

In today's consumer society, the product and the user should be treated as a pair. The same product can be used differently by two different consumers. Exploring these differences and harnessing the potentials within them is a highly forward-thinking business strategy.

Digitization establishes the foundation for this new mindset, providing tools to uncover attitudes based on specific consumer feedback and data provided by the devices. Shifting towards selling services could be the future for many companies, where an increasingly smaller portion of revenue comes from the product itself, and a larger portion comes from related services that can be offered throughout the product's lifecycle.

Autonomus systems can raise services on higher level as they are more flexible, they can adapt themselves to personal demands and can handle unexpected situations well.

4. First Results

This article presents the results of a comprehensive national survey aimed at assessing the state and possibilities of digitalization in Hungarian companies. The survey questionnaire was completed by more than a hundred participating companies.

Regarding the size distribution of respondents, the survey included micro-sized companies (2%), small-sized companies (23%), medium-sized companies (45%), and large-sized companies (30%). Notably, the majority of respondents were from medium-sized companies. In terms of ownership structure, the survey revealed that Hungarian ownership was dominant, accounting for 40% of the companies surveyed. Additionally, 34% of the companies were exclusively owned by Hungarians, 19% had majority foreign ownership, and 7% were exclusively owned by foreigners. Notably, no responses were received from state-owned companies.

Regarding industry classification, the respondents were evenly distributed across various sectors (see Figure 1)

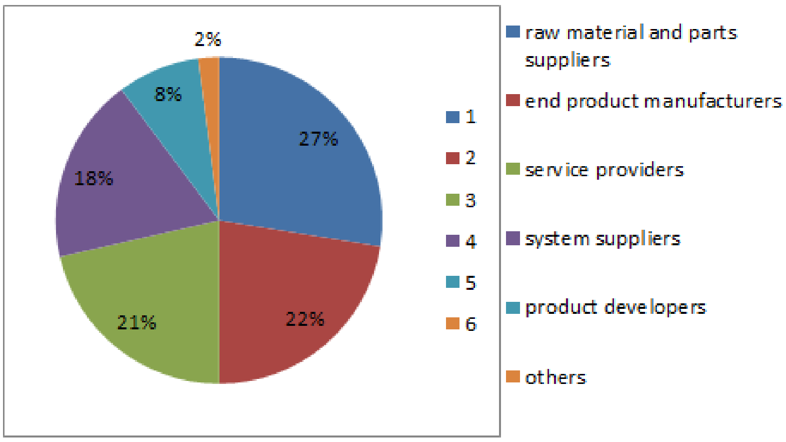

Figure 1: Dashboard visualizing the respondents in term of sectors

Ecosystem pillar, Value chain dimension: During the assessment of the value chains, the primary question was their number (below 10, between 10 and 50, over 50), how many domestic and foreign suppliers and exporters the companies are in contact with. Domestic small and medium-sized companies mostly have between 10 and 50 domestic and foreign suppliers, among which there are generally more domestic suppliers, while on the supplier side they are more separated, with either low (less than 10) or high (over 50) customers. All large companies have over 50 supplier and customer relationships.

To the question assessing the technological need for autonomous systems, "In your industry, to what extent is the support of business and sales processes with autonomous systems typical or will it be typical in the given time frame?" In the short-term (2023) and medium-term (2024-2025), regardless of industry, more than 80% of the respondents gave the answer "to a large extent", at a higher level than completely, the answers from the vehicle manufacturing industry were overrepresented. At a lower level than this, 15% of the respondents answered, "to a certain extent", and no answer was received that "autonomous solutions are not typical in this area", and answers to "not justified" were also possibly received, without industry distinction.

Ecosystem pillar, Environmental criteria dimension: The environmental criteria mainly focused on questions related to the availability and financing of innovation, as well as the evaluation of areas related to sustainable development. Along the dimension, it turned out that more than 80% of the companies need external help to assess the operation of their processes, their products and services, improving efficiency, optimizing processes, uncovering possible errors, evaluating processes, steps that can be refined in order to explore. Each company identified at least two of the options as challenges related to this: lack of capital, availability of expertise, training, further training, existing outdated production technologies, processes and lack of local cooperation opportunities. Most of them used some form of EU grant (32%), domestic grant (12%), own funds (11%), development loan (10%) to finance the current and past corporate industrial digitization developments and research. Regarding how the state could contribute to the success of industrial digitalization in Hungary, the areas primarily indicated by large companies are the financing of target programs, State / MNB business development lending policy, infrastructure.

Smart Factory pillar, Organization, and strategy dimension: The organizational principles, discussed earlier in this chapter, serve as a significant differentiator, and provide insights into the characteristics that best distinguish the participating companies based on their size, industry, and location. In terms of digitalization strategy, companies were given the option to indicate its existence and current status. It is evident that large companies have a digitalization strategy in place and are actively implementing it. However, nearly half of the small and medium-sized companies do not have such a strategy. Among the remaining two-thirds, the majority are in the development phase, with a smaller portion already implementing their strategies. More than 83% of the respondents expressed the need for their company's processes to be digitally represented and interconnected. However, currently, only large companies have implemented a digital twin process representation, accounting for a mere 27% of the total. Even among these larger companies, the implementation is only partial at the company level.

Smart Factory pillar, Autonomous Systems dimension: The Autonomous Systems dimension played a significant role in the survey, examining both past investments and developments as well as future plans from various perspectives. In the previous year, 67% of the companies undertook developments and investments in support of autonomous solutions. The realized projects predominantly focused on production and manufacturing (42%) and logistics (31%), with additional emphasis on supporting non-primary activities such as quality assurance (21%), sales (11%), and partnerships (7%). When asked about the utilization of automated tools/equipment in production processes and logistics, all large companies responded affirmatively. Additionally, 37% of medium-sized companies reported using such tools, primarily in production processes. Regarding future plans for expanding the use of these devices, there was a clear continuation of expansion among current users, and 68% of non-users expressed their interest in adopting these technologies. Regarding the timing and completeness of robotic and autonomous solutions, it is evident that companies expect progress in the short term (2023) and medium term (2024-2025). However, achieving complete implementation is not a medium-term goal for current technology users.

These findings highlight the increasing adoption and investment in autonomous systems, with companies recognizing their potential for improving efficiency and performance across various areas of operation. While large companies lead the way in implementing these solutions, there is growing interest and willingness among smaller enterprises to embrace this technology in the near future.

Human pillar, Employment dimension: An important consideration in the survey was the impact of implementing autonomous devices, systems, and technologies on the conditions of human work. Two-thirds of the companies expressed similar views on this matter, with almost equal proportions of acceptance in responses such as 'New jobs will be created' and 'Some jobs will disappear, but new roles will emerge', as well as 'Robots are meant to support workers' and 'Robots and machines will replace traditional manual labor'. Additionally, 96% of the companies agreed that new types of skills and qualifications are necessary to adapt to the changing working conditions.

The survey also shed light on the availability and perceived value of specific organizational units and expertise within the companies. Half of the respondents indicated having organizational units for 'Automation of production and logistics' and 'IT support of business processes', while 'Production and production optimization', 'Data analysis and evaluation', and 'Development and introduction of autonomous systems' were present in only one case each or not available at all. The presence of an internal team for the development and introduction of autonomous systems was reported by less than 3% of the companies, and the question on 'Manufacturing and production optimization' received relatively low responses (below 15%).

Human pillar, Knowledge transfer dimension: In terms of knowledge transfer, participants were asked about the areas in which they conduct internal training programs. The most common training topics included robotics, autonomous systems, Big Data management, and additive processes (e.g. 3D printing), while areas such as data protection and innovation management were less frequently covered. Most companies, regardless of size, had at least two training areas, with large companies covering almost all training topics. The labor market availability of specialists was also assessed. Companies were asked to rate the availability of specialists in various areas as satisfactory, partially satisfactory, or unsatisfactory.

Product pillar: The survey aimed to explore the customer needs that companies were preparing to address in the future. The results indicate that more than four-fifths of the respondents are equipped to adapt their production processes to accommodate "Higher complexity" and "Individual production." However, only 31% of the respondents intend to consider aspects such as the "Incorporation of smart, autonomous capabilities," "Environmental awareness," and a "Shorter product life cycle," with less than 15% representation for each of these factors.

The product life cycle holds valuable insights for future development and production. However, the data generated during the production or usage of products or services is primarily utilized by large companies. It is worth noting that a common attitude emerged among these companies, where the data is collected but not evaluated. Moreover, on a smaller scale, many companies do not even collect such data.

5. Conclusions

Due to the exponential advancement of technology, digitalization is indispensable for domestic companies. While we can say that Hungary's lag in this field is only a few years, the rapid development makes this lag much more significant in absolute terms than in previous decades. Among the national-level factors influencing readiness for ASys, we must mention the general guidelines resulting from digitalization policies, which affect the operational processes of businesses at a general level. Digitally accessible government services (e-government), strengthening online trust and security, and expanding fast and efficient electronic administrative procedures are essential for harmonious development.

Large companies demonstrated more extensive supplier and customer relationships, while smaller companies often had industrial partnerships. The majority of respondents expressed a strong need for autonomous systems in business processes. Challenges related to financing, expertise, and outdated technologies were identified in the environmental dimension. Companies recognized the importance of new skills and qualifications to adapt to changing working conditions, and knowledge transfer through internal training programs was prevalent, although specialists in certain areas were lacking in the labour market.

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