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Surveying the landscape of Human-Centric Manufacturing in Lombardy: insights from the practices and perspectives of Italian enterprises

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Abstract

The ongoing technological changes raise the need for socially sustainable paths of digital innovation, putting technology at the service of humans positioned at the centre of production processes. Indeed, in digital factories, where increasingly complex and high-performance models and technologies are strongly considered, humans have been almost neglected. In that sense, Industry 5.0 recognizes worker well-being as a driver for the transition toward smart factories. However, human-centric manufacturing is still an early-stage concept, thus lacking standardized terminology and frameworks. The development of a shared understanding is also hindered by stakeholders being concerned about job displacement, costs, or uncertainty about the benefits. This article aims to bridge that gap by mapping the state-of-the-art of several Italian companies in terms of technology readiness and human friendliness, thus providing best practices and solutions to foster the technological transition required by Industry 5.0 and the development of trustworthy human-machine synergies. A specific survey questionnaire was developed to evaluate the digitalization level of companies in terms of funds destination, technology development, and integration with operators. The data gathered through the survey allowed the definition of a model that highlights a general attitude toward innovation and human centrality, even though the latter still results far from maturity.

Keywords: Industry 5.0; Human-centric manufacturing; Human centrality; Digitalization

1. Introduction

With the advent of the steam engine and the mechanization of manufacturing processes, the 1st Industrial Revolution allowed the replacement of human labor with Craft production, characterized by low production volumes and low product differentiation. The 2nd Industrial Revolution saw the integration of electricity and the introduction of assembly lines, which allowed a shift toward mass production and fabrication of standardized goods on a large scale. The employment of electronics, information and communication technology (ICT), and field-level computers during the 3rd Industrial Revolution led to decentralized production systems and the rise of mass customization. Nowadays, the 4th Industrial Revolution brings together nine enabling technologies [1], i.e., big data and analytics, autonomous robots, simulation, system integration, industrial Internet of Things (IoT), cybersecurity, cloud, additive manufacturing, and augmented reality to achieve a smart manufacturing paradigm that enables mass personalization. Even though the manufacturing paradigm has undergone a substantial evolution since the 1st Industrial Revolution, the same system-centric principles have prevailed up to Industry 4.0, aspiring to maximize productivity and efficiency by keeping up with automation while restricting humans to a subservient role [2].

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The ongoing technological changes of our era share the stage with the pursuit of a societal development that is not oriented to the Gross Domestic Product (GPD), but rather driven by the concept of a well-being economy powered by the mutual reinforcement of long-term economic growth and individual well-being [3]. Observing that Industry 4.0 is focusing more on increasing production efficiency and flexibility at the expense of social fairness and sustainability [4], the digitalization trends set into motion over the past decade need to be complemented by socially sustainable paths of digital innovation, putting technology at the service of humans positioned at the center of production processes. In this scenario, the term Industry 5.0 (I5.0) was first introduced by Micheal Rada for entailing the use of collaborative robots to help human workers perform their tasks [5]. This vision recognizes that the growing degree of automation should be exploited for the delegation of dull, dirty, and dangerous jobs to machines, thus creating new emerging roles for human beings to work alongside intelligent systems [6,7], combining technology and digital skills with uniquely human skills to yield the highest productivity in a human-machine symbiosis setting [8]. Through Industry 5.0, the European Union envisions "the power of industry to achieve societal goals beyond jobs and growth, to become a resilient provider of prosperity, by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the center of the production process" [9]. This means that values can be encouraged by tailoring technology and that technological innovation can be built on ethical objectives [10]. Thus, the new Industrial Revolution finds its roots in three interconnected core principles: human-centricity, sustainability, and resilience.

Human-centricity is a key prerequisite for the future of the industry. By putting human needs and interests at the heart of production processes, workers can finally be considered investments rather than costs, thus achieving a new human- and society-centric manufacturing paradigm [4]. This concept allows the creation of a safe and inclusive work environment in which physical health, mental health, and well-being are prioritized, and fundamental rights of autonomy, human dignity, and privacy are safeguarded [9].

Sustainability is needed to respect planetary boundaries. Natural resources must be re-used, re-repurposed, and recycled for waste and environmental impact to be reduced, ultimately leading to a circular economy with better resource efficiency and effectiveness [9].

Resilience refers to the need for the industry to achieve a degree of robustness high enough to respond to geo-political shifts and natural emergencies, and to better provide and support critical infrastructures in times of crisis [9].

Even if it is still debated whether Industry 5.0 is a complement to the paradigm of Industry 4.0 or a completely new evolutionary advancement [4,11,12], the research field surrounding the concept of Industry 5.0 is experiencing rapid expansion. Since the publication of the first related academic article in 2016 [13], Industry 5.0 has shown an upward trajectory with exponential growth in publication volume in recent years [14].

To ensure the implementation of enabling technologies and paradigms of Industry 5.0, enterprises need to be guided through support and expertise. The first step in conceiving and implementing a successful innovation strategy is to map the current state of companies [15]. However, there is still a lack of developed Maturity Models (MMs) for Industry 5.0 and existing MMs for Industry 4.0 do not take into account human-centered approaches, in particular for what concerns small-medium enterprises (SMEs) [16].

Considering that the inclusion of industry partners and stakeholders is a key element in increasing the acceptance and ensuring the practicality of results [17], this article proposes a first exploratory quantitative analysis that aims at mapping the human-centricity level of different-sized Italian companies (large, mid-cap, and small-medium enterprises) in terms of technology readiness and human friendliness. Data were collected through a specifically devised survey questionnaire and analyzed to identify the potential benefits provided by Industry 5.0 technologies and the barriers to their implementation. The results of the present study, stratified per company size, are discussed to provide best practices and solutions to foster the technological transition required by Industry 5.0 and the development of trustworthy human-machine synergies.

2. Research methodology

A survey approach was adopted for this study. The case studies were collected considering the pool of industrial partners of Intellimech, a consortium operating in the Lombardy region to fill the gap between the research and industrial sector. The consortium currently involves 52 high-tech enterprises, making it one of the most important Italian private initiatives in this field. Access was granted to a variety of companies with different dimensions (large, mid-cap, and small-medium enterprises) and levels of digital intensity [18], as well as operating in different industrial sectors [19].

A structured web-based survey was devised and deployed to map the enterprises' level of adoption of human-centric principles and technologies and to identify best practices to help them fulfill the transition toward Industry 5.0. A set of preliminary information was first collected to identify the industrial sector, the role of the respondents, and the size of each company. The core of the survey questionnaire was then composed of 60 questions, organized in 8 sets as reported in Table 1. The items included both multiple-choice and Likert scale questions.

Once finalized, the web-based survey was distributed to all 52 industrial partners of Intellimech, and responses were collected between June and July 2022. A total of 28 complete responses were received and stored, thus translating to a response rate of 54%. The most frequent response and the range of responses were identified for each item to assess central tendency and variability, respectively. Given the reduced variability of the responses, the results in Section 3 were presented in terms of average values or percentage of respondents.

Table 1. Survey structure and topics.

Set	Topic	Questions
I	Destination of funds and investments	8
II	Integration of assets management and interconnectivity of ICT systems	2
III	Digitalization level	4
IV	Employees engagement	2
V	Impact of internal processes on enterprise success	7
VI	Adoption of I5.0 core concepts	10
VII	Knowledge and implementation of I5.0 technologies for direct and indirect employees	23
VIII	Benefits and barriers related to I5.0 technologies for direct and indirect employees	4

3. Data analysis and results

This section provides a brief description of the main results of the questionnaire and the proposed map of human-centricity levels. Considering the aim of the study to stratify the analysis based on company size, the acquired sample of 28 Italian companies was composed of 11% large enterprises, 46% mid-cap enterprises, and 43% small-medium enterprises.

3.1. Survey main results

3.1.1. Priority of present and future investments

Present and future investments in terms of automation, quality monitoring, and safety and ergonomics were assessed by means of six Likert scale questions. The answers were classified as “very low”, “low”, “average”, “high”, and “very high” and later coded on a scale from 0 to 4. The results in Fig. 1 show that priority is mainly focused on automation regardless of company size, with budgets being kept almost unaltered. Mid-cap enterprises foresee the highest increase in investments in quality monitoring, as well as in safety and ergonomics, even though the priority will still be lower compared to automation. The analysis also highlights how the importance placed on investing in safety and ergonomics increases with company size.

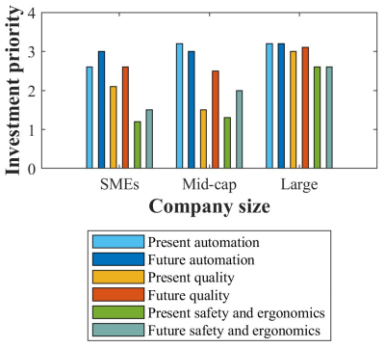

Fig. 1. Present and future investments stratified per company size.

3.1.2. Involvement of employees in the innovation process

The involvement of employees in the innovation process was evaluated through a Likert scale question in which the answers were classified as “very low”, “low”, “average”, “high”, and “very high” and later coded on a scale from 0 to 4. Fig. 2 shows that the highest score is achieved by large enterprises, probably due to structured bottom-up procedures engaging employees from all levels. It is also highlighted that SMEs score higher than mid-cap enterprises. Such a result might be attributed to a greater ease in directly engaging a lower number of employees.

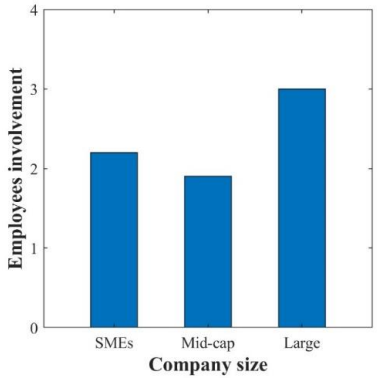

Fig. 2. Involvement of employees in innovation stratified per company size.

3.1.3. Economic, social, and environmental sustainability

The sensitivity of enterprises toward sustainability was evaluated through three Likert scale questions assessing economic, social, and environmental sustainability. The level of sensitivity was classified under “very low”, “low”, “average”, “high”, and “very high” and later coded on a scale from 0 to 4. The results in Fig. 3 show that economic sustainability represents the main priority for all company sizes, with large enterprises having the highest scores for all three topics.

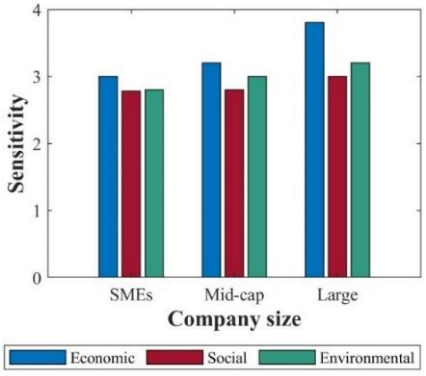

Fig. 3. Sensitivity to sustainability stratified per company size.

3.1.4. Social sensitivity

The social sensitivity of enterprises was assessed through six Likert scale questions, each one evaluating a different topic among safety, valorization of competencies, ergonomics, automatization of dull and repetitive tasks, corporate welfare, and inclusivity. The level of sensitivity was classified under “low “average”, and “high” and later coded on a scale from 0 to 2. Fig. 4 shows that regardless of company size, safety is put

in the first place, most probably due to the strict standards in that domain, while the valorization of competencies appears in either the second or third place. It is interesting to notice that SMEs hold corporate welfare in high regard compared to mid-cap and large enterprises, which leave it in the last place. This might depend on SMEs not having the resources to provide employee benefits on their own, making them reliant on corporate welfare to provide support.

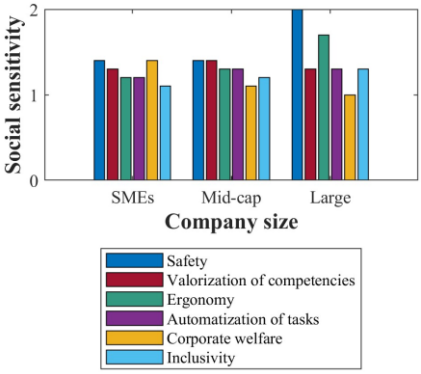

Fig. 4. Social sensitivity stratified per company size.

3.1.5. Implementation of Industry 5.0 technologies

The knowledge and implementation level of each Industry 5.0 technology was evaluated through a Likert scale question with four possible scores, i.e., “not known”, “known”, “known and implementable”, and “known and implemented”. Two sets of questions were used to separately assess direct employees and indirect employees supporting technologies. All the considered technologies were chosen according to Gartner’s 2022 Hype Cycle [20].

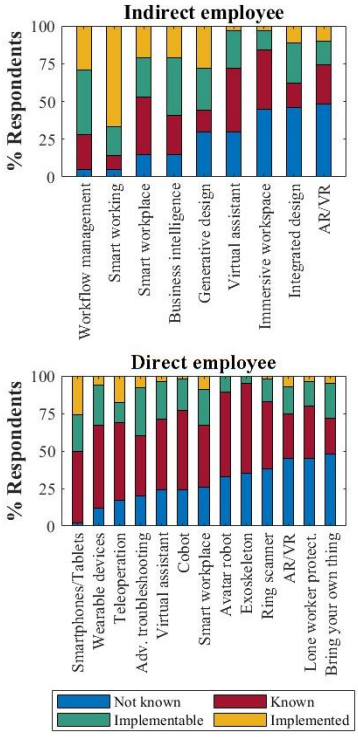

Fig. 5. Knowledge and implementation level of I5.0 technologies.

Fig. 5 shows that all technologies are known by at least 50% of the respondents. As concerns indirect employees, the responses highlight that the most known technologies are not necessarily the most implemented or implementable, as in the case of smart workspace. As concerns direct employees, no company implemented either avatar robots or exoskeletons, probably because of the high costs required. Bring your own thing (i.e., a policy that permits the use of employees’ mobile devices to access company information and perform their jobs [21]), as well as tablets and smartphones for digitalization, are the most implementable technologies as easily expected. It also appears that the respondents are more informed about the possibility of implementing AR/VR technology for direct employees rather than indirect employees.

3.1.6. Benefits from the implementation of I5.0 technologies

Two multiple-choice questions were used to ask respondents which benefits I5.0 technologies brought (or would bring) to direct and indirect employees. The results in Fig. 6 show that the development of new competencies, work safety, and productivity are the most expected benefits for indirect employees. On the other hand, productivity, workplace safety, and psychophysical well-being are the major benefits for direct employees. It is interesting to notice that economic growth is perceived as a benefit brought only from technologies supporting indirect employees.

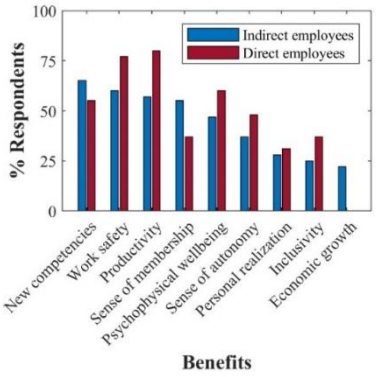

Fig. 6. Benefits brought to indirect and direct employees.

3.1.7. Barriers to the implementation of I5.0 technologies

Two multiple-choice questions were used to ask respondents which barriers were perceived as hindering the implementation of I5.0 technologies for direct and indirect employees. Fig. 7 shows that implementation times and costs, conservative workers, and lack of internal competencies represent the main barriers to the introduction of technologies supporting both indirect and direct employees. In particular, it results that the barriers are perceived as more hindering for the latter. It is interesting to notice that the managerial mindset is not perceived as a barrier, most probably because the industrial partners of Intellimech are prone to innovation.

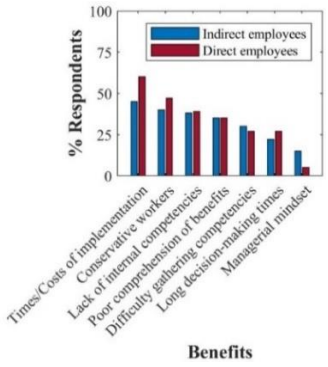

Fig. 7. Barriers for indirect and direct employees.

3.2. Human-centricity mapping

The human-centricity level of companies was mapped considering all the questions in the survey, except for those identifying benefits and barriers related to the implementation of I5.0 technologies. The score assigned to each answer was converted to a percentual scale by dividing it for the maximum achievable score. The questions were used in variable numbers to define ten evidences, each describing a different technological or social aspect of the propensity toward human-centric manufacturing. Technology-related evidences were then grouped into three evaluation criteria, i.e., automation-centric innovation, technology maturity, and availability of economic resources. Instead, social-related evidences were grouped into two criteria, i.e., social awareness and human-centric innovation. The score of each criterion was calculated as the average of the percentual scores assigned to all the pertaining answers. Finally, two indicators termed technology readiness and human friendliness were proposed and calculated as the average of the scores of the respective evaluation criteria. A summarization of how the indicators were obtained is provided in Table 2.

Table 2. Relation between indicators, evaluation criteria, and evidences.

Indicator	Evaluation criterion	Evidence
Technology readiness	Automation-centric innovation	Focus on I4.0 projects and assets
	Technology maturity	Automation level
		Interconnection level
		Priority of automation in future investments
	Availability of economic resources	Propensity to investment in R&D
Human friendliness	Social awareness	Involvement level of employees in the innovation process
		Importance level of human factors for enterprise success
		Attention toward employee well-being
	Human-centric innovation	Priority of employee well-being in future investments
		Knowledge and implementation level of I5.0 technologies

Based on the aforementioned indicators, a map of human-centricity stratified per company size was outlined (Fig. 8). The technology readiness and human friendliness scales were used to propose four categories: followers, human-oriented, automation-oriented, and human-centric. Most of the sample can be identified as automation-oriented, thus technologically mature and characterized by a pronounced tendency for innovation. The map also highlights that a good number of companies can already be defined as human-centric. However, the general propensity toward the adoption of human-centric approaches appears yet far from maturity, and a particular size-based segmentation cannot be observed.

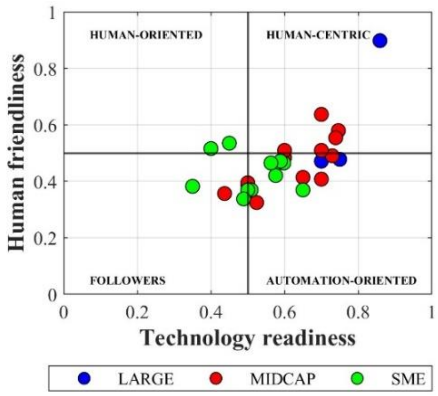

Fig. 8. Stratified map of human-centricity level

4. Discussion and best practices proposal

This study underlines that local enterprises are still behind in the transition toward the Industry 5.0 paradigm, with the situation being more evident as the size of the company decreases. The results of this investigation indicate that despite a strong propensity for automation and innovation, companies are still far from a mature adoption of the human-centric approach. The elaboration of the collected information highlights the scarce adoption of I5.0 technologies despite good knowledge of the same and the benefits they would bring to employees. The respondents indicated the times and costs of implementation as the main barriers to the development of I5.0 technologies. However, it emerged that conservative workers and lack of competencies are also recognized as important drawbacks. Considering that the respondents perceived management mindset as open to innovation, the skepticism of conservative workers may be due to factors such as lack of trust and comprehension, fear and resistance to change, as well as attachment to traditional practices. On the other hand, the lack of internal competencies may be a symptom of either insufficient investment in workforce training or incapacity in retaining skilled employees. Investing only in technology is therefore not sufficient. Enterprises also need to invest in the well-being of their workforce and in the workforce itself, engaging employees in the innovation chain and fostering both their personal and professional growth.

Based on the previous considerations, the authors propose hereafter a series of best practices to help enterprises in the technological transition required by Industry 5.0 and the development of trustworthy human-machine synergies.

4.1. Bottom-up innovation strategies

Typical of startups, bottom-up innovation strategies encourage employees at all levels to contribute their ideas and take full ownership of the innovation process. As more people get involved, viewpoint diversity increases and a higher number of new ideas can be gathered. Adopting a bottom-up approach can help foster creativity, as well as increase motivation and productivity.

4.2. Incentivization policies

New internal incentivization policies should be structured to reward productivity not only in terms of money but also in terms of personal enhancement. Incentives should promote physical and mental well-being, as well as offer opportunities for professional growth and the development of new skills. Structuring an efficient welfare plan enabling a safe and healthy work environment would allow companies to increase engagement and retention of skilled employees.

4.3. Industry 5.0 dedicated figures and teams

The transition towards Industry 5.0 and the adoption of a human-centric manufacturing approach are tasks that require planning long-term strategies. Enterprises would benefit from the introduction of professional figures or working teams completely dedicated to this purpose, and thus able to devise and pursue ad-hoc strategies for faster achievement of the goal.

4.4. Periodical monitoring of employee satisfaction

Regularly tracking employee satisfaction levels can be a useful tool to increase the sensitivity of enterprises toward the needs of the workforce. Surveys, focus groups, and one-on-one interviews are all valid options that dedicated figures and teams can exploit to help companies better identify areas that need to be addressed to increase employee engagement and establish a positive workplace culture.

4.5. Enhancement of I5.0 technologies comprehension

Figures and teams dedicated to I5.0 innovation should also provide employees with proof of effectiveness and benefits brought by I5.0 enabling technologies. Helping the workforce experiment and learn about such technologies can convince the most conserving workers of the long-term positive impacts on their well-being. Progress in this direction should be periodically monitored, so that companies can evaluate also the growing development of new competencies.

5. Conclusions

This article presents the results of a survey conducted to assess the state-of-the-art of Lombardy enterprises amidst the transition from Industry 4.0 to Industry 5.0. Large, mid-cap and small-medium enterprises were considered to carry out a stratified analysis and map their level of human-centricity. The insights obtained from the analysis are used to propose a series of best practices to increase the maturity of companies in terms of both technology readiness and human friendliness. The adoption of such practices would prove useful to better face the new challenges posed by the Industry 5.0 paradigm.

Being a first exploratory study, this paper offers new opportunities for future research. The sample considers only enterprises from the Lombardy region that are industrial partners of Intellimech. Therefore, the analysis could be first extended to other companies operating in the same region to gain more significant findings and validate the proposed mapping model. The survey could then be used to map enterprises in other Italian regions, thus allowing a comparison on the national level.

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References

[1] Rüßmann M, Lorenz M, Gerbert P, et al. Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. 2015;
[2] Lu Y, Adrados JS, Chand SS, et al. Humans Are Not Machines - Anthropocentric Human–Machine Symbiosis for Ultra-Flexible Smart Manufacturing. Engineering 2021;7:734–737.
[3] Llena-Nozal A, Martin N, Murtin F. The economy of well-being: Creating opportunities for people's well-being and economic growth. 2019;
[4] Xu X, Lu Y, Vogel-Heuser B, et al. Industry 4.0 and Industry 5.0 - Inception, conception and perception. J Manuf Syst 2021;61:530–535.
[5] Rada M. Industry 5.0 - from Virtual to Physical. 2015;
[6] Wellener P, Dollar B, Manolian HA, et al. The future of work in manufacturing: what will jobs look like in the digital era? 2019;
[7] Nahavandi S. Industry 5.0 - A Human-Centric Solution. Sustainability 2019;11:4371.
[8] Taisch M, Casidsid ML, Despeisse M, et al. The 2019 world manufacturing forum report. Skills for the future of manufacturing. 2019.
[9] Breque M, De Nul L, Petridis A, et al. Industry 5.0 : towards a sustainable, human-centric and resilient European industry. 2021;
[10] Müller J. Enabling Technologies for Industry 5.0: Results of a workshop with Europe's technology leaders. 2020;
[11] Özdemir V, Hekim N. Birth of Industry 5.0: Making Sense of Big Data with Artificial Intelligence, "The Internet of Things" and Next-Generation Technology Policy. OMICS 2018;22:65–76.
[12] Szporer R. Industry 5.0 an 'Industrial Evolution' Instead of Revolution. 2021;
[13] Sachsenmeier P. Industry 5.0 - The Relevance and Implications of Bionics and Synthetic Biology. Engineering 2016;2:225–229.
[14] Madsen DØ, Berg T, Di Nardo M. Bibliometric Trends in Industry 5.0 Research: An Updated Overview. Applied System Innovation 2023;6:63.
[15] Cozmiuc DC, Pettinger R. Consultants' Tools to Manage Digital Transformation. J. Cases Inf. Technol. 2021;23:1–29.
[16] Hein-Pensel F, Winkler H, Brückner A, et al. Maturity assessment for Industry 5.0: A review of existing maturity models. J Manuf Syst 2023;66:200–210.
[17] Shneiderman B. Human-Centered Artificial Intelligence: Reliable, Safe & Trustworthy. Int J Hum Comput Interact 2020;36:495–504.
[18] Calvino F, Criscuolo C, Marcolin L, et al. A taxonomy of digital intensive sectors. 2018;
[19] Wynstra F, Rooks G, Snijders C. How is service procurement different from goods procurement? Exploring ex ante costs and ex post problems in IT procurement. Journal of Purchasing and Supply Management 2018;24:83–94.
[20] Gartner I. Gartner Hype Cycle. 2022;
[21] Cho V, Ip WH. A Study of BYOD adoption from the lens of threat and coping appraisal of its security policy. Enterp Inf Syst 2018;12:659–673