

Maintenance and university-industry collaboration¹

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Introduction

Analysts examining the challenges facing modern societies built on the application of complex technologies often contrast two fundamental functions: *innovation* and *maintenance*. In a technological context, the latter is generally translated into Hungarian as ‘*karbantartás*’, although the meanings of the two words do not entirely overlap. In Hungarian, we use the word ‘maintenance’ much less frequently in a broader, metaphorical sense (e.g. ‘maintaining a relationship’), so it may come as a surprise to a Hungarian person to discover the profound philosophical significance that this word and the concept it denotes can hold. It is no coincidence that the title of Hungarian translation of the American author *Robert M. Pirsig*’s famous book, published in the 1970s (‘*Zen and the Art of Motorcycle Maintenance*’), features

¹ This study – and the lecture presenting its contents – was produced as part of the research programme entitled “*University–Industry Integration Policies and Practices in China – Potential Applications in Hungary*” (<https://wsne.hu/en/about-us/uii-research>), which is supported by the Hungarian government. The research program is implemented by *Wekerle International University* (WIU) in collaboration with the *Learning Research Institute of Mathias Corvinus Collegium* (MCCLI). The authors are the professional leader and research assistant of the research program.

the word ‘care’ rather than ‘maintenance’.² Yet this work, which a Hungarian distributor presents as “one of the most important and influential books of the past half-century”, and of which he claims that it was “the ‘bible’ and guiding manual for university students and intellectuals, and a memorable read for the most diverse literature lovers”,³ is about nothing other than maintenance.

Innovation generally not only receives far greater public attention than maintenance. The latter – apart from those cases or periods when a major system collapses and serious damage results – also enjoys far greater social recognition. The function of continuous operation or maintenance is often mentioned in the same breath as the concept of fault correction or repair; in other words, innovation that creates a new product ready for market is contrasted with the function precisely expressed by maintenance and fault correction together. In his influential, much-quoted essay, a well-known researcher on the subject writes vividly on this topic:

“At first glance, nothing could seem further apart than the seemingly separate issues of innovation and repair. Innovation, in the dominant narrative, comes first: at the beginning of the technology chain, in those quasi-mythical moments of creation, a creation born of garage-turned-corporate engineers, operating with or without the benefits of market research and user experience operations. Repair comes later, when screens and buttons fail, firmware is corrupted, and the iPhone is sent back to where the iPhone is born” (Steven, 2014).

The increasing complexity of the technological systems that surround us and shape our daily lives, coupled with the growing scale of potential damage caused by malfunctions within them, has prompted many thinkers to attempt to shift the focus from innovation towards operation, and maintenance (or often repair), whilst also seeking to secure greater social recognition for those who carry out this work. They are supported in this by the organisations (companies or public authorities) that operate complex technological systems, which are naturally stepping up their efforts to ensure the reliable operation of the systems they manage. They do this partly for market reasons – systems that are prone to failure and lack maintenance support become unsellable – and partly because regulatory authorities compel them to do so.

The rise of maintenance issues to the fore in the developed Western world is now being reflected at a philosophical level. This is illustrated by a recently published collection of essays by two European researchers entitled *Maintenance and the Philosophy of Technology*, in the introduction to which they analyse in detail why, although maintenance and repair are ‘one of the most fundamental and comprehensive ways in which people relate to technologies’, the philosophy of technology has long neglected this perspective, assuming that “everything worth examining in relation to technologies is connected to how they are made and how they are used” (Young & Coeckelbergh, 2024).

One area that has so far received little attention in relation to this significant shift in focus, and which merits closer examination, is the collaboration between academic and industrial/economic organisations – commonly referred to as *university-industry cooperation* (UIC). The question is how the shift in emphasis from innovation aimed at bringing new products to market towards maintenance that guarantees the continuous and reliable operation of existing systems affects the relationship between universities and industry (UIC), and how

² Robert M. Pirsig: *A zen meg a motorkerékpár-ápolás művészete* (*Zen and the Art of Motorcycle Maintenance*). Európa. Budapest. 1998.

³ Moly (<https://moly.hu/konyvek/robert-m-pirsig-a-zen-meg-a-motorkerekpar-apolas-muveszete>).

this is reflected – or should be reflected – in the policies and institutional strategies supporting UIC.

The vast majority of research on UIC focuses on the issue of innovation. Researchers in this field are most often interested in how knowledge generated at universities is transformed into marketable products, thereby strengthening not only the competitiveness of a national economy, economic sector or individual company, but also creating a source of revenue for the universities. Far fewer people are concerned with how universities can contribute to the reliable day-to-day operation of companies (or indeed public institutions), that is, to strengthening their maintenance or troubleshooting capabilities.

It is worth emphasising that whilst contrasting innovation—which aims to create new products and is most often research-based—with maintenance (or repair in the event of failure or collapse) designed to ensure the reliable operation of existing systems may help to structure our thinking, this contrast is often unrealistic in practice. Preventing the failure or collapse of complex technological or social systems, and resolving problems once they have occurred, often requires sophisticated tools and knowledge, the development of which may rely just as heavily on research – including, where appropriate, basic research – as does classic innovation that creates new market products. The development of these tools can often be regarded as an innovative process in itself, and it is not uncommon for them to appear on the market as new products in their own right, which organisations operating complex systems can purchase from external suppliers. The literature on maintenance often treats the repair of faults as a form of maintenance, distinguishing between preventive and corrective maintenance (Benhanifia et al., 2025).

The main argument of this study is that university-industry collaboration not only serves innovation but also plays a key role in developing and maintaining the maintenance capabilities necessary for the operation of complex technological and social systems, particularly in the field of *intelligent predictive maintenance*, as outlined in the following section. To support this assertion, we use the example of a country (China) where particularly advanced UIC practices have developed. The study also proposes extending the concept of maintenance to non-technical systems.

Intelligent predictive maintenance

Representatives of the philosophy of technology who deal with the problem domain of maintenance often emphasise *the invisibility* of this activity (Young & Coeckelbergh, 2024). Most people focus their attention on production activities, and few are aware of the significant impact that maintenance—which ensures safe operation—has on costs and, through this, on the competitiveness of companies, individual sectors and entire national economies. According to a frequently cited study on the subject, for example, maintenance expenditure in the oil and gas industry accounts for 15–70% of total production costs, whilst organisations lose an average of \$138,000 per hour due to data centre downtime (Zhu et al., 2019).

One increasingly popular approach to mitigating damage caused by faults or system failures and reducing maintenance and operational costs is the preventive approach known as *intelligent predictive maintenance* (IPM). The maintenance of complex systems (e.g. transport safety, energy, IT or financial systems) is increasingly characterised by the analysis of continuously generated, large volumes of data and the application of artificial intelligence, to estimate the probability of faults occurring (e.g. due to material ageing or contact between moving surfaces)

and to carry out maintenance interventions accordingly. This approach can also be described as a further stage in the process leading from reactive (i.e. responding to failures) maintenance to preventive (i.e. systematically integrated into normal operation) maintenance, and represents a more advanced, sophisticated and qualitatively new form of the latter.

Over the past decade, driven by technological advancements and the increasing complexity and digitalisation of industrial and economic processes in the broadest sense (*intelligent manufacturing; smart infrastructure systems; intelligent socio-technological systems; digital infrastructure ecosystems*), interest in intelligent predictive maintenance has grown dramatically (Benhanifia et al., 2025). The creation, continuous operation and development of IPM systems require extremely complex research and capability development tasks. Based on our current knowledge of the field and the relevant literature (see e.g. Achouch et al., 2022; Zhu et al., 2025), it is probably no exaggeration to state that IPM has become a distinct disciplinary and professional field requiring the establishment of specialised research and training infrastructure. Establishing and operating this infrastructure necessitates the involvement of university/academic resources for the industrial and economic sectors, and can optimally only be achieved through university-industry collaboration.

As we will emphasise further on, the industrial and economic sector alone, without utilising the capacities of universities, is unable to make effective progress towards intelligent predictive maintenance, and the academic sector is also unable to produce research and training outcomes relevant to practice in this field without direct involvement in industrial, economic and related socio-organisational processes.

The case of China

Analysing how university-industry links can contribute to the development of the maintenance sector can be greatly aided by studying the experiences of other countries in this regard. Experience shows that if the emphasis on elements related to *skills development* or training increases within these relationships, this can have a positive impact on raising awareness of maintenance-related issues. Whilst research- and innovation-oriented UICs most often focus on the creation of new products, training-oriented UICs place a stronger emphasis on the perspective of operating existing systems. Business organisations primarily expect universities to train a workforce capable of ensuring the reliable operation of existing systems, and only to a lesser extent to train those whose main task is to create new products for the market. In line with what has been said previously, it is worth adding that the training of this workforce requires the development of creativity, initiative and other high-level transversal competences just as much as that of a workforce specialising in the development of new products (think, for instance, of specialists in the preventive/predictive maintenance and troubleshooting of particularly complex IT, transport or energy systems, or those involved in the operation of cities or ensuring the sustainability of biological ecosystems).

Among foreign models, it is worth paying particular attention to the example of the country where we find perhaps the highest level of support for and deepening of university-industry collaboration focused on skills development: that country is China. Research aimed at exploring China's policy and institutional practices regarding university-industry integration⁴ convincingly demonstrate that elements relating to maintenance and troubleshooting feature

⁴ See the studies available for download from the website of the research programme mentioned in the previous footnote (<https://wsne.hu/en/about-us/uii-research>).

prominently in the training programmes implemented by universities in close cooperation with companies. The reason for this is that corporate specialists—who operate highly complex technological systems built on existing, often sophisticated technology, and who continuously maintain these systems and resolve operational faults—are deeply embedded in virtually every aspect of the world of university education. This means that their involvement shapes the definition of training requirements and teaching content, the design of learning environments, as well as the assessment of acquired competences. Consequently, the day-to-day operational challenges are strongly reflected at every level of training, with a greater emphasis on maintenance and troubleshooting than on the creation of new solutions.

University-industry integration in China

Thanks to the research programme within the framework of which this analysis was prepared, we are gaining an increasingly deep insight into the Chinese policy and practice of cooperation between universities and industry (Huang & Halász, 2024; Halász-Huang, 2025a; 2025b). As a result of this policy and the institutional practices that have become widespread and commonplace in its wake, *an* extremely strong *fusion* is taking place in China between the university-academic and industrial-economic spheres, leading to radical changes in the functioning of both universities and economic organisations. As a result of this process, the boundaries between the university and industrial-economic spheres are, in many cases, becoming extremely blurred. In this country, we should no longer speak of a university-industry relationship or partnership, but rather of the integration of the two spheres (the relevant policy and practice almost exclusively use this term). *University-industry integration* (UII) has become highly institutionalised: a multitude of new institutional, organisational, ownership and funding models have emerged that are highly attuned to specific sectoral, geographical and administrative contexts.

This integration process is particularly advanced in sectors that employ the most advanced technology and are at the forefront of digitalisation. This is not only characteristic of traditional industrial manufacturing sectors, but also applies to virtually all areas of the service sector, including fields such as urban management, tourism, healthcare, finance, media and communications, and indeed the cultural industry as a whole.

The role of maintenance within the university-industry integration ecosystem

Although the philosophical strand of thinking about maintenance, as previously mentioned with reference to the collection of studies by Young and Coeckelbergh, is as yet of little direct and visible significance in China, there is a school of thought that rethinks the world of technological problems much more from the perspective of continuity, sustainability, order, the day-to-day operation of infrastructure, and the embedding of technology within civilisation, rather than from the perspective of innovation (Rippa & Oakes, 2023; Liu & Peng, 2025). This shift in perspective naturally also requires a rethinking of the relationship between universities and industry.

In this new perspective, universities do not appear as they did within the classical research-innovation conceptual and policy frameworks; that is, their primary mission is no longer to support industrial innovation leading to new products by creating pioneering technological solutions. Instead, they are viewed as institutions that must contribute to the safe and sustainable operation of existing technological systems, partly by establishing the knowledge base for the complex maintenance solutions required by complex technological systems, and partly by

continuously providing a highly skilled workforce capable of operating such solutions. One such solution is intelligent predictive maintenance, which is integrated into the day-to-day operation of complex technological systems and requires sophisticated IT, data analysis and decision-making capabilities that universities and the companies operating these technological systems can only develop jointly. As we mentioned earlier – this cannot be achieved by universities acting in isolation from the industrial world and lacking familiarity with the practical challenges of day-to-day technology operations, nor by companies that do not possess the depth of background knowledge and data analysis capabilities found in the world of scientific research embedded within the academic sphere.

China is at the forefront of global research into intelligent predictive maintenance, particularly in the application of artificial intelligence for this purpose. According to a bibliometric analysis published a few years ago (Keleko et al., 2022), the United States was only marginally ahead, and by now the rankings may well have reversed.

Sectoral examples

We will now illustrate the above points with three sectoral examples. Two of these relate to traditional industrial and technological fields, whilst one concerns a service sector where the use of the terms ‘maintenance’ or ‘intelligent predictive maintenance’ may seem unusual, but is by no means unjustified given the nature of the processes involved. With the latter, in line with what was mentioned in the introduction, we also wish to demonstrate the potential of an extended interpretation of IPM. A common feature of the cases presented is that not only technological innovation but also the transformation of human capabilities plays a key role in the development of intelligent predictive maintenance. One of the most important functions of the UII is the systematic development of these capabilities.

The example of high-speed railways

A frequently cited and particularly noteworthy example of the role played by university-industry collaboration in the field of maintenance in China is the development and operation of high-speed rail transport. It is well known that China is a world leader in this field, not only in terms of the number of such railway lines, but also in the speed with which it has reached its current level of development. This could not have been achieved without the integration of the academic and scientific sphere with companies in the rail transport sector. A World Bank analysis published in 2019 described it as follows:

“Cooperation between railway manufacturers, universities, research institutes, laboratories and engineering centres enables capacity development, rapid technological progress and the localisation of technology. (...) Design institutes and university railway programmes are key players in sector development. (...) China has developed a broad ‘ecosystem’ comprising universities and research organisations, which, in collaboration with suppliers, deliver better products. For example, for the development of the 350 km/h ‘Fuxing’ train set in 2008, the Ministry of Science and Technology and the former Ministry of Railways jointly signed a cooperation agreement on the Joint Action Plan for Independent Innovation of China’s High-Speed Rail. This plan involves six major central enterprises, 25 key universities, 11 first-class scientific research institutes, 51 national laboratories and engineering centres, and a scientific and technological team comprising 68 academicians, 500 professors and more than 10,000 engineers and technicians. This collaboration has enabled China to introduce, process, adopt and re-innovate advanced, multi-component electrical technology from abroad within a short period of time in order to create a successful product.” (Lawrence et al., 2019)

The construction and operation of high-speed rail services naturally require both the development of new solutions (innovative design activities) and the ongoing work necessary for the safe operation of existing systems and the extension of their service life (maintenance and repair activities). The safe operation of the technology poses a particularly significant challenge here: a single operational anomaly or failure can result in disasters causing immense damage and claiming many lives. Typically, this is a field where a complex system must be operated comprising sensors that continuously monitor every minute detail of operations, intelligent systems that constantly process and analyse the data provided by these sensors, and the coordinated decisions made on this basis; the planning, constant development and reliable operation of which require such a high level of dynamic capabilities that their creation, development and maintenance are only possible within ecosystems such as those mentioned in the World Bank analysis cited earlier.

A key element of this ecosystem is the continuous development and maintenance of the human skills required to operate complex systems. It is worth noting that China began this process well before the construction of its high-speed rail network commenced: they identified and adopted the high-speed rail technologies available internationally, which they further developed and localised, whilst investing significant sums in the modernisation of technological training within the institutional framework of an ecosystem comprising universities, design institutes, companies with highly skilled staff, and related state institutions.

In this process, the creation of new solutions and the assurance of the operational safety of existing technologies appeared in a balanced manner: these two perspectives continuously complemented and reinforced one another. This is well illustrated by an analysis in which the authors – specialist engineers working in the field – provide a comprehensive overview of how *the design theories* for high-speed railway tracks (and the foundations supporting them) and their maintenance technologies . The latter required research under laboratory conditions into issues such as the effect of environmental and loading factors influencing the fatigue of steel and reinforced concrete particles on these particles (Ren et al., 2021). Consequently, it was possible not only to define quality standards and establish complex maintenance technologies and systems , but also – within the framework of university-industry collaborations – the creation of training and skills development programmes that enabled the development of human resources (i.e. communities of qualified professionals) capable of operating these technologies and systems.

The authors of this study were able to experience first-hand some of the elements involved in creating the human resources required for the safe operation of high-speed rail transport. One of the authors was able to learn about the establishment of the national industry-education consortium—which provides the most important institutional framework for the integration of universities and industry in the railway sector—during a personal conversation with a senior manager at China’s largest company developing and operating high-speed networks (CRRC).⁵ The authors also had the opportunity to directly observe the technical infrastructure used for training at a Chinese university playing a leading role in this field. In addition, they were able to consult with the owner-manager of one of the companies collaborating with the university.

⁵ See the policy document published in 2023 entitled *Notice of the Ministry of Education on Supporting the Construction of a National Rail Transit Equipment Industry Industry-Education Integration Community* [教育部关于支持建设国家轨道交通装备行业产教融合共同体的通知]. (http://www.moe.gov.cn/srcsite/A07/s7055/202307/t20230714_1068862.html).

A key element of this company's product portfolio is the development of intelligent predictive maintenance systems for the rail transport sector.⁶

Based on the relevant literature and personal experience, we can identify at least four interconnected channels through which university-industry integration has contributed to the development of IPM systems in the field of high-speed rail transport. The first, to which the World Bank report cited earlier also referred, is the joint development of the knowledge base without which a safely operable high-speed rail system could not have been established. The second is the joint development, based on research, of standards—particularly quality standards—that can guarantee the reliability of the materials used and the processes involved. The third is the joint implementation of a shift in mindset that enabled a move from the previous practice of preventive maintenance towards a predictive approach. Finally, the fourth is the joint development of training capacities that enable not only reliable operation and fault rectification, but also the development of the human skills necessary for maintaining the monitoring and analysis systems essential for predictive maintenance.

The example of electric road vehicles

Another area where university-industry integration significantly supports the shift towards IPM is the safe operation of electric cars. It is well known that in this field, China – much like in the operation of high-speed railways – also plays a leading global role. In some cities or regions, the number of electric cars in operation far exceeds that of conventional internal combustion engine vehicles, which has created maintenance requirements that are entirely different from those of the past. This primarily involves addressing issues such as ensuring the operational safety of batteries or increasing the range on a single charge, but also maintaining the operational reliability of the cars' complex electronic systems or even – particularly in the case of self-driving cars – ensuring road safety.

In transport based on electric cars, the most serious challenge is the safe operation of batteries, which involves ensuring that they do not cause malfunctions—including those involving destructive fires—whilst also ensuring that cars have sufficient range and enabling fast and trouble-free charging. The latter is highlighted as a particularly critical factor in a study analysing the smart maintenance of electric vehicles. Given that “most charging systems are installed outdoors, they are susceptible to environmental factors (e.g. rain and dew), which reduces the reliability of charging components” (Hsu et al., 2023),

To maintain operational reliability, traditional preventive maintenance is no longer sufficient; instead, monitoring and diagnostic systems capable of continuously analysing large volumes of data and predicting potential faults in advance must be operated – in other words, intelligent predictive maintenance is required. Just as with high-speed trains, the development, continuous improvement and operation of these systems require capabilities that electric vehicle manufacturers and maintenance companies cannot develop on their own; this requires a knowledge and skills development ecosystem that can emerge from the fusion of the academic and industrial worlds.

The emergence of this new ecosystem – or local ecosystems – has enabled the development in China of the research and testing infrastructure required for the reliability, diagnostics and

⁶ See the sections on Southwest Jiatong University and Tanguan Intelligent Control Ltd. in our case study “*Using university-industry integration to modernise university education in the Chengdu-Chongqing Economic Area: a case study*” (https://wsne.hu/media/dokumentumok/uii_dokumentumok/chengdu_chongqing_case_study_2025.pdf)

condition management of smart electric vehicles, and – among other things – the development of battery forecasting and condition management as a key area of expertise in the operation of electric vehicles. Here, preventive (and predictive) maintenance is no longer about oil changes or conventional engine wear, but rather the continuous monitoring of battery condition, the determination of remaining useful life, thermal risks, charging behaviour, or even the cloud-based/on-board monitoring of battery systems (Sida et al., 2024). The UII has contributed significantly to the replacement of the automotive sector’s maintenance logic with a connected, data-rich, lifecycle management system, supplanting the workshop-based service function. What is most interesting to us, however, is how the emerging new ecosystems have transformed the system of human capabilities required to operate this new model of maintenance.

A series of education-industry integration communities have been established, within the framework of which a multitude of new university-affiliated training centres and new training programmes have been created, focusing on smart new energy vehicles. An example of this is the 2023 Shanghai Initiative, which led to the creation of an education-industry integration community dedicated to the development of new energy vehicles.⁷ This community – like many others of its kind – is “developing a series of digital courses through joint curriculum development between schools and companies” and “building an industry-education integration training base for the smart new energy vehicle industry”.

A number of universities, in collaboration with industry partners, have developed new energy vehicle (NEV) programmes and training centres that are directly linked to local automotive clusters and employment pathways, and enable the training of technicians, engineers, data analysts, software specialists and service personnel required by the new sector. Another example illustrating the emergence of such ecosystems is the strategic cooperation agreement signed in 2025 between China’s largest car manufacturer and one of the world’s leading automotive groups, the *Shanghai Automotive Industry Corporation* (SAIC Motor), and one of the leading technical universities (*Beijing Institute of Technology* – BIT) stating that the parties “will implement high-impact talent development programmes building on their academic and automotive expertise”⁸ As the press release stated: “These efforts include professional training initiatives, a talent exchange mechanism for high-level researchers, and mutual support for student development, professional placements and vocational training. Their combined aim is to develop engineers with exceptional abilities and cutting-edge talent with a global perspective.”

The authors of this study had the opportunity to examine several similar UII-based training initiatives at first hand. One of these is the “*New Energy and Intelligent Automobile Industrial College*”,⁹ jointly established by the Geely automotive group and Sanya University, whose training programme, with the direct involvement of industry players, prepares students for the reliable operation of electric cars and thus for carrying out the associated servicing tasks. Another example, which we were able to observe first-hand, is the industrial training centre jointly operated by *Shenzhen Polytechnic University* and BYD, where similar training activities

⁷ See a report by a local online portal entitled “*Industry-Education Integration Community of National Smart New Energy Vehicle Industry Established in Hongkou*” here: <https://www.shhk.gov.cn/English/006002/006002001/20231113/5aa6d555-c989-4748-8c41-11b5c9395fd8.html>

⁸ See the news article titled “*SAIC Motor, Beijing Institute of Technology to co-boost innovation in vehicle electrification, intelligence*” on the website of one of China’s leading automotive news portals here: https://autonews.gasgoo.com/articles/news/saic-motor-beijing-institute-of-technology-to-co-boost-innovation-in-vehicle-electrification-intelligence-70035743?utm_source=chatgpt.com

⁹ See the related news item, “*Geely New Energy and Intelligent Automobile Industrial School is inaugurated at University of Sanya*”, here: https://www.sanyau.edu.cn/en/2022/1130/c925a75215/page.htm?utm_source=chatgpt.com.

take place within the framework of programmes that have been jointly developed and are being implemented by industry experts and university lecturers.

In the case of electric vehicles, it is also worth noting that – as in other advanced technological fields – the line between product innovation and maintenance innovation is becoming increasingly blurred. Battery management systems, cloud-based analytics, charging systems and ‘digital twins’ (virtual replicas of physical systems) are simultaneously part of product design and subsequent predictive maintenance. In UII processes related to electric vehicle transport, these do not generally appear under the heading of ‘maintenance’, but rather under labels such as ‘smart manufacturing’ or ‘battery innovation’; however, functionally they also constitute maintenance, i.e. diagnosis, prognosis and fault prediction, preventive maintenance interventions or service optimisation throughout the vehicle’s entire life cycle. All of this creates training needs – as a training guide for the automotive industry put it – that “are aimed at training service maintenance and repair technicians in the fields of electric vehicles, batteries, analysis, diagnostics and repair”¹⁰

The safe operation of smart electric vehicles requires a workforce with skills that are entirely different from those needed in traditional internal combustion engine motoring. The new skills development systems established within the framework of the UII not only enable the acquisition of new knowledge relating to diagnostics or battery condition, but also the development of a new workforce architecture for a maintenance system that is increasingly digital and predictive in nature. Intelligent predictive maintenance of electric vehicles is not an isolated specialised function, but lies at the intersection of vehicle electronics, battery systems, software, cloud platforms, high-voltage safety, charging infrastructure and service operations, which requires a complete transformation of the skills system.

Without the fusion of academia and industry, this new capability system and workforce architecture could not have emerged in China. The UII has enabled the creation of training environments that resemble a real-world maintenance ecosystem rather than traditional classrooms. In the aforementioned training bases, and others like them, which are operated in collaboration with industrial companies, there are, for example, virtual simulation systems and real-life smart production lines, which are indispensable because predictive maintenance cannot be learnt through lectures alone. This requires simulated faults, the analysis of real diagnostic data, actual battery system management, digital interfaces, and direct practice with intelligent vehicle systems. Essentially, the UII has enabled skills development to shift from abstract theories towards a platform-based practical environment, thereby creating a new, hybrid workforce that is simultaneously a mechanic, electrician, diagnostician and digital operator, and which is indispensable for the intelligent predictive maintenance currently taking place in the electric vehicle sector (Luo et al., 2025).

The example of the financial sector

As mentioned earlier, our third sectoral example may seem unusual to the professional community involved in maintenance, particularly those working in technical fields. In this sector, the concept is not used, or is used much less frequently, despite the fact that, when considering the nature of operational or business processes and the disruptions, failures, or even severe crisis situations that can be described as ‘collapses’ arising within them, we are discussing similar issues. The example of the financial sector also illustrates that it is possible,

¹⁰ Quote from the information booklet entitled “*European Electric Vehicle College. New Energy International R&D, Training and Educational Platform*”, provided to us by Mike Danilovic, a member of our research programme’s advisory board and a leading analyst in the field.

indeed worthwhile and justified, to use the concept of IPM in an extended sense, applying it to areas that are not traditional technical fields. As mentioned in the introduction, this study proposes extending the concept of maintenance to non-technical systems: an attempt is made to do so in this section. It is worth emphasising in advance that this is not a matter of metaphorical usage, but of analytical extension. We consider that in the case of financial systems, where maintenance—as in other systems—means maintaining the stability, reliability and integrity of operational processes, a similar logic applies as in the case of physical systems.

Whilst IPM is self-evident in the context of rail and electric vehicles, in finance it may require a more nuanced interpretation; however, here too, the focus is on the proactive, intelligent operational maintenance of complex systems. The aim here is to maintain the reliability of existing platforms, detect anomalies early, prevent system failures, maintain the performance of the models used, curb fraud, and ensure continuity and compliance before failures occur. In the financial sector, IPM involves predicting potential disruptions or failures in complex financial infrastructures and service operations, and subsequently carrying out preventive interventions. Here too, the monitoring of micro-processes and the continuous collection and analysis of the large volumes of data associated with them play a decisive role, which is typically achieved through the use of artificial intelligence (Aldasoro et al., 2024).

China's related strategy explicitly links digital technology with financial services, operations, management and security (Zhou, 2022). This means that the perspective, logic and procedures associated with intelligent predictive maintenance also prevail in this world of intelligent socio-technical systems. Consequently, everything we have said about the new knowledge and expertise requirements emerging in the high-speed rail and electric vehicle sectors, and the demand for a workforce with new hybrid skills, applies here as well. Here too, we see that the institutions in the sector under examination (e.g. banks, insurance companies) are only able to meet their needs for high-level new knowledge and skills by cooperating with the university and academic world, and – conversely – universities offering business and economics programmes are only able to meet these needs through close cooperation with institutions in the financial sector. This means that industry and business stakeholders here, too, become direct participants in the development and implementation of university programmes, whilst academic stakeholders become involved in the day-to-day operations of financial service providers.

Here is one example among many: the *Institute of FinTech* (SWIFT), a training institution jointly established and operated by *Shenzhen University* and the financial institution WeBank.¹¹ WeBank is China's first bank offering exclusively digital services, established by Tencent in 2014. SWIFT was jointly founded in 2018 under an agreement between the university and the bank. The dual-board governance model established here, the educational mechanism implemented through close cooperation in various forms, the banking internship system, the shared laboratory infrastructure and the joint certification system have created an embedded system for skills development or talent cultivation that is generally characteristic of UII practice in China. In the broader context of Chinese UII, this case clearly illustrates joint university-industry governance, interdisciplinary talent development and strategic alignment with priority economic sector players. In the narrower context of smart predictive maintenance in financial services, SWIFT and similar institutions can also be seen as platforms for developing the hybrid talents required for the predictive maintenance of digital financial infrastructures, risk management systems and operational resilience. These contribute significantly, both directly and indirectly, to intelligent predictive maintenance by creating the human and organisational

¹¹ See the website presenting SWIFT here: <https://swift.szu.edu.cn/en/as/xyjj.htm>.

conditions under which predictive, preventive and flexible digital operations can be implemented.

As with the railway and electric vehicle cases described earlier, in the case of SWIFT, the UII contributes to the practical implementation of predictive maintenance not only through research but also through skills development, establishing the institutional pathways necessary to build the required workforce. This is achieved through mechanisms such as joint training for lecturers and practitioners, equipping dual-qualified lecturers with corporate experience, structured work placements, shared laboratories, project-based, competition-based and certification-based learning, and scholarships and study visits funded by the corporate sector. These enable the development of the hybrid skills required by intelligent predictive maintenance in the financial sector, namely a workforce that is neither purely ‘business’ nor purely ‘technical’, but possesses a mix of competencies, including financial knowledge, data analysis skills, expertise in artificial intelligence, a systems approach, risk awareness and a thorough understanding of the operational environment.

SWIFT bridges the ‘transition gap’ between academic learning and the operational digital financial environment. In rail transport and the automotive industry, this gap lies between school and the operational environment; in FinTech, it lies between classroom learning and high-speed digital financial transactions. This UII-based training model bridges this gap by embedding the corporate side not only in the internship phase, but also in the management of the training programme, curriculum development, mentoring, certification and the provision of resources.

Conclusion

The starting point of this study is the observation that, in the functioning of modern societies built on complex technologies, attention is traditionally focused on innovation, whilst the maintenance activities necessary for the continuous operation of systems – although no less significant – receive less attention. Our analysis shows, in part, that this shift in emphasis is evident not only in thinking about technology but also in the interpretation of the relationship between universities and industry; and, in part, that deepening cooperation between universities and industry (economy) is essential for this shift in emphasis to take place and yield results.

The main argument of the study is that university–industry collaboration (UIC), particularly its integrated form (UII) most clearly observed in China, plays a key role not only in supporting innovation but also in developing and maintaining the maintenance capabilities necessary for the operation of complex technological and social systems. This is particularly evident in the field of smart predictive maintenance, which represents a data-driven, forward-looking operational logic that goes beyond reactive and preventive approaches.

An analysis of examples from China has shown that where the relationship between universities and industry takes an integrated, institutionalised and skills-development-focused form, the development of the knowledge and competencies required for IPM is significantly accelerated. The examples of high-speed rail transport, the electric vehicle industry and financial services presented three distinct yet complementary areas in which IPM manifests itself in various forms: in the operation of physical infrastructure, intelligent product and platform systems, and digital service infrastructure.

A comparison of the three cases also highlights that intelligent predictive maintenance is not merely a technological issue, but a phenomenon fundamentally linked to human capabilities. Operating IPM systems requires a new type of workforce with hybrid skills, possessing technical, IT, data analysis and systems-level thinking abilities, as well as a deep understanding of how the sector in question operates. The UII plays a key role in this regard: it enables the creation of training and learning environments that are directly linked to real-world operational systems, thereby bridging the gap between academic knowledge and practical application.

The example of the financial sector particularly well illustrates the potential for extending the concept of maintenance. Although the term ‘maintenance’ is used less frequently in this field, ensuring the operation of digital financial systems – including the early detection of anomalies, the prediction of risks and the maintenance of operational continuity – can be interpreted analytically as a specific form of intelligent predictive maintenance.

One of the most important conclusions of this study is that, in future thinking about university–industry collaboration, greater emphasis must be placed on the maintenance and operational dimensions. This does not imply a decline in the importance of innovation, but rather its complementation with a perspective that prioritises the long-term sustainability, reliability and operational safety of complex systems.

This shift in perspective could have important implications for both public policies and university strategies. Skills development, practice-oriented learning environments and the deep involvement of industry stakeholders may become crucial even in areas that have hitherto been organised primarily along the lines of innovation. Experience from China shows that university–industry integration in this field is not merely an opportunity, but increasingly a necessity.

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Possible discussion questions:

1. What changes in attitude and mindset are needed to strengthen public attention towards maintenance and repair, and to enhance the social standing of these fields? What role might universities and related research (examining the social role of technology) play in this?
2. What sector-specific characteristics define the shift towards smart predictive maintenance, and to what extent can this approach be extended beyond traditional technical fields?
3. What role do universities play, and what role could they play, in developing the organisational/institutional (corporate, public sector) capacities required for the maintenance of existing systems and the rectification of their faults?
4. How might the shift in perspective regarding maintenance and repair, and knowledge in this field, affect public policies and institutional practices aimed at strengthening university-industry collaboration? In what ways do these need to change, and how can these changes be achieved?
5. What analysis of domestic and international examples could assist this process? What successful examples and effective best practices are known to us, how can we gain a better understanding of them, and what and how can we learn from them? Is it possible to adapt anything from successful practices outside Europe?