SYNTHESIS REPORT

The move to smart manufacturing. Proposal for a national plan

ASSOCIATION NATIONALE RECHERCHE TECHNOLOGIE

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THE POWER OF COLLECTIVE INTELLIGENCE

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INTRODUCTION

Smart manufacturing is seen as a new industrial production model. It results when companies work in digital platforms aimed at manufacturing. Thus the growing use of the cloud and its variants is an integral part of smart manufacturing. From an analytical point of view, it comprises two dimensions, one of which is technological and the other organizational. Like for the platformization process in general, reducing this systemic shift to one or the other of these two dimensions would be meaningless. The factors that impede or foster its dissemination can therefore be found in both.

This new smart manufacturing model is not just about the digitalization of manufacturing processes, or the intense use of manufacturing data. Companies that adopt digital platformization are subject to changes in their skills and capacities. The business ecosystems that employ smart manufacturing also undergo a profound shift in relations, involving the renewed circulation of data. These new relations require setting up new contract packages based on trust. The first step involves contracts between companies, systems manufacturers-integrators, frontline subcontractors, service providers specializing in a particular link of the data value chain, start-ups, etc. Next come public stakeholders likely to act on the appropriate framework conditions for this new production model (research system, contribution to producing standards, incentive mechanisms, etc.). All of the above explains the angle taken by this report, which looks closely at the state of practices and the techno-economic issues facing companies in order to formulate a suggested national strategy for smart manufacturing.

The aim of this document is to propose a national plan for smart manufacturing, which can be found in the third part. The first part defines smart manufacturing and sets out the issues that explain this shift in our production system. The second part identifies the main obstacles and the factors conducive to the development of smart manufacturing.

01 DEFINITION AND ISSUES INVOLVED

Smart manufacturing brings an opportunity to reindustrialize production in France. In doing so, it is likely to play a role in reinforcing the country's strategic independence. The major change that it represents, and the innovations that this new production model embodies, point to the development of a new industry, and a new phase of industrialization both in France and in Europe. This shared conviction is based on points of analysis such as the high level of skills and expertise in companies (majors, SMEs, midcaps, start-ups) and state laboratories concerning the fundamental digital components of intelligent manufacturing in France.

1/ IN THE BEGINNING, THE BUSINESS ECOSYSTEMS OF SMART MANUFACTURING

In our collective work, we looked at smart manufacturing by identifying the main business ecosystems involved, at a pertinent scale: (1) the industrial internet of things and cyber-physical systems; (2) industry clouds; (3) additive manufacturing; (4) machine intelligence, including artificial learning techniques; (5) industrial 5G and 6G applications; (6) cybersecurity methods and technologies for critical industrial systems. The dosage of the solutions resulting from these six business ecosystems depends on the industries and companies, and shows the extent to which this model is disseminated. The working group was put together based on these business fields.

1.1. The example of industrial robotics

Industrial robotics, as a cyber-physical system employing the IoT, is a component of the France 2030 national plan, and one of the areas of expertise of Inria[1], CEA-List[2] and LAAS-Cnrs[3], among others[4]. Politicians are aware of the importance of this business ecosystem for industrialization. In most of these areas, intense technological research is being pursued at public research institutes. While start-ups tend to act as the transferrers of knowledge, there is also a clear need for partnership-based R&D projects. Several techno-organizational components of smart manufacturing, whose maturity remains to be demonstrated, have not been sufficiently tested.

As part of France 2030, a budget of €800 million has been allocated to industrial robotics. Half of this amount will support the manufacture of robots integrating artificial intelligence techniques, known as "adaptive

1- Cf. https://www.inria.fr/fr/taxonomy/term/1276. At the time when the WG meetings took place, Inria was working on producing a detailed, comprehensive cartography of its resources on this subject.
2- Cf. https://list.cea.fr/fr/lindustrie-du-futur-numerique-connectee-et-intelligente/
3- Cf. https://www.laas.fr/public/fr/lindustrie-du-futur
4- Non-exhaustive list featuring the organizations of participants in this WG. In addition, we should mention Benoît Eynard from the UTC's Roberval Laboratory, who contributed to this WG, cf. https://uteam.fr/consultant/presentation/benoit-eynard

robots"; the other half will help transform industrial sites to install smart machines. The reference company in this area is Siléane[5], which produces smart robots that can, for example, pack infusion bags or deal with nuclear waste.

The ScanR[6] database features about 2,240 entities that are developing robotics research and solutions in France, or are already using them. Depending on the typology employed, in addition to over 450 research units, there are around 700 SMEs, 200 midcaps and more than 130 major companies (including subsidiaries).

Box 1
Robotics at Inria (2021), an illustration

Inria, the National Institute for Research in Digital Science and Technology, includes several project teams focusing on robotics, in particular collaborative robots (cobots). Inria also works on other domains contributing to smart manufacturing. The strategic partnership manager at Inria's innovation department has a mission to identify and describe the content of the Institute's Industry of the Future. Out of the 200-odd project teams at Inria, about 70 have the research skills required for smart manufacturing ecosystems.

The aim of this analysis is to organize the research produced and ensure that it corresponds to industrial demand. One particular focus is to ensure that the Institute's work fits in with major public support programmes and projects, for example the cybersecurity priority research programme (PEPR) (co-led by the Institute), and 5/6G, etc. The project team is the right scale to ensure the necessary impetus and response on these emerging subjects (at political level).

Source: Participation from Guillaume Turpin, Inria, in the WG's work.

1.2. Definition

Rather than simply providing examples of the technical sub-systems of intelligent manufacturing, it is useful to make the clearest definition possible. Among all of those mentioned, we have chosen the following definition, which comes from the reference centre in the field, CESMII[7].

> *"Smart manufacturing is the information-driven, event-driven, efficient and collaborative orchestration of business, physical and digital processes within plants, factories and across the entire value chain.*
>
> *"In smart manufacturing, resources and processes are integrated, monitored and continuously evaluated with the sensing, information, analytical modes and workflow needed to automate routine actions, and prescribe action for non-routine situations.*
>
> *"In smart manufacturing, organizations, people and technology work in synergy via processes and technology-based solutions that are secure, scalable, flat and real-time, open and interoperable, proactive and semi-autonomous, orchestrated and resilient, and sustainable.*
>
> *Smart manufacturing is transformational, radically impacting the performance of the manufacturing ecosystem through measurable improvements in areas such as: speed, agility, innovation, quality, costs/profitability, safety, asset reliability and energy productivity. Consequently, improving profitability which in turn accelerates investments in innovation."*

This definition underlines the systemic character of intelligent manufacturing, its technological and organizational dimensions, and its potential to radically transform the industrial system. It also puts the accent on the energy savings that can be made by this platformization of industrial production: a distinctive characteristic identified by the working group experts.

5- Cf. https://www.sileane.com/
6- Cf. https://scanr.enseignementsup-recherche.gouv.fr/,
7- Le CESMII (Clean Energy Smart Manufacturing Innovation Institute) is the US national institute created to accelerate the widescale adoption of smart manufacturing.

2/ THE TWOFOLD CHALLENGE INVOLVED IN SMART MANUFACTURING: REINDUSTRIALIZATION AND REDUCTION OF INDUSTRIAL CARBON IMPACTS

In 2020, the manufacturing industry[8] represented 13.5% of total added value and 10.5% of wage employment in France. French industry consumed about 35 million tonnes of oil equivalent[9].

By comparison, the manufacturing industry in the European Union on average amounted to 14.5% of GDP in 2020. At this scale, it is the main energy consumer and, at 32% of the energy consumed, a high producer of carbon dioxide. In France, industry is only the third emitter of GHG, with around 19% of emissions, after road transport (27%) and agriculture/forestry (21%)[10].

The reindustrialization of France and Europe constitutes a major challenge for the coming years. It is vital to reindustrialize via a new production model in order to develop jobs for tomorrow and reduce the size of value chains. This reindustrialization represents both a source of questions needed for technological research, and the outcome of substantial scientific and technical efforts in the European Union, and France. Reindustrialization is also the best way, for France and the EU, to reinforce strategic independence.

Strategic independence, as the events of the past few months have all too painfully reminded us, concerns supply chains of inputs, materials and energy. The consumption of industrial fossil fuels makes up a large share of the EU carbon footprint, both during the different production phases, and during the usage of products and services, which incorporate greenhouse gases and sometimes produce more of them.

Conversely, at European scale, given the wide range of industrialization situations, this industrial energy burden constitutes a lever whose activation can still have a considerable effect. At national scale, the smart manufacturing production model must be considered as a key factor in reindustrialization, while mitigating industry's carbon footprint.

8- Except energy, small-scale retail and extraction industries.
9- Gross energy consumption includes electricity, steam, gas, solid mineral fuels, and oil products, along with wood since 2012 and hydrogen since 2019.
10- Cf. "Émissions de gaz à effet de serre par activité. Données annuelles de 1990 à 2020" [greenhouse gas emission by sector of activity. Annual data from 1990 to 2020], Insee, 17.03.2022

02 OBSTACLES AND FACTORS THAT ENCOURAGE ADOPTION

The expected benefits of widescale implementation of smart manufacturing are mainly of two types. First, the use of these much more effective technologies, in particular when combined, improves the production processes involved. Improvements in terms of well-being and occupational health are also expected. Second, a large part of the benefits come from improved end-to-end circulation of manufacturing data. A number of obstacles are likely in the wider adoption of intelligent manufacturing practices and technologies by companies.

1/ OBSTACLES TO OVERCOME FOR EFFECTIVE SHARING OF MANUFACTURING DATA

Given the large number of people involved, including on the same link in the manufacturing value chain, the first difficulty is setting up inter-company agreements for sharing data. This is a sensitive subject that technical solutions can work to alleviate, provided that the technical dimensions of protection and security are tackled properly. While persistent difficulties are partly due to misjudging the respective stakes involved for industrial partners, they can mainly be put down to the genuine intrinsic complexity involved in the industrial organization of manufacturing chains. The impact of adopting cloud computing is ambivalent here. The customer company gives up ownership of its computing infrastructure and rents it instead. Services related to the production computing system (security, availability, load variation, etc.) are thus managed by contract. The part of the manufacturing process that is moved to the cloud benefits from increased flexibility, and the manufacturing data are monitored more closely.
The major gains in efficiency and productivity brought by digital technology, which are omnipresent at multiple scales, are embodied by a subtle range of software programs and components. These can be operated by distinct companies operating on different business models. The systems integrator therefore has to manage numerous relations subject to different contractual bases. The digitization of industrial processes tends to take the form of platformization, in which each partner seeks to play the primary role.

From the point of view of the fluid circulation of industrial data, progress has been made and smart manufacturing plays its part. However, it can go further. In the practitioners' opinion, the following need to be established:

- Widely adopted communication protocols between smart manufacturing devices; in their absence, interoperability is held back and the system is less efficient.
- Protocols and standards for making a cost/energy benefit analysis of the digital devices involved; common standards for storing and sharing information relating to energy consumption and energy savings in industrial manufacturing processes.
- Cybersecurity protocols and standards common to manufacturing processes.
- A versatile, open smart manufacturing platform to create a network of commercial systems and automation of several suppliers.

Given the perspective we have been pursuing for several years, we cannot state strongly enough the decisive importance of setting up a versatile, open, smart manufacturing platform.

2/ FROM SMART MANUFACTURING STANDARDS TO THE VIRTUOUS CIRCULATION OF MANUFACTURING DATA

Standards work like agents of change, and are a useful way for companies to make the move from traditional manufacturing methods to "smart" methods. Their adoption and ownership are compulsory steps to smart manufacturing. The first phase in any digital shift towards intelligent manufacturing consists in identifying and choosing the standards employed. As soon as one or more smart manufacturing components, which may be exploratory, are used, the appropriate standards then need to be applied, adopted and assimilated.

2.1. Standards as tools to characterize challenges and as agents of change

A common representation of standards for a company's digitized production system is composed of four independent levels (/"layers")[11].

- The highest level, i.e. the level of the whole enterprise, involves standards relating to the reference architecture and methods for the automation and integration of systems; in other words, standards concerning the company's operations.
- The second level concerns MOM (Manufacturing Operations Management) standards, which are employed for the use of management systems software for end-to-end manufacturing processes. These standards apply at the scale of factory operations.
- The third level involves standards that are applied to the connected operations of electronic devices and supervisory control and data acquisition (SCADA). These standards regulate operations at the scale of the production workshop (human-machine interfaces, programmable logic controllers, component protocols and their communication).
- The fourth and final level features standards that are applied generally, whatever the level, and concern procedures to digitally secure the implementation of automation and industrial control systems, and all quality procedures (including CSR).

11- Which can be found, for example in Ahmadzai Ahmadi, Chantal Cherifi, Vincent Cheutet, Yacine Ouzrout. Recent Advancements in Smart Manufacturing Technology for Modern Industrial Revolution: A Survey. Journal of Engineering and Information Science Studies, 2020. hal-03054284

Table – International standards relating to production-digital divided into four levels

LEVEL	STANDARDS	DESCRIPTION
Company	ISO 15704 ISO 20140	• Modelling and architecture of the enterprise – Requirements for enterprise-reference architectures and methodologies • Automation systems and integration – Evaluation of energy efficiency and other factors involved in manufacturing systems that impact the environment
MOM	IEC 62264 ISO 22400	• Enterprise-control system integration – Integration between the activity domain and the control of manufacturing and the enterprise domain • Automation systems and integration – Key performance indicators for managing manufacturing operations
Devices and SCADA	IEC 61158 IEC 61784 IEC 65512	• Industrial communication networks – Fieldbus specifications -Specification of the protocol for the application layer • Defines a set of protocol-specific communication profiles, mainly based on the IEC 61158 series, to use in the design of devices involved in communications, factory manufacturing, and process control • Batch control system for manufacturing processes
Transversal/ multi-level	IEC 62443 ISO 50001	• Industrial communication networks – Computer security of networks and systems • Energy management systems – Requirements and recommendations concerning implementation

Source After Ahmadzai A. et al. (2020), cf. infra. NB: Non-exhaustive table listing selected examples.

Integration is a challenge at every level. Therefore, when it involves shifting the entire standards ecosystem (and the underlying processes) towards a smart manufacturing model, with which design processes then become even more closely associated, the challenge becomes truly enormous. To make things even more complicated, each company is part of a network in which it interacts with other companies in order to supply its own products and services. A systems manufacturer-integrator (such as an automobile, aerospace or rail constructor, or a manufacturer of computers, telephones or machine tools) that takes this route may bring with it dozens, or even hundreds of partners... and a plethora of standards and norms. The requirement for digital continuity represents a key challenge in the shift towards smart manufacturing.
Standards and norms act as both hindrances and favourable factors for disseminating smart manufacturing.
Hindrances because:

- the entire spectrum is not covered and standardization is insufficient;
- they are also very numerous and not all are produced by international standards organizations, while the most popular come from OEMs.

Favourable factors because:

- they constitute agents of change in themselves;
- it is thanks to their implementation (and the implementation of de facto standards emanating from practices) that the shift in the production model takes place.

2.2. The circulation of manufacturing data as a source of value creation

A close look at smart manufacturing value chains shows that sharing manufacturing data between stakeholders is likely to contribute to creating value. The increased circulation of data, enabled by the implementation of standards and other semantic ontologies initiated by actors, should foster value creation by[12]:

- Enhancing asset optimization. Combining data from multiple users of the same type of machinery allows manufacturers to improve algorithms that, for example, enable predictive maintenance.
- Tracking products along the value chain. By gaining end-to-end visibility of their value chains, manufacturers can react quickly to unexpected events and reduce inventory.
- Tracing process conditions along the value chain. Manufacturers can instil trust and more efficiently comply with stringent regulatory requirements by having access to a continuous and complete digital record along the value chain.
- Exchanging digital product characteristics. Sharing data on product shape and composition allows manufacturers to synchronize and optimize connected production processes. A digital product twin that is shared between a supplier and an original equipment manufacturer (OEM) can, for example, help to eliminate incoming quality inspections or topographical measurements needed to automatically process parts.
- Verifying provenance. Customers increasingly demand more transparency regarding where their products come from and they want to verify authenticity.

3/ FAVOURABLE FACTORS, CONDITIONS OF SUCCESS

The shift of the industrial production model towards smart manufacturing will take advantage of its efficiency, in particular regarding the need for energy efficiency. The qualities of smart manufacturing could boost the regeneration of industrial networks on a territorial scale.

12- Cf. World Economic Forum, 2020, "Share to Gain: Unlocking Data Value in Manufacturing", White Paper, January.

Basically, smart manufacturing can be a route to reindustrialization compatible with decarbonization goals (cf. Paris Agreement on climate).

The automation associated with robotization and additive manufacturing can mean using shorter supply circuits, locating production capacities closer to requirements, and reducing consumption of matter and energy. We can also expect a more robust, agile logistics chain. Better integrated logistics chains that get the most out of digital technologies (cf. below) would contribute to better management of risks related to climate change, epidemics (cf. automobiles and semiconductors) and/or geopolitics.

A key problem that smart manufacturing is likely to help resolve is that of overproduction. The costs of endemic overproduction are enormous and involve inappropriately employing numerous limited resources. Some estimate that this amounts to a quarter of the cost of initial manufacturing. Smart manufacturing has the capacity to produce "as close as possible to requirements" thanks to better matching of supply with demand.

From the producer's point of view, therefore, smart manufacturing can provide more precise knowledge of demand. The circulation of data on products, up to and during their usage, leads to financial savings and reduces environmental impacts: short circuits, circular economy, optimal supply, etc. Improving the circulation of data is crucial. It is worth repeating: heterogeneous systems should be interconnected by carefully thought-out agreements between industrials in the data value chain. Taking this thinking one step further, the digital platformization of smart manufacturing can encourage manufacturers and clients-users to make their relations part of a "functional economy[13]." In this type of business model, it is the use (function) offered by products and equipment that is purchased (rented) rather than the product itself. Customers no longer need to own the product and, without purchasing it, benefit from its services (a number of washes in a washing machine for final consumers[14], flight hours with an aeroplane engine for an airline[15], miles of tyre usage for a road transport company[16], etc.).

By using cloud-based additive manufacturing (cloud manufacturing), the production resources themselves are shared in a pool. The economies of scale obtained are shifted toward the pooled platform. Clients benefit from high-volume production runs and lower unit costs without having to bear the fixed costs. This "physical production as a service" has numerous positive impacts including bringing programmed obsolescence to an end, so that the interests of final consumers and producers (which are also intermediate customers of cloud manufacturing services) favourably converge.

Lastly, because smart manufacturing implements the capacities of predictive analytics, negative environmental externalities can be internalized. The operation of machines, equipment, and in silico products based on detailed behavioural models, in the form of digital twins, guarantee perfect anticipation of the environmental impacts of using products and services. The price of a product is therefore a fair reflection of the consequences of usage, which market mechanisms do not consider.

13- Cf., e.g., Bourg, D., Buclet, N., 2005, L'économie de fonctionnalité: changer la consommation dans le sens du développement durable, Futurible, Numero 313, November 2005, p.27-37.
14- Cf. e.g., https://www.forbes-rentals.co.uk/listing.asp?Category=J
15- Cf. e.g., the TotalCare package offered by Rolls-Royce for its Trent engines https://www.rolls-royce.com/media/press-releases/2021/17-11-2021-poweroftrent-rr- announces-totalcare-agreement-with-mng-airlines.aspx ;
16- Cf. e.g., https://business.michelinman.com/freight-transportation/freight-transportation-services/michelin-fleet-solutions

Box 2
Beelse cloud manufacturing: dematerialized stocks and just-in-time production

The Beelse cloud manufacturing platform provides production services on request as close as possible to usage thanks to additive manufacturing. The company can do this thanks to a new manufacturing production system that takes advantage of pooling. Customers that want to produce parts by additive manufacturing can therefore benefit from a flexible, just-in-time production service, in a short circuit and that provides good value for money.

The client does not have to cover the cost of physical storage and machine investments. The stock is virtual, held in a secure repository in the Beelse cloud. The company possesses the "DNA" of the physical product to produce, containing all of the characteristics to ensure quality production, without having to possess its own production equipment. As a result, Beelse has the capacities to produce new "servicized" products for a large clientele. This type of manufacturing brings a positive environmental impact:

- "Zero stock"
- "Lifetime" availability of parts
- "Short circuit", meaning less pollution from transport
- Bio-based inputs as far as possible.

This is a fast-growing market, and Beelse boasts the most advanced additive manufacturing platform to date.

As a final point, this approach to smart manufacturing boosts the attractivity of careers in industry. High-tech positions that make a positive environmental contribution are likely to encourage young talented people to work in companies moving in this direction. The substantial renewal of skills in industrial companies goes hand in hand with the move towards smart manufacturing. Preserving some "core skills" and values in these evolving companies is also crucial.

03

DRAWING UP A NATIONAL PLAN FOR SMART MANUFACTURING

Despite the urgency, to date no nationally coordinated action plan is in place. Such a national plan for smart manufacturing needs to be produced in order to give this shift the necessary impetus. It could logically be part of France 2030. The Académie des Technologies should be consulted to produce, monitor and evaluate this plan. The Directorate General for Enterprise, working with the Directorate General for Research and Innovation and relying on the opinions of the Académie des Technologies, would draw up a national plan for the development and roll-out of intelligent manufacturing in order to improve the productivity and energy efficiency of the French manufacturing sector. Scenarios of the move to a low-carbon economy, when including the technologies needed for less-polluting industries, are based on process changes similar to those driven by smart manufacturing.

This national plan for smart manufacturing must identify the domains in which the actions taken under the General Secretariat for Investment and with its financial support will be able to:

- Facilitate the faster development, roll-out, and adoption of smart manufacturing technologies and process.
- Improve competitiveness and strengthen manufacturing companies.
- Result in greater energy efficiency and lower environmental impacts for manufacturers.

Considering the high stakes involved – reindustrialization and economic prosperity under environmental constraints – the plan should be short term, five years maximum, and equipped with adequate resources.

Depending on the means to be determined for the different actions (calls for projects, calls for tender, subsidies, loans, skills support, etc.), the actions in the plan should:

1/ Identify the standards (including de facto standards), norms and semantic ontologies that are strictly necessary and sufficient for the development of smart manufacturing.

2/ Establish the list (1) and production of these standards and norms, interacting with user companies – lead users in the most in-demand or advanced companies and sectors – and technology producers, based on an agile, rapid development model that fosters adoption along the way. AFNeT and the ATLAS programme, as well as the GAIA-X association, should be mobilized for the sets of action (1) and (2), or at least consulted on the preparation of action and as action intermediaries. Lead users' appetite for adopting smart manufacturing could be usefully tested through a national survey. This survey would also provide a reference to appraise the impacts of the plan.

3/ Follow on from the PIA4 (government investment programme) call for expressions of interest, "future trades and skills", by supporting new talents and the accelerated adaption of training to match smart manufacturing skills and trades.

4/ Deploy the results of research, when mature enough for industrial adoption, led by the public organizations concerned by the six smart manufacturing business ecosystems (cf. 1.1.).

5/ Disseminate guidelines and tested methods on cybersecurity of infrastructures – including open public platforms – underlying smart manufacturing.

6/ Employ existing high-performance calculation infrastructures or develop them further.

7/ Carry out a thorough evaluation of the plan, including an initial evaluation of past or current action undertaken by the different ministries and that intend to contribute to actions totally or partly in favour of smart manufacturing. This plan should result in a true acceleration of the implementation of smart manufacturing in a large number of industrial companies. In contributing to reaching the objectives of the national low-carbon strategy, and as a factor of increased competitiveness for industrial companies, its lifespan should be short, five years maximum. Apart from an annual presentation of the progress of the plan at the National Assembly, a decisive mid-term evaluation will consequently be necessary.

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