Moving Towards a Sustainable Model: Societal, Economic and Environmental

Patrick Martin[1], Maroua Nouiri[2] and Ali Siadat[1]

[1] *Arts et Métiers Institute of Technology, University of Lorraine, HESAM University, LCFC, Metz, France*

[2] *LS2N UMR CNRS 6004, Nantes University, IUT de Nantes, France*

2.1. Industry of the future and sustainable development

The industrial transition mentioned in Chapter 1 is accompanied by the consideration of sustainable development constraints (Nouiri *et al.* 2019a). Indeed, environmental issues, such as the reduction of pollution, carbon dioxide (CO_2) emissions, the reduction of raw material resources, biodiversity as well as the control of climate change, are becoming increasingly important. Some authors have even started to build a new paradigm (Industry 5.0), greatly emphasizing ecology and humans (Nahavandi 2019; Région Grand-Est 2020; EU Horizon 2020). Whatever the name, achieving a balance between production of goods, ecological aspects and human factors is a major challenge in the transition to the industry of the future.

Sustainable development is a concept of development that meets the needs of the present without compromising the ability to meet the needs of future generations (WCED 1987). A sustainable model must therefore ensure a balance between economic, environmental and social impacts. Figure 2.1 illustrates the three working dimensions, leading to a model consistent with sustainable development. The objective of this chapter is to show how industrial cyber-physical systems (ICPS) have characteristics that contribute to solving the sustainable development challenges presented above. Our approach is thus positioned within the framework of sustainable engineering, defined in recent works as the combination of three interacting environmental, societal and economic dimensions (see Figure 2.1). Therefore, these three aspects applied to ICPS will be addressed consecutively, starting with the societal aspect, and more particularly, focusing on the role and integration of humans in ICPS.

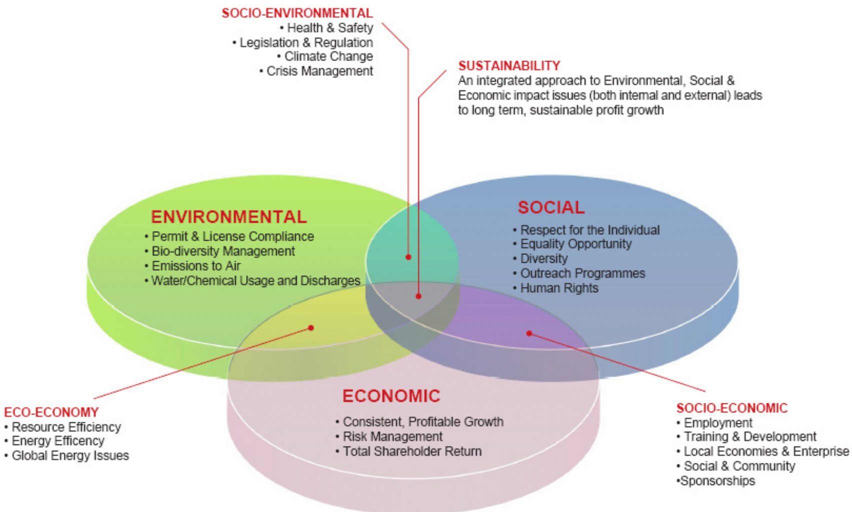

Figure 2.1. *The three dimensions of sustainable development (Mann 2009)*

2.2. Contribution of ICPS to the social dimension

2.2.1. *Background*

Humans have always been present in the industrial environment, but their scalability and versatility have not improved productivity and profitability in the face of an exponential increase in demands. Cost reduction and system efficiency optimization are among the main objectives of most industrialists, often to the detriment of a relevant integration of the human in these systems. Numerous studies (FUTURPROD 2013; Veltz and Weil 2015; EFFRA 2019; Neumann *et al.* 2021) thus underline the importance of taking into account the humans in the new challenges related to the industry of the future. New and crucial objectives are emerging, for which human expertise is relevant (Nouiri *et al.* 2019a): improving system resilience, adapting to disturbances (physical, economic, societal, etc.), taking into account environmental and social constraints, etc.

Figure 2.2 repositions the different dimensions of sustainable development presented previously on the impacting elements of an ICPS, as defined in Chapter 2. At the level of social objectives, the presence of humans is plural: observer, supervisor, operator and decision-maker, at the level of the workstation, as well as at the level of design or industrialization managers, in the physical as well as the cyber layer. The constraints specific to humans concern safety (accidents), physical health (musculoskeletal disorders, fatigue, vibrations, dangerous environments, etc.), psychological health (psycho-social risks, stress, cognitive fatigue) and, more generally, well-being at work.

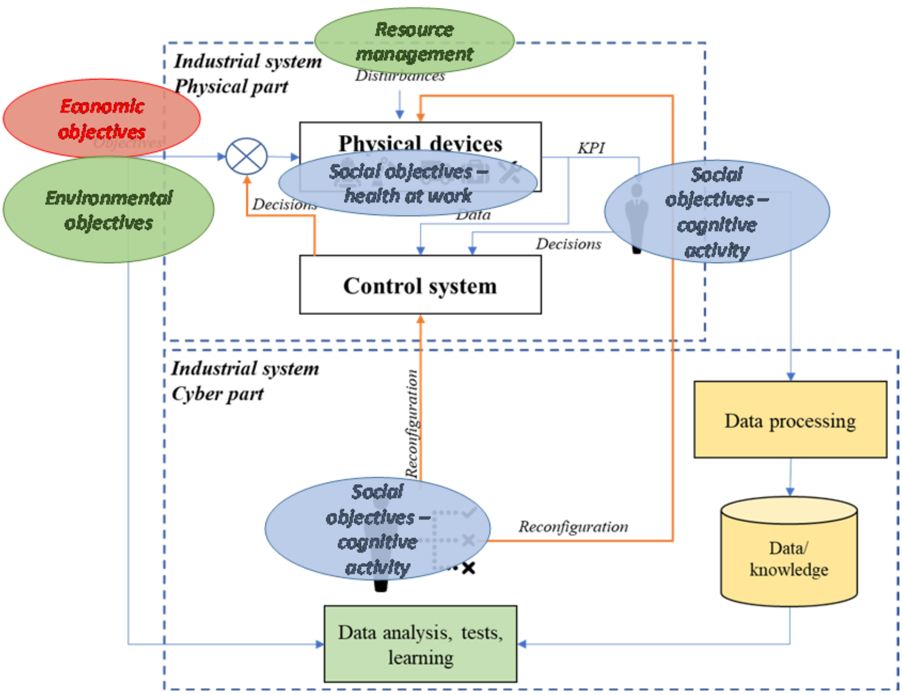

Figure 2.2. *Positioning of humans within the ICPS*

In the context of ICPS, technological developments, identified as levers for the deployment of the industry of the future with regard to work flexibility, show an evolution of equipment, manufacturing processes and procedures, and functional and even organizational constraints. Tasks can indeed be performed alternatively by a human, automated equipment, several operators or human–robot cooperation (Krüger *et al.* 2009; Murashov *et al.* 2016; Kousi *et al.* 2019), depending on the use. Automated industrial systems have made it possible, since the third industrial revolution, to ensure the repetitiveness of tasks, the rate and the constant quality of the manufactured product. Thus, humans can be relieved of tedious, repetitive tasks (physical or decisional), and with their global and contextual vision, adaptability, experience and non-formalized skills, can adapt to various tasks, make decisions adapted to complex situations and face the unknown. Nevertheless, some tasks are difficult to automate: flexible products of small dimensions, fragile, difficult to access. Thus, the interaction, cooperation, and permanent and dynamic coordination between the human and the automated system constitute the paths to be developed within the ICPS (see Figure 2.3) at the level of equipment (mechanics, sensors, communication networks, fixed or mobile robots, exoskeletons), interfaces, decision-making and organization (implementation, planning). Five levels of integration have been identified, from local solutions to the optimization of sustainable production involving humans (see Figure 2.4, EU Horizon (2020)): paper documents, software and siloed data, connectivity, offline optimization, real-time optimization. Within this process of evolution of tools and technologies, ICPS is part of the connectivity between equipment, planning and logistics.

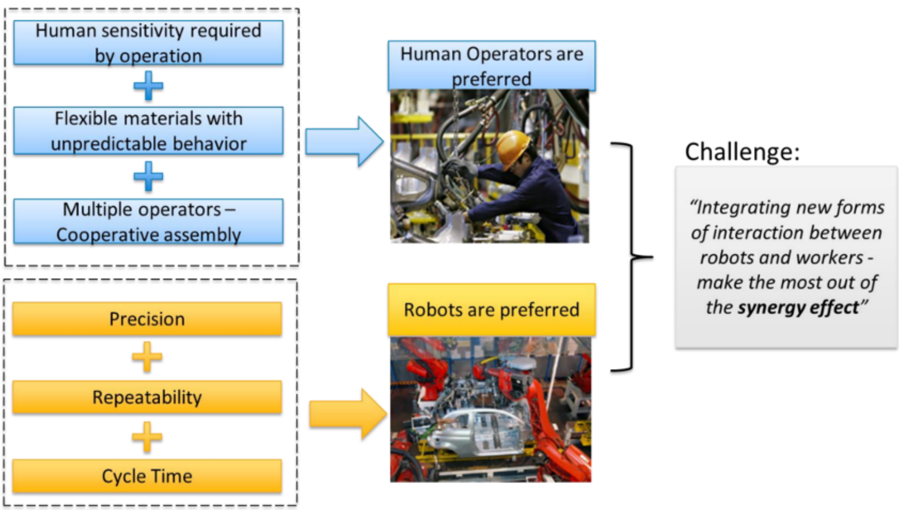

Figure 2.3. *Respective human–robot advantages (Thomas Project 2014)*

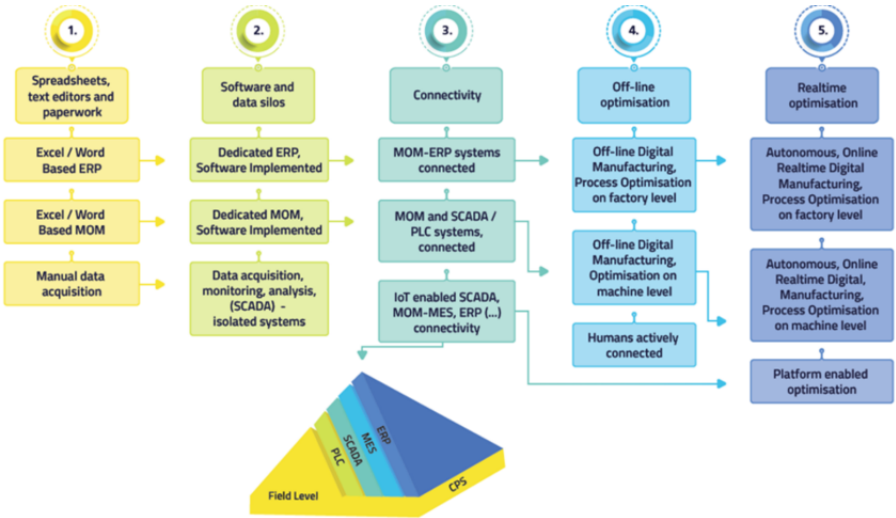

Figure 2.4. *Different stages of digitalization of production (EU Horizon 2020)*

The advantages of ICPS in favor of humans will thus be found in the different categories of aspects: the cognitive aspects, where ICPS collaborate with humans for better decision-making or to relieve humans who may be victims of mental overload, and the OHS aspects (occupational health and safety), where the adaptation capacity of ICPS will make it possible to physically relieve humans, while providing them with more advanced interaction conditions and guaranteeing their safety. The rest of this section is dedicated to the description of these two families of aspects.

2.2.2. *Cognitive aspects*

One of the major interests of ICPS is their ability to adapt to the context and diversity, both in terms of external elements (constraints, objectives, disturbances) and within themselves. Thus, it is expected that the ICPS can adapt to the presence of the human during various decision-making processes. The collaboration between the operator and the ICPS is positioned at the level of decision-making within the physical system (assistance for the accomplishment of a task, individualized training, etc.), at the level of the organization and planning of tasks within this same physical part with the objective of optimizing and eliminating unproductive time, or at the level of monitoring within the cyber part. Flow tension, reconfiguration and sharing the task with artificial intelligence are all parameters that should not be neglected in the evaluation of psycho-social risks engendered in operators, particularly via the stress generated by change. This cooperation leads to the need to identify characteristic parameters and develop new models combining structural, organizational and human points of view.

Chapter 10 of this book discusses the opportunities offered by ICPS to establish a fruitful relationship with the human in these different decision-making processes, in more detail. In this context, the human is then alternatively considered as an “Operator 4.0”, or as a constituent part of a cyber-physical human system.

2.2.3. *Health and safety aspects at work*

The adaptation of ICPS to humans is also at the purely physical level: gender, origin, age, disability and culture are all factors that characterize the operator, which must be taken into account to optimize this relationship and offer assistance adapted to each user, in order to reduce health and safety risks (adaptation in space and in the planning of tasks, identification of weak warning signals).

Several projects have been carried out on work organization, monitoring of muscle fatigue and ergonomics (posture, vibrations, environment: temperature, humidity, noise, etc.), which are aimed at improving working conditions and reducing the workload. Mobile industrial robots are used to reduce the difficulty of tasks and the physical effort required by operators when transferring heavy products, etc. Collaborative robots, “cobots”, are increasingly integrated in the industrial environment (Julien and Martin 2018). Several modes of cooperation thus exist, depending on the types of interactions possible:

– common working area when the robot is stopped (control, finishing operation, etc.);

– physical assistance (exoskeleton, third hand);

– physical and cognitive cooperation (effort, trajectory, etc.) to meet product quality and precision in the repetitiveness of the task;

– presence of the operator in the working area of the robot with stop associated with proximity or contact sensors.

These different types of robots make it possible for the humans to be relieved of heavy loads or very precise tasks, but their use is associated with the acceptability of the operator (permanent presence, physical or psychological constraint). The interfacing between the human and the robot is declined according to two major aspects:

– Sensors: in the industry, presence sensors (light barriers, pressure detection mats, cameras, distance or contact sensors, etc.), effort sensors, fatigue or vigilance sensors are increasingly being developed. In addition, measurements of environmental parameters (brightness, noise, temperature, radiation, dust, etc.) are necessary to prevent harmful effects on health.

– Interaction: this is based on interfaces that enable operators to interact with their environment (touch screens, keyboards, tablets, joysticks, etc.), to have assistance interfaces for a better knowledge of their environment (virtual and augmented reality, haptic interfaces, visualization of the state of the product, the process, the production to which they cannot have access, simulation of an operation to help its realization, etc.) and to receive real-time feedback on processing and decision-making (connected watch, tablets, etc.). However, this can only be achieved if the integration of the human in the ICPS is made in such a way that the problems related to the exchange of information between the digital and human worlds are handled in an intelligent way, taking into account the specificities and constraints of both worlds. The "shell administration" concept of the BASE architecture clearly illustrates this aspect (Sparrow *et al.* 2021). Finally, it should be noted that interaction is the basis for the cooperation mechanisms in ICPS, which are specifically studied in Chapter 10 of this book.

If many hopes are placed in the technological offer to improve working conditions, it is essential for designers to make a precise assessment of the risks they present, by endeavoring to identify those that are new, accentuated or more difficult to control. Particular attention must be paid to technologies that aim to "increase" the physical or cognitive capacities of operators (exoskeletons, physical assistance robots, augmented reality, artificial intelligence). The boundary is indeed imprecise and subject to discussion between a use that makes it possible to preserve health and safety at work and one that would, on the contrary, have negative effects because it would be primarily aimed at working faster, carrying more loads, standardizing work, etc. The opening of industrial equipment control systems to the Internet can also, in the presence of viruses, affect the operation of installations and consequently be more or less directly a cause of accidents for employees (see Chapter 6).

2.2.3.1. *Safety at work*

The accident is directly associated with the simultaneous presence of the operator and a potentially dangerous object at the workstation. The identification of dangerous situations, and thus prevention, therefore requires investigation of:

– scheduling of tasks, including those of the operator;

– identification of characteristic design parameters related to risk qualification;

– quantification of risks and their exploitation in order to help the designer in their activities of safe design of work situations.

In this sense, the concept of Design for Safety recommends the improvement of knowledge sharing between the different trades, with a strong involvement of the health and safety expert as early as possible in the design process. This has been the subject of numerous works (Fadier and De la Garza 2006; Shahrokhi and Bernard 2009; Houssin and Coulibaly 2011). The analysis of all of these methods, techniques and design tools made it possible to produce the findings synthesized by de Galvez *et al.* (2017) and Jafari-Sadeghi *et al.* (2019). In order to identify hazardous phenomena as early as possible during the design process, it is first necessary to identify the different functional elements constituting a production system. The significant parameters (energy and volume of influence) related to potential risks can be associated with each element. In these definitions, the operator is at the same level as functional modules and can perform most of these operations. The association of functional elements able to perform a task constitutes a workstation. A production cell is a set of workstations. Figure 2.5 illustrates the typology of the different elements making up a production cell in the manufacturing field.

Each module has mechanical, physical, electronic or software elements that ensure physical, quality and functionality control, and decision actions. The operator also has the same functionalities. The interaction, at a given moment between the modules and the operator(s), generates actions that can lead to dangerous phenomena. The granulometry is chosen by the designer, taking into account their objective (organization link, space management, use, etc.), knowledge of the system state and accuracy of analysis sought. It thus plays a decisive role in monitoring hazardous phenomena and their level of severity according to the modifications made to the production system.

The strong assumption for the analysis of the production system to identify and quantify the hazardous elements for health and safety is that the hazardous phenomena are related to the presence of energy. These energy flow parameters can be divided into two families: the main energy parameters that characterize a generalized energy flow (technological description of the way in which this flow circulates: mechanical, electrical, thermal, chemical/biological, radiation) and the complementary parameters (shape, material, surface condition, trajectory).

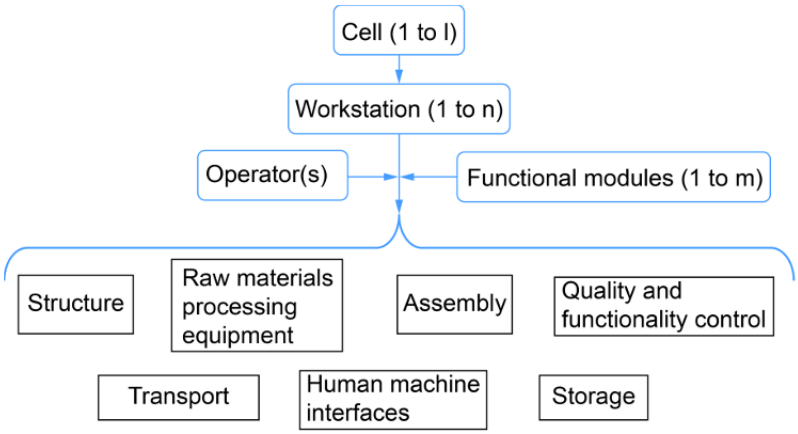

Figure 2.5. *Typology of elements constituting production cell (Gomez Echeverri* et al. *2019)*

The accident is linked to the presence of the operator in the space occupied at a given moment by the dangerous object. This dangerous object can potentially appear at the level of the task carried out (cutting tool, etc.) or in the machine, released at the time of the task in a voluntary way or not (potential mechanical energy, fluid under pressure, pollutant, etc.). The hazardous area (geometry) is defined by the spaces occupied at each stage studied (sequence of static images) by the zones of influence of the equipment and the operator (simplified modeling) (see Figure 2.6).

The quantification of the severity is carried out by analyzing the standards associated (INRS 2006; ISO 2016; INRS 2017; INRS 2021) with each type of energy identified. From this information, the maximum energy value to which the worker is exposed is usually classified on a severity level scale (Gomez Echeverri *et al.* 2019). This information allows the designer to choose a technical or organizational solution so as to eliminate severe and very severe cases.

In the framework of ICPS, advanced strategies of collaboration within the physical parts, in particular through a relevant use of multi-agent or holonic systems (see Chapters 7 and 8), can propose, for example, a set of cooperative solutions, making it possible to complete the design solutions by a dynamic management of the working areas between the various controlled elements and the humans.

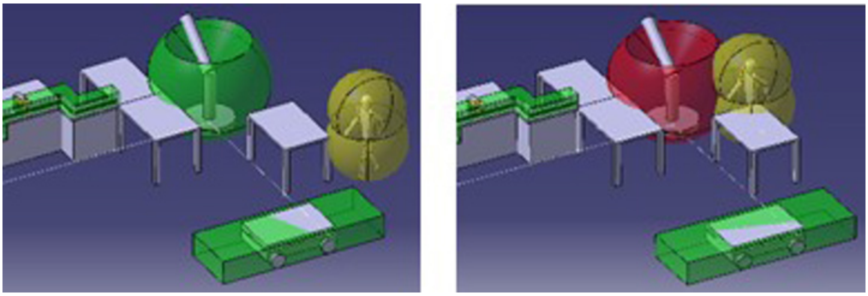

Figure 2.6. *CAD modeling of influence volumes (Gomez Echeverri* et al. *2019)*

2.2.3.2. *Health at work*

Occupational health is an important aspect of a company's sustainable development. There are many standards, structures and committees that ensure this aspect. Beyond these regulatory aspects, there are possible actions to be carried out within the ICPS itself that contribute to guaranteeing it: scheduling of tasks under ergonomic constraints, taking fatigue into account in activities, optimizing preventive maintenance operations, etc. The study of the margins of maneuver illustrates the first action. For several years now, the ergonomics community has considered the margins of maneuver as a means of preventing musculoskeletal disorders (MSDs) and psychosocial risks, as well as a condition for keeping senior or disabled operators at work. Designing a system with room for maneuver therefore means giving it a certain "plasticity", to enable operators to manage variability without jeopardizing their health, by developing new practices and reinventing their uses, and to enable a dynamic work activity. Thus, Lean Manufacturing (operational excellence), whose objective is to eliminate non-value-added activities in order to improve the company's performance, is becoming the subject of questioning, particularly in terms of employees' working conditions. It is necessary to develop tools for the "monitoring" or "surveillance" of operator solicitations during the production phase, in order to predict "drifts" that lead to work situations or states that will cause disorders or fatigue. The margins of maneuver (see Figure 2.7) is defined as the possibility or freedom available to a worker to develop different ways of working, in order to meet production requirements, without adverse effects on their health.

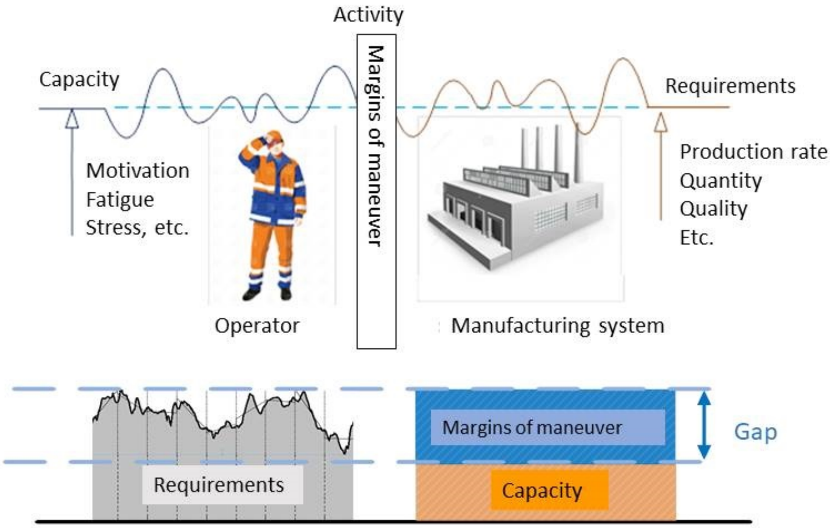

Figure 2.7. *Margins of maneuver (Lanfranchi and Duveau 2008)*

We consider that it is possible to reduce the organizational and spatial margins of maneuver to temporal margins. Thus, thanks to simulation, the effects of variability disrupting production, as well as the effects of these temporal margins left to the operator, could then be studied from the dual point of view of occupational health and safety and system performance: beyond a certain threshold of "flow tension" or "organizational rigidity", it is likely that the system is no longer capable of absorbing variability, and that the operators are no longer able to operate the regulations necessary to maintain performance under good conditions. As an illustration, this point has been studied for an ICPS purpose by El Mouayni *et al.* (2017) and focused on the simulation of "operator" variability implemented in a multi-agent model (see Figure 2.8) by studying the following points:

– parameterization of the fatigue model;

– parameterization of the learning model;

– error model parameterization: HEART (human error assessment and reduction technique) method.

2.3. Contribution of ICPS to the environmental dimension

2.3.1. *Objectives and expectations*

The consideration of the environmental impact must be ensured from the design phase and throughout the lifecycle of systems. A typical approach is to carry out a lifecycle assessment (LCA) of the production systems and products made within the ICPS (Ballarino *et al.* 2017) and verify the sustainability of the ICPS themselves, due to the intensive use of digital technologies in particular.

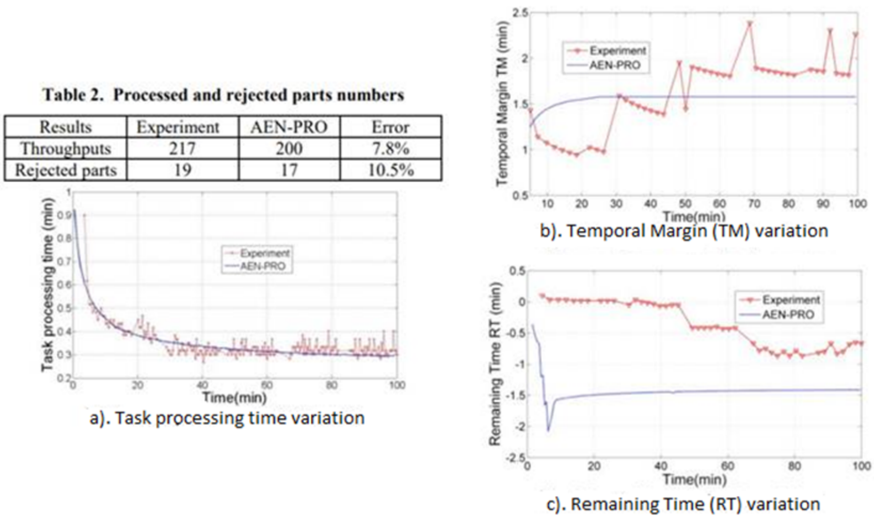

Table 2. Processed and rejected parts numbers

Results	Experiment	AEN-PRO	Error
Throughputs	217	200	7.8%
Rejected parts	19	17	10.5%

Figure 2.8. *Simulation of the times of maneuvering margins (El Mouayni* et al. *2017)*

This type of study typically leads to the use of bio-sourced materials as raw materials or recycled materials with less environmental impact (Kovarik *et al.* 2020; Carrodeguas *et al.* 2020). Reverse logistics is also developing. It is based on the use of reusable materials and packaging to reduce the environmental footprint (Ruel *et al.* 2021). Sustainable production strategies are also being developed, such as mass customization. This type of strategy aims to produce goods and services to meet the needs of each customer while ensuring effective and efficient productivity. Thus, the customer is involved in the design phase of the product. Product customization implies a specified production that best satisfies the customer's needs, thus guaranteeing an increase in the product's lifespan.

State organizations can also participate in the sustainable transition by imposing certain binding regional policies (variation of the cost of carbon, taxes, penalties for exceeding an energy or pollution threshold).

Thanks to the use of information and communication technologies (ICTs), everything within the ICPS becomes communicative: consumers, logistics operators, goods producers, energy producers, etc. This communication encourages interaction and negotiation for the local benefit of each ICPS and thus optimizes the global gain.

The concept of ICPS is relevant to reduce environmental impacts within the industrial environment (subject to its LCA, as mentioned previously). Indeed, the cyber layer makes it possible to retrieve data in real time and extract useful information in the environmental component. For example, a major advantage of ICPS is that they can be designed to use real-time information to reduce local energy consumption, manage waste or collaborate with other ICPS to optimize global energy and raw material consumption. The intelligence built into ICPS also allows them to react dynamically to internal energy constraints (exceeding an expected energy threshold) or external constraints (variation in the availability of renewable energy).

The ICPS management system can thus integrate new performance indicators relating to environmental effectiveness and efficiency. These indicators will be used to quantify an estimate of the impact on the environment (energy, waste, pollutants, greenhouse gases, etc.) during the predictive phase and monitor their evolution in real time.

2.3.2. *Example of application*

Mazumder *et al.* (2021) presented research books related to power electronic innovations in cyber-physical systems (CPS), more precisely new energy distribution architectures, protection techniques taking into account a wide integration of renewable energies in smart grids, simultaneous transmission of energy and information, etc. Nouiri *et al.* (2019b) proposed a multi-agent architecture named EasySched, based on the collaboration between goods producers (energy consumers) and renewable energy producers. Two types of ICPS are considered in this example: cyber-physical production systems (CPPS) and cyber-physical energy supply systems (CPES). As illustrated in Figure 2.9, the Industrial Internet of Things (IIoT) enables communication between CPPS and CPES. External communication enables the coordination and control of the energy consumption of the connected plants and the availability of renewable energy.

Renewable energy production is difficult to predict, as it is highly dependent on uncontrollable conditions (e.g. weather conditions). A disturbance related to the decrease in renewable energy availability is communicated and broadcasted to the connected plants, which then cooperate with the CPPS in order to respect this constraint. Rescheduling techniques are then executed to react quickly to this disturbance. The originality of this architecture lies in the fact that the scheduling is performed taking into account the production needs and the dynamic level of available renewable energy.

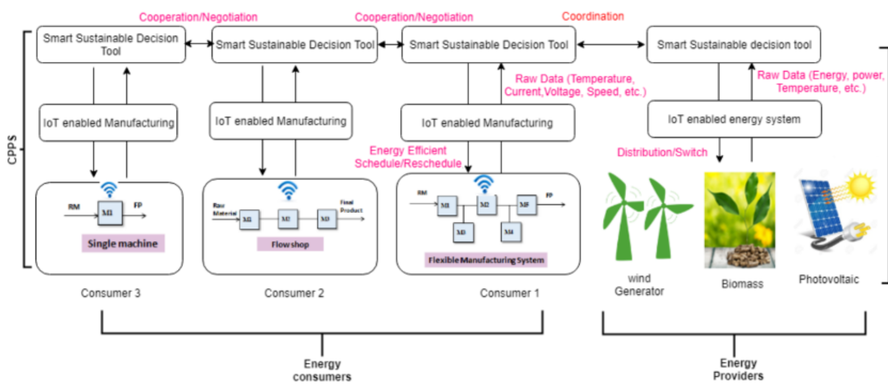

Figure 2.9. *EasySched: a multi-agent architecture for predictive and reactive scheduling of goods production systems based on available renewable energy in an Industry 4.0 context (Nouiri* et al. *2019b)*

2.4. Contribution of ICPS to the economic dimension

Because of their ability to adapt quickly (to markets, hazards, urgent requests, etc.), optimize (scheduling, planning) and integrate the various information systems, ICPS clearly contribute to the economic dimension of companies. Because of their ability to process large masses of data at the cyber level, they also allow for the implementation of mechanisms to optimize the various "assets" of companies, in particular by optimizing maintenance processes (predictive, opportunistic, etc.), and to monitor the life of the various fleets of equipment, machines, tools, etc. via IIoT technologies, for example.

However, the transition to a sustainable model also implies optimizing the overall economic gain, in the longer term, beyond compliance with classic short-term financial constraints (turnover, market share, profit, margin, etc.). Typically, taking into account environmental constraints, *a priori* restrictive, can then be a source of long-term gain. For example, the use of recycled materials aims to reduce production costs, the impact on the use of non-renewable resources and the generation of non-valuable waste. In this context, the ICPS, capable of fine and global control of a production, can help to monitor the impact of the integration of these elements in the products and processes.

Reverse logistics or the implementation of dismantling channels is also an illustrative example of this global vision and is a major issue for the future (Tolio *et al.* 2017). In particular, dismantling aims to break down a product into homogeneous components, parts and materials, thus making it possible to meet the requirements of reuse or treatment at the end of life. It includes different phases: disassembly and size reduction, sorting and separation, recycling, inspection, cleaning, repackaging and logistics (see Figure 2.10). Within these phases, digital technologies associated with the Industry of the Future are present, particularly in terms of online and offline data collection, knowledge capitalization and feedback to the operator (AR headset, haptic interface). With the cyber dimension, ICPS can thus facilitate the interconnection between the various logistics chains and the information systems of the players to contribute to this global financial optimization.

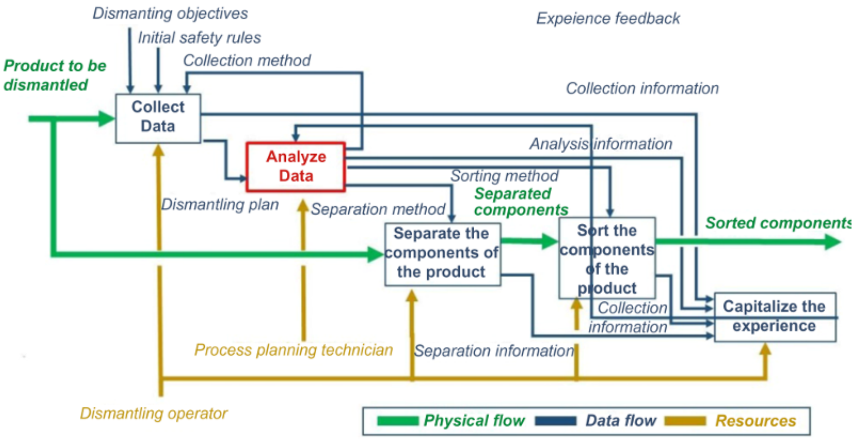

Figure 2.10. *Modeling the dismantling process (Hu 2021)*

In another area, the reduction of internal transport costs thanks to ICPS would be possible by setting up horizontal collaboration between ICPS, for example, thanks to fleets of mobile transport robots. Just-in-time or just-in-sequence delivery of components would reduce the cost of storage in warehouses, both intra- and inter-site, which is often variable. Smart management of logistics within ICPS makes it possible to not only react to disruptions (increased demands, closure of a distribution platform, etc.) but also reduce expenses related to internal and external transport and storage costs. Optimizing the filling of trucks and efficient communication within the fleet would help to minimize the overall transport costs (see Chapter 12).

The benefits in terms of health and safety and well-being at work also have a significant economic impact, only if the production resource capacity is available, through their day-to-day efficiency or the reduction of costs incurred by accidents or illnesses at work. Here again, the ICPS can contribute through their ability to capitalize on the events that have occurred and link them together to analyze the root events that cause incidents, accidents, work stoppages, etc.

2.5. Conclusion

In this chapter, the main challenges of the industrial transition towards a sustainable model were presented. The three pillars of sustainable development (environmental, social, economic) were put into perspective with the evolutions brought by ICPS, which make it possible to respond to these new challenges efficiently. A particular focus was given to the importance of the cyber layer to collect and process data from the physical layer, in order to make decisions that are increasingly in line with sustainable development. This decision-making is generally performed in the framework of a collaboration between the ICPS and the human decision-maker.

However, the digitalization of the industry is still handicapped by factors related to the adaptability of the human to accept these changes, train technologically (increase in skills, use of digital technologies) without forgetting the risk of quality degradation due to the diversification of human tasks, and the challenges of cybersecurity.

2.6. References

Ballarino, A., Brondi, C., Brusaferri, A., Chizzoli, G. (2017). The CPS and LCA modelling: An integrated approach in the environmental sustainability perspective. In *Collaboration in a Data-Rich World*, Camarinha-Matos, L.M., Afsarmanesh, H., Fornasiero, R. (eds). IFIP Advances in Information and Communication Technology, Springer International Publishing, Cham.

Carrodeguas, L.P., Chen, T.T., Gregory, G.L., Sulley, G.S., Williams, C.K. (2020). High elasticity, chemically recyclable, thermoplastics from bio-based monomers: Carbon dioxide, limonene oxide and ε-decalactone. *Green Chemistry*, 22(23), 8298–8307.

EFFRA (2019). European factory of the future association, Effra vision for a manufacturing partnership in Horizon Europe [Online]. Available at: www.effra.eu.

El Mouayni, I., Etienne, A., Siadat, A., Dantan, J.-Y., Lux, A. (2017). AEN-PRO: Agent-based simulation tool for performance and working conditions assessment in production systems using workers' margins of manoeuver. *IFAC-PapersOnLine*, 50(1), 14236–14241.

EU Horizon (2020). The ConnectedFactories project. EU Horizon 2020 grant no. 723777 [Online]. Available at: https://www.connectedfactories.eu/pathways-digitalisation-manufacturing.

Fadier, E. and De la Garza, C. (2006). Safety design: Towards a new philosophy. *Safety Science*, 44(1), 55–73.

FUTURPROD (2013). Les systèmes de production du futur, atelier de réflexion prospective de l'ANR [Online]. Available at: www.cluster-gospi.fr.

de Galvez, N., Marsot, J., Martin, P., Siadat, A., Etienne, A. (2017). EZID: A new approach to hazard identification during the design process by analysing energy transfers. *Safety Science*, 95, 1–14.

Gomez Echeverri, J.C., Martin, P., Daille-Lefevre, B., Godot, X., Marsot, J. (2019). Prise en compte dans la conception et l'exploitation des postes de travail de l'usine du futur des aspects sante – securité. *16ème colloque national S-mart*, Les Karellis, 73.

Houssin, R. and Coulibaly, A. (2011). An approach to solve contradiction problems for the safety integration in innovative design process. *Computers in Industry*, 62(4), 398–406.

Hu, H., Godot, X., Daille-Lefevre, B., Martin, P. (2021). Analyse des aspects santé-sécurité lors du démantèlement/de-manufacturing. *Proceedings of the S-mart National Conference*, 189–196.

INRS (2006). Les rayonnements ionisants. Prévention et maitrise des risques. Booklet, ED 958.

INRS (2017). Interventions à proximité des réseaux électriques aériens. Place des détecteurs de lignes électriques dans la démarche de prévention, ED6292 [Online]. Available at: https://www.inrs.fr/media.html?refINRS=ED%206292.

INRS (2021). Valeurs limites d'exposition au bruit et port de protecteurs individuels. Information pack, Fiche pratique de sécurité, ED 133.

ISO (2016). Robots and robotic devices – Collaborative robots, 1st edition. Technical specification ISO/TS 15066.

Jafari-Sadeghi, V., Kimiagari, S., Biancone, P.P. (2019). Level of education and knowledge, foresight competency and international entrepreneurship: A study of human capital determinants in the European countries. *European Business Review*, 32(1), 46–68.

Julien, N. and Martin, É. (2018). *L'usine du futur – Stratégies et déploiement : Industrie 4.0, de l'IoT aux jumeaux numériques*. Dunod, Malakoff.

Kousi, N., Stoubos, C., Gkournelos, C., Michalos, G., Makris, S. (2019). Enabling human robot interaction in flexible robotic assembly lines: An augmented reality based software suite. *Procedia CIRP*, 81, 1429–1434.

Kovarik, J.-B., Villarreal, A., Ramos, E.A., Alferaiheedi, Y., Modiselle, K.G. (2020). Carbon neutral buildings and recycled materials: How cities want to solve the challenge. Royal commission for Riyadh city in the Kingdom of Saudi Arabia, Urban 20 Mayors Summit – U20.

Krüger, J., Lien, T.K., Verl, A. (2009). Cooperation of human and machines in assembly lines. *CIRP Annals*, 58(2), 628–646.

Lanfranchi, J.-B. and Duveau, A. (2008). Explicative models of musculoskeletal disorders (MSD): From biomechanical and psychosocial factors to clinical analysis of ergonomics. *European Review of Applied Psychology*, 58(4), 201–213.

Mann, S. (2009). Visualising sustainability. *Computing for Sustainability* [Online]. Available at: https://computingforsustainability.com/2009/03/15/visualising-sustainability/.

Mazumder, S.K., Kulkarni, A., Sahoo, S., Blaabjerg, F., Mantooth, A., Balda, J., Zhao, Y., Ramos-Ruiz, J., Enjeti, P., Kumar, P.R. *et al.* (2021). A review of current research trends in power-electronic innovations in cyber-physical systems. *IEEE Journal of Emerging and Selected Topics in Power Electronics*, 1–1.

Murashov, V., Hearl, F., Howard, J. (2016). Working safely with robot workers: Recommendations for the new workplace. *Journal of Occupational and Environmental Hygiene*, 13(3), D61–D71.

Nahavandi, S. (2019). Industry 5.0 – A human-centric solution. *Sustainability*, 11(16), 4371.

Neumann, W.P., Winkelhaus, S., Grosse, E.H., Glock, C.H. (2021). Industry 4.0 and the human factor – A systems framework and analysis methodology for successful development. *International Journal of Production Economics*, 233, 107992.

Nouiri, M., Trentesaux, D., Bekrar, A. (2019a). EasySched : une architecture multi-agent pour l'ordonnancement prédictif et réactif de systèmes de production de biens en fonction de l'énergie renouvelable disponible dans un contexte industrie 4.0. *Génie industriel et productique*, 2(1).

Nouiri, M., Trentesaux, D., Bekrar, A. (2019b). Towards energy efficient scheduling of manufacturing systems through collaboration between cyber physical production and energy systems. *Energies*, 12(23), 4448.

Région Grand-Est (2020). Région Grand-Est Business act Grand Est [Online]. Available at: https://www.grandest-ba.fr/.

Ruel, S., Bourcier-Bequaert, B., Domont, S. (2021). Pratiques de logistique inverse au sein d'une coopérative : une motivation environnementale ? *Logistique & Management*, 1–14.

Shahrokhi, M. and Bernard, A. (2009). A framework to develop an analysis agent for evaluating human performance in manufacturing systems. *CIRP Journal of Manufacturing Science and Technology*, 2(1), 55–60.

Sparrow, D.E., Kruger, K., Basson, A.H. (2021). An architecture to facilitate the integration of human workers in Industry 4.0 environments. *International Journal of Production Research*, 1–19.

Thomas Project (2014). Mobile dual arm robotic workers with embedded cognition for hybrid and dynamically reconfigurable manufacturing systems. Grant no. 723616 [Online]. Available at: http://www.thomas-project.eu.

Tolio, T., Bernard, A., Colledani, M., Kara, S., Seliger, G., Duflou, J., Battaia, O., Takata, S. (2017). Design, management and control of demanufacturing and remanufacturing systems. *CIRP Annals*, 66(2), 585–609.

Veltz, P. and Weil, T. (2015). L'industrie, notre avenir. Report, Post-Print, hal-01111151 [Online]. Available at: https://ideas.repec.org/p/hal/journl/hal-01111151.html.

WCED, S.W.S. (1987). World commission on environment and development. *Our Common Future*, 17(1), 1–91.