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White paper- for industry 5.0- What if human factor was truly involved ?

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Introduction :

Our civilization has experienced numerous technological changes throughout its history. Regardless of what perspective we take on their benefits, it is undeniable that each and every change has brought upon social changes that were unforeseen and often even undesirable. One can only wonder the anxieties of previous generations as they experienced similar social changes, but somehow the scale and depth of transformation that looms today seems to touch upon the social fabrics in ways that are unprecedented. Consideration of problems and challenges should therefore begin with how social values and ethics are brought to question, before projecting any form of organisation or structure under an idealised technological future.

The means classified in the “artificial intelligence” category, “Robots” generate many questions and concerns, particularly regarding the future of jobs, the role of humans in production units, in services, etc., and quite simply on the future of the human species. In the industry 5.0 topic, new technologies and equipment open up possibilities for rebuilding our society. Additive manufacturing (better known as a “3D printer”), virtual reality, big data, cobots, artificial intelligence, etc. a technological mosaic can be assembled to create our society of tomorrow. But we must be aware that what is at stake is not only technological. It is also a social project. The revolutions already in motion involve transformations to how we relate to one another and to our environment. Social and biological sciences are increasingly disputing the Cartesian thinking (i.e. “brain centrism”) that for decades has dominated our cultural and social views, and the importance of experiencing the relations with others and the world are rapidly emerging as fundamental vehicles for vital human processes such as learning. Yet an increasing number of such valuable experiences are rapidly becoming mediated by technology and their inherent processes. As human cornerstones like “learning through the experience of the world around us” become increasingly compromised, all relations at work and around it will inevitably be deeply affected. The division of labour itself is at stake.

We have an opportunity to take advantage of these possibilities. The hopes raised by these changes are at the confluence of the needs for relocation of activities, circularity of economies, jobs, respect for the environment, etc.

The question of purpose must be asked: we are not only subject to the developments that surround us; we decide them in significant proportions. What do we want for our civilization? For our children? Is it sustainable? What innovations? What is the project ?

Here too, both the areas of hope and the dangers are obvious, and arise from our current collective intelligence. Politics, in the sense of “the art of managing the city”, has a fundamental role to play.

In this document, we want to show some of the very consistent return of experience in modernization projects, which is developed in the annexes. The different chapters aim to explicit in a direct way the principles that need to be followed to succeed in the projects to come.

The contain is structured following this logic :

- Chapters I to III identifies the stakes, give a history and definitions
- Chapter IV enumerates the 4 principles for success
- Chapters V and VI present the scientific references used, and four examples of return of experience
- Chapter VI.C summarizes the HFE approach and the 4 principles

I. From industry 1.0 to industry 5.0

Current discourses emphasize that Industry 5.0 will put forward a more ethical vision, integrating factors such as sustainability, environment and social aspects. In Industry 5.0, rather than basing business strategy on a logic of production performance, humans should be the driving force behind factory competitiveness.

In this approach, taking the environment into account has become a stake. New methods of waste recovery are possible, as well as the use of renewable energies or the integration of sensors to reduce energy consumption.

But how should these goals be achieved? How are such technical solutions to be developed and implemented in such a way that they are effectively placed at the service of such goals? What is being considered in terms of the social transformations that are needed so as to ensure that effectiveness? There seems to be an underlying belief that technological solutions on their own will put in motion the necessary transformations at all levels or that other aspects of that transformation are of minor importance and will not compromise the effectiveness of Industry 5.0 vision. History has shown countless times that this is unrealistic and that more interdisciplinary and integrated approaches are needed. Perhaps even more so than at any other previous era of transformation, given the depth and breadth of the foreseeable impacts. The technical approaches that we have been able to listen to give no information on these issues. For this, we have decided to show some business examples in the appendices, which show that technology alone is not enough.

Let's see the 4 known steps below for modernization :

	18° Industry 1.0	19° Industry 2.0	20° Industry 3.0	First part of 21° Industry 4.0	What's next?
Main technical change	Use of steam and mechanization of production. Steam engines replace human muscles and animal power	Electricity, gas, oil, internal combustion engine, chemical synthesis,... First production lines, industrialization	Information technology: electronics and computing Beginning of automation of production lines.	Production machines capable of exchanging information, triggering actions and controlling themselves autonomously without human intervention. Interconnected networks, algorithms, digital spaces	
Reliability, incidents, accidents,	Paris: explosion of the Grenelle powder factory in the middle of the urban area	Lyon, (Rhone, France), the Drerheims, a steamer, performs its first tests on the Rhone near the left bank. Its boiler explodes, and it sinks immediately, 28 dead and many injured	Seveso (Italy), the explosion of a chemical reactor causes a large-scale ecological disaster. 193 people are affected by chloracne and other symptoms. 70,000 animals will be slaughtered to prevent dioxin from entering the food chain.	Toulouse (France)- explosion of the AZF chemical plant. 30 dead and more than 2,500 injured, and also causes significant destruction throughout the southwest of the city; And… Beyrouth harbor, Lubrizol (Rockton, Rouen), Leverkuzen,…	

Figure 1 : Synthetic representation for 4 industry steps

II. Industry 5.0 definition

The European Commission underlines [17] that "*Industry 5.0 literature shows a lot of uncertainty about what it will bring and how it will disrupt business in detail, as well as about its potential to break down barriers between the real world and the virtual*".

The European commission defines three strategic criterias for the changes :

- **Human-centered approach**- "*Rather than taking emergent technology as a starting point and examining its potential for increasing efficiency, a human-centric approach in industry puts core human needs and interests at the heart of the production process. Rather than asking what we can do with new technology, we ask what the technology can do for us. Rather than asking the industry worker to adapt his or her skills to the needs of rapidly evolving technology, we want to use technology to adapt the production process to the needs of the worker, e.g. to guide and train him/her.*"

- **Sustainable industry-** "*For industry to respect planetary boundaries, it needs to be* ***sustainable****. It needs to develop circular processes that re-use, re-purpose and recycle natural resources, reduce waste and environmental impact. Sustainability means reducing energy consumption and greenhouse emissions, to avoid depletion and degradation of natural resources, to ensure the needs of today's generations without jeopardizing the needs of future generations.*"

- **Resilient industry**- "***Resilience*** *refers to the need to develop a higher degree of robustness in industrial production, arming it better against disruptions and making sure it can provide and support critical infrastructure in times of crisis. Geopolitical shifts and natural crises highlight the fragility of our current approach to globalized production. It should be balanced by developing sufficiently resilient strategic value chains, adaptable production capacity and flexible business processes, especially where value chains serve basic human needs, such as healthcare or security*."

As Human Factor Specialists, we know that robots, Cobots and Artificial Intelligence are not the panacea, neither now nor in the decades to come. Several feedbacks show the interest of integrating human capacities and limits in design, which remains the intelligent regulator of work situations.

As complexity, dynamics and integration become ever more present in every industry, static standards will be of little impact in dealing with ever-changing real work conditions. This paper is in the line of many other ones, such as the one edited by IEA and ILO in 2021 [18]. It focuses on the possible bringing's and risks for what is called today Industry 5.0

The different returns of Experience included in this document show some design error or successes in project management. The keys are about giving the operator the means to play his role as regulator of the situation, taking into account the know-how of the teams, being aware of the impacts of technical choices on human functioning, and so on.

Industry 5.0 opens up new possibilities; in order to apply them, we should learn from our past mistakes and successes.

III. The principles for success

Four HFE principles are involved in the success of a project :

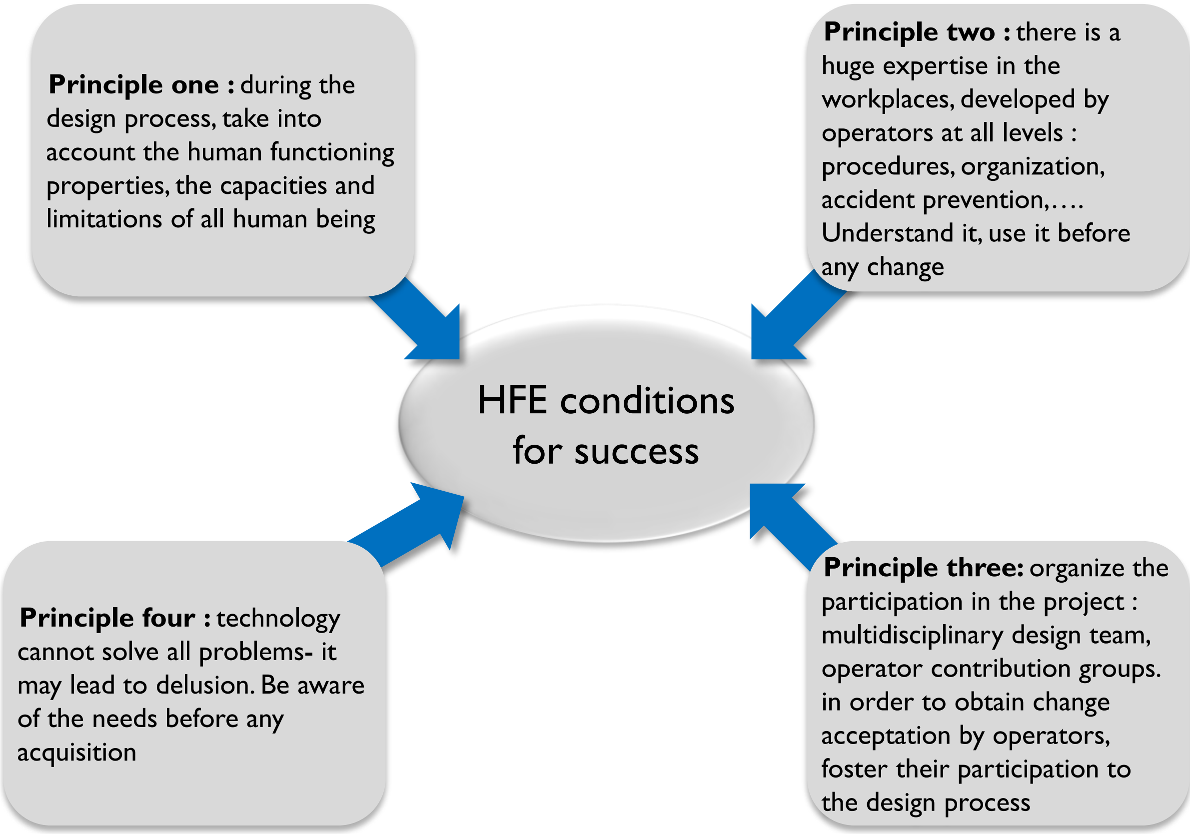

*Figure **2 : the four HFE principles for a project success***

They are explained in the following pages, and linked with illustrations in the annexes

A. Principle one : to include in the design of the equipment / installation the human operator with his capacities and limitations

Human operators are the ultimate barrier against industrial accidents. Their experience, capabilities, flexibility in front of unforeseen situations are more effective than any machine. They can make mistakes particularly if the machines are not adapted to them

While it's impossible to foresee every potential scenario in a work situation, the constant deviations and the need for safeguards highlight the importance of considering human capabilities and limitations, as humans, despite making sometimes mistakes, have the unique ability to adapt to unexpected situations and rectify them, if the resources are aligned with their functioning.

In parallel with the developments in our industries, reliability became an object of concern, accidents becoming unbearable. The first aspect of reliability to be studied was that of technology: the machines had to stop breaking down. Subsequently, work focused on human reliability, and the question of man/machine coupling was studied. Initially, this coupling was to the disadvantage of the role of humans. The human operator was considered the cause in 80% of operating anomalies and incidents. In the design of the systems, he was therefore excluded from the regulation loops, the machine having to ensure "despite human weaknesses", the reliability of the situation. This approach resulted in a set of "automatic" factories that never worked, or which caused disasters. Equipment design saw a paradigm shift from the 1980s, and the turning point came with the major work of specialists during the 1990s, relating to the incidents in industries. It demonstrated that the design of machines could not foresee all possible situations, and that the human operator contributed to reliability, provided that the man/machine coupling was designed for this. Further studies and empirical evidence have shown that, on the one hand, no matter how much effort is invested in it, design can never adequately anticipate complex operational requirements. On the other hand, such requirements extend far beyond a suitable exchange of information between human operators and technology. The gaps between the technological and the human processing of information is not an issue of capacity nor limitations, but rather one of a radically different nature. To some extent, one that is inherently linear processing in the case of technology, and one that is multidimensional and multileveled in the case of humans. Hence, far beyond the capacities and limitations of human operators, their experience and expertise must be considered an active and core contribution, and throughout the entire life-cycle of the industry processes.

The role of the human operator in the design of equipment and installations is crucial, as they are often the key factor in system performance and safety [1]. This requires a deep understanding of the operator's capabilities and limitations, which can be achieved through the application of ergonomic criteria in the design process [2], [18]. The human operator should be seen as a vital link in closed-loop control systems, necessitating close cooperation between bioscientists and engineers [3]. In the context of cobotic systems, the human operator's role is particularly important, and effective consideration of their expertise and experience is essential in the design process [4].

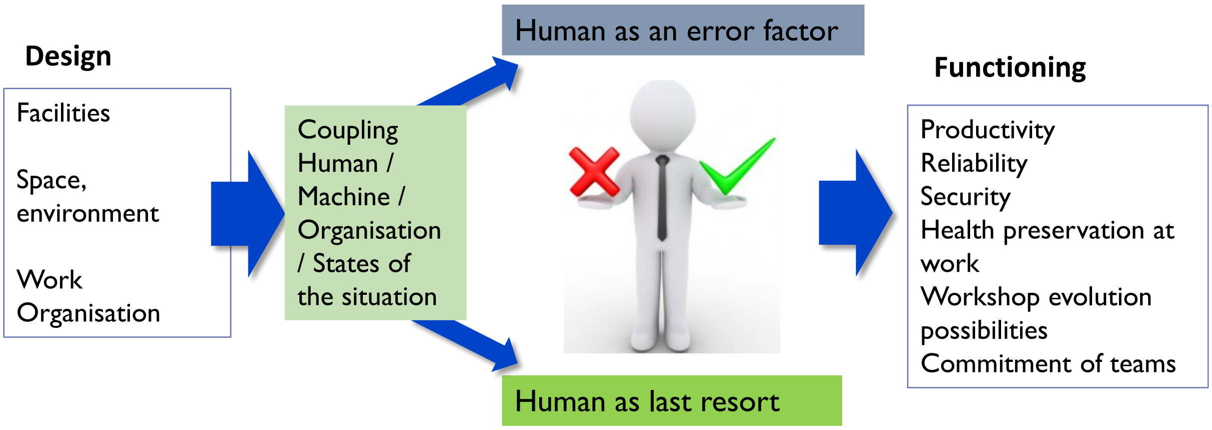

*Figure **3 : Possible position given to the operators during a project management***

The design leads to decisions defining the characteristics of equipment, space, organization, ... These decisions are based on requirement sheets at first, and then comes the detailed specification, and finally comes the realization

These decisions determine the coupling between the technical features and human characteristics. For example, Lisanne Bainbridge pointed in 1983 [5] what can be called a major design error, in his article "ironies of automation." It shows that the operator, considered as the error factor to be eliminated (1950-1980, period about with the rise of knowledge in robotics), is in an impossible situation. He is positioned as a “press button" and asked to follow a strict procedure. The machine will ensure treatments. But when the machine is in a situation not foreseen, it cannot treat it. And in this case, the operator is asked to "take control" and to handle the situation, but he has no information about what happens in the machine; he does not have the knowledge and competence to make sense of this situation, since he is positioned as a "press button“.

The designs processes that followed this type of work **have repositioned the operator in the control loops**. But there are still too often, including in sensitive industries, obsolete and dangerous approaches.

Today, a good design is the best possible coupling between the constraints and equipment resources, workspaces, ..., related to the men and organizations, including the variability of possible situations. We cannot afford to design for a unique situation where "everything would be fine." There will be degraded situations, the teams in the workshop will have to face them.

Nowadays, with the AI technology, this issue is stronger than ever. Some studies [19] show the impacts of AI systems on working situations, this impact depending on the inclusion of humans in the regulations loops. The authors of this last study call the result “Hybrid intelligence”.

According to this coupling, operators will find themselves in situations resistant to errors, or prone to them. The fact that we make mistakes is the price of our vast adaptability.
The performance in the operation, with productivity, reliability, ... but also the evolving capacities, satisfaction and commitment of the teams ... is a result of the quality of the human/machine coupling.

Principle 1 highlights the importance of including the human operators functioning in the design of equipment and installations, taking into account their capacities and limits. In the context of this principle, ergonomics plays a key role in ensuring that equipment design matches human characteristics and functions, in order to improve worker efficiency, safety and comfort. Ergonomics deals with adapting the work environment, tools, equipment and systems to human abilities and their limitations. It involves the study of human physical, cognitive, social and emotional characteristics to ensure that the design matches the needs and abilities of the worker. In this way, ergonomics contributes to the creation of a work environment that supports the well-being of workers, increases productivity and reduces the risk of injury or fatigue. In the context of principle 1, ergonomics helps to ensure that the design of equipment and installations takes into account human capacities and limits, which can contribute to improving the performance, safety and satisfaction of workers in industrial processes.

The example number 4 illustrates this principle.

B. Principle two : there is a huge expertise at the workplaces, developed by the operators. Understand it, use it before any change!

The expertise of operators is a major resource. The issue is about reliability, safety, health, but also the relevance of investments, the cost and delay of adaptation for the teams

The expertise of operators at workplaces, refined over years and often surprising, must be thoroughly analyzed and understood prior to defining technical development requirements, as it impacts not only reliability, safety, and health, but also the appropriateness of investments and the cost and time required for team adaptation. It is essential to analyze and understand it before defining the requirement sheets for technical developments.

The importance of leveraging the expertise of operators in the workplace is highlighted in several studies. Kaasinen et al. [6] emphasizes the need for solutions that empower and engage workers, allowing them to contribute to the design of their work environment and share their knowledge. Ohashi and Yuki [7] discuss the potential of expert systems and knowledge management in capturing and utilizing the practical knowledge of operators for job scheduling and productivity improvement. Cellier et al. [8] further underscores the value of expertise in dynamic environments, where expert operators demonstrate superior inference production, anticipation, and process understanding. These findings collectively support the principle of understanding and utilizing operator expertise before implementing any changes in the workplace.

Operators and teams adapt to the variability of situations, by developing know-how and expertise, but without always seeing the collateral effects of the adaptations made. This is the importance of analyzing the gaps between the prescribed work (how we planned to operate a process, operate a building) and the observable work (how people adapt to make it work, optimize it). The teams know how to adapt, within the means at their disposal. Knowledge of adaptation methods, their causes and their limits, provides useful elements for improving productivity and safety, helps support the criteria for choosing machines, etc. The predictive value of work analysis has proven itself as an instrument in project management.

When the situation exists, looking at the operating modes, the regulations carried out by the teams makes it possible to locate the points on which transformations are necessary, in order to make production requirements, economic requirements, human operating requirements more compatible.

When the situation is to be created, we never create from nothing. Work analyzes carried out in Reference Situations have a predictive value on the operation of the project, and avoid numerous errors in the choice of materials and organization.

An example of know-how in current life- a driving experience from Gaston

> *During one of my many trips, I arrived at Lille-Lesquin airport to pick up a rental car. At the counter, the receptionist informs me that there is no longer a car in the category I reserved, but that she will give me another larger and more comfortable one, with automatic gearbox. In the exchange that followed, I explained to him that being larger and more comfortable, I had nothing against it, but that I was not at all keen on an automatic gearbox, having not*

used one until now. SO. Nothing to do, no argument could have created a car not available. So I took the automatic transmission. It was late, I was tired, it was dark, it was winter. Bad tongues chatter about my failing or even absent sense of direction, but in this case, if I got lost, it is because of the differences in the configuration of the intersections, the presentation of the signs and the names of the places, in relation to the regions that I crossed. In short, I searched, fuming against the road that resisted me. As I passed an intersection, I read the name of the street of my hotel, perpendicular to my direction. I could still turn, provided I braked. I braked. And I spun on the wet winter road. On this occasion, I discovered an aspect of my driving. With a "normal" car, I wouldn't have had a problem. In fact, every time I brake at low speed and prepare to take a turn, I disengage the clutch. It's automatic, I never thought about it. With this car, I deliberately pressed the brake pedal with my right foot (which was in the same place as on a normal car), and my left foot wanted to fulfill its function, disengage, without any agreement on my part. That's when he encountered the brake pedal, which takes up all the space in the "normal" control system. So I braked with both feet, unable to do anything, totally surprised.

That evening, I was lucky: no pedestrians around, no cars behind. I would have been responsible in the event of an accident

All the classic causes of an accident are brought together here: being in a new configuration, being tired, using a device different from the usual equipment, etc. From the point of view of the law, in the event of an accident, the fault lies with Gaston. But where did this fault lie? Don't know the region? Being tired, having never driven a car with an automatic transmission? It is of course a coincidence of factors which determined this incident. It would have been enough for one of them to be absent for the event not to appear. In work situations, training can help (depending on its adaptation to needs) the operator, the team, the management. The work collective can cope with a temporary "burst" from one of its members. But nothing will ever allow a human to forget the kind of know-how that is at stake here. The action, braking by disengaging, is classified in sensorimotor automatisms. The research carried out and the models constructed show the power of these automatisms in all of our activities: they allow us to be more efficient, to free up attention capacities for the benefit of particular elements of a task. Their problem is that they cannot be forgotten, and re-emerge during moments of danger, stress, etc. This is only one of the existing models in the human sciences; there are thousands of them, on physiological, organizational, cognitive, psychological aspects, etc. In fact, it is possible today to construct work situations or others that would "trap" the people found there. In a controlled context, errors in a task are predictable, the behavior of individuals and teams can be anticipated.

Principle 2 emphasizes the importance of understanding the expertise developed by operators in the workplace and its use before any change. In the context of this principle, ergonomics plays an important role in studying and understanding how people adapt their work environment and work processes to achieve optimal performance.

Ergonomics deals with the interaction between people and their work environment, including equipment, tools, processes, and work organization. This includes studying how people use equipment and tools, how they move in a work environment, how they organize themselves, and how they communicate. Ergonomic considerations can be focused on how people adapt their work environment to achieve optimal performance, including developing expertise and knowledge about work processes.

In the context of Principle 2, ergonomics helps to understand the expertise developed by operators in the workplace and how this expertise can be used to improve the work process. The ergonomic approach regarding studying how people adapt their work environment to achieve optimal performance can contribute to the development of new ideas and innovations in work processes. An ergonomic approach can channel the operator's expertise on a scientific basis and have an appropriate corrective function according to the need (taking into account the limits of the operator's expertise on the other hand). In this way, ergonomics can help improve efficiency, productivity and employee satisfaction in industrial processes.

Example number 3 and 4 illustrate this principle

C. Principle three: to include the teams in the design process

Participation is an important key to success. If the operators contribute to the construction of specifications and the development of solutions, they will bring their "know how" knowledge to the project

A crucial factor for success relies in active participation, wherein operators' input in formulating specifications and developing solutions leverages their workshop expertise, ensuring a comprehensive understanding of the forthcoming system and necessitating meticulous, project-integrated methods for genuine engagement.

The methods allowing a real participation cannot be improvised. They have to be rigorous, and included in the project management

The mobilization of the operators is a criterion for success in a project. However, this mobilization must be organized using rigorous methods. The division of labor is a constant shape of our current civilization. This is the separation between the people who design the situations, the organizations, the tools, the distribution of tasks, and those who live in it. Today, in some bad scenarios, people are asked for their opinion when an adjustment of situation is needed, and immediately afterwards the see reproaches for the divergence of their answers, the gaps in the information given, their refusal of solutions, etc. Only too often the engagement of the worker in a change process is expected to be nothing more than the confirmation of solutions already considered technically and financially viable.

Obviously, how, around a meeting table, can we talk about expertise that took years to acquire? How can we talk about points of know-how which are so integrated that we no longer know that we know?... To change a situation, we must know what work we are talking about, and for that, the only reliable approach is to see the activity, note the exchanges of information, the processing sequences, the operating methods, etc. in order to inject the reality of the work into the design, as opposed to preconceived ideas that we may have about it. One of the major faults of current project management methods is to refer to an "average" situation. The organization of work, the tools, the planning, etc. take as their basis the standard situation, where everything goes well, where the tools are never broken, where one is never sick, where an error is a mistake, ...Of course, when we simply question the teams without really seeing what is happening in the workshop, what requirements they are facing, we cannot identify what needs to be responded to. However, current methods are reliable; just use them.

The challenge ahead is to shift from an approach based on the questioning of "work experts" towards one that builds on listening to that expertise through open and explorative conversations and iteratively throughout the lifecycle of change processes, as opposed to closed and isolated "check points".

The importance of including teams in the design process is highlighted in several studies. Koenig et al. [9] emphasizes the need for a model-driven design process that considers the interplay of people, process, and technology. McCreery and Bloom [10] underscores the value of work teams that align with the organization's competitive and manufacturing strategies. Smith [11] discusses the effectiveness of cross-functional design teams, which bring together professionals from various departments. Hoffman and Court [12] presents a unique approach to organizing project teams, using a company-based model to ensure individual accountability and active participation. These studies collectively underscore the significance of team inclusion in the design process, emphasizing the need for a holistic, strategic, and collaborative approach.

Principle 3 emphasizes the importance of involving teams in the design process. In the context of this principle, ergonomics plays a key role in ensuring that the design of processes, equipment and work environments takes into account the needs and perspectives of different teams and individuals. Ergonomics is partly concerned with the study of how people work together in teams, how they communicate, how they organize themselves and how they cooperate. It involves studying how process design can support effective communication, collaboration and coordination between different teams and individuals. Computer-supported cooperative work (CSCW) is one such area that has been considered from the ergonomics standpoint. Ergonomics also studies how process design can take into account the different perspectives and needs of teams and individuals to ensure that the design fits the different roles and tasks within the organization.

Examples 2 and 4 illustrate this principle.

D. Principle four : technology cannot solve all problems- it may lead to delusion

While technology providers often highlight the potential of their products, it’s crucial to analyze the existing operations in a workshop before investing, as the effectiveness of the technology depends on its alignment with the needs, and promises only bind those who believe in them.

It is the role of business leaders to manage the company, ensure its development, and decide on developments. To do this, you have to manage all the people on the site, develop an organization, develop the process, the technical system, the IT, etc. Very often, you have to call on specialists in this or that aspect of operation. It is to decision-makers that organizations increasingly turn in the event of a problem. It is to decision-makers that shareholders turn when investments are not as profitable as expected. It's a difficult position. Furthermore, it is easier and tempting to listen to a simplifying, even simplistic, speech by the carriers of technological solutions. This discourse makes people believe in levers that are quickly within reach, establishing accessible cause and effect relationships. Those responsible are free to believe it or not. When truly looking to scale a production processs, the only real key is complexity [18]. A working situation is like a living organism: life is not about laying organs next to each other and saying “get together”; in a living organism as in a production process, the state of each part, its properties, depends on its relationships with the other parts. When we make investments in equipment, when we modify an organization, if we only use technical criteria, we ignore the selection criteria relating to human functioning, we take a risk. Of course, this deadlock results in short-term savings in time and money. The risk may materialize or not. The choice depends on the stakes.

Often problems at the source of change processes are poorly defined. This opens up for too loose interpretations. Whilst diversity of perspectives is fundamental for the understanding of problems without effectively listening to these different perspective we are simply collecting noise. This inevitably leads to the definition of the problem through the lens of the solutions at hand. No single manager (or anyone at any other position in a company) can ever hold the knowledge and understanding of problems to a satisfactory degree. Continuous “listening to different perspectives” is a fundamental cornerstone for decision making. No problem faced today by industry can be considered to have “ONE SOLUTION”. There is always an infinite world of possibilities and to explore these in any meaningful way requires listening to as many diverse perspectives as possible, in particular those concerning strategic positions and values, which eventually define what constitutes an opportunity for the company.

Spath et al. [13] emphasizes the need for technology providers to align their products with market and user needs, a sentiment echoed by Hofstra and Dean [14] who stresses the importance of reviewing contracts to ensure the technology meets operational requirements. Probert et al. [15] provides a five-step process for building a business case for technology investment, which includes understanding the value of the technology and its potential benefits. Fox [16] highlights the need to balance assessments of potential benefits with assessments of potential disbenefits, reliability, and utilization. These studies collectively underscore the importance of analyzing existing operations and needs before investing in new technology.

The figure below shows the costs of a project, from its start to the end of the system. Once the opportunity phase ends with a kickoff, the design process begins, then comes the industrialization phase and production begins; The vertical scale indicates the cost of the product, from 0 to 100% As we see, the expanses increase throughout the cycle. Very weak at the beginning, they rise until the end of the use of the system. During the production phase, there are maintenance and renewal costs, which are increasingly significant. At the end, the whole cycle starts again, in order to set up a new sustainable production unit.

The difference between the blue curve and the black curve lies in the reality or prediction of the expanse. For example, during the design phase, investments for industrialization are not made yet. They will arrive later. However, they are decided, they will be effective at some point.

Now consider the design costs. They mainly involve specialized project services, project management, possibly some prototypes, testing, documentation, etc. This constitutes around 5% of the total cost.

Feedback from last decades shows that these 5% costs represent 70% of the total cost. **This means that you should not make mistakes when making decisions about the project, the earlier possible in the project.** These REXs also show that the Human Factor Engineering is sometimes a cause of project failure, by not taking it into account.

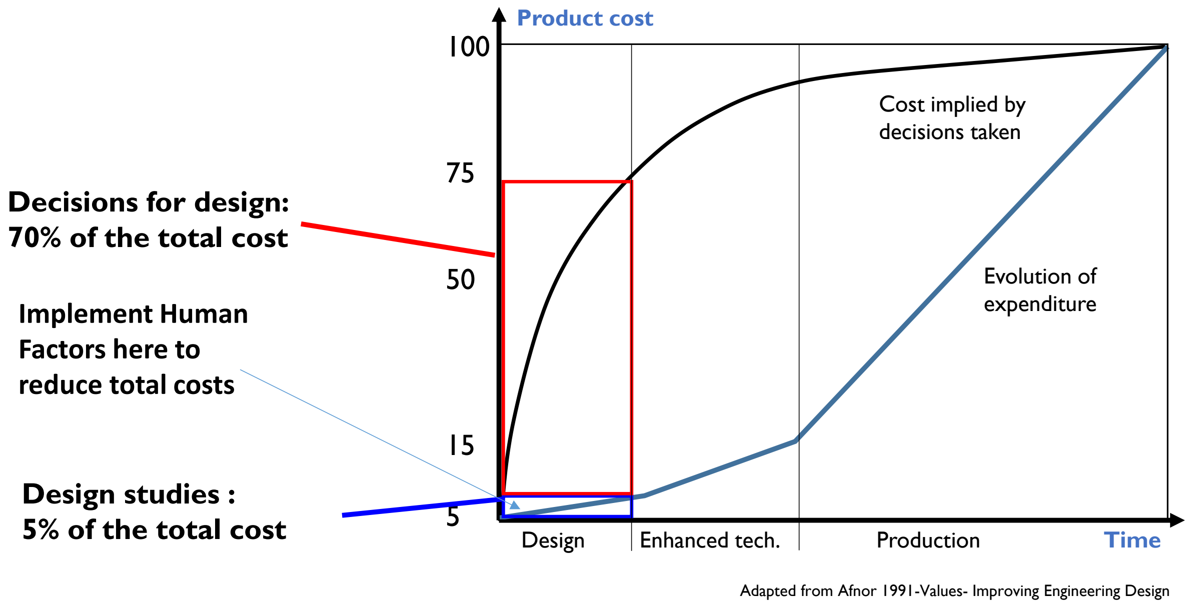

*Figure **4 : Stakes in studies and design in a project process***

A project must have a logic and duration. It must also integrate the fact that the specialties to be included today are much more important, with regard to the development of our knowledge.

Principle 4 emphasizes the fact that new technology can't solve all the problems in the organization. In addition to the possibility of the influence of ergonomics on the efficient use of technology, it is important to achieve an effective management system within the organization on the basis of the ergonomics approach. ~~Effective management of people and organization can be achieved by applying ergonomic principles in the following ways:~~

Example 1 illustrates this principle

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IV. Annexes

A. The point of view from Gaston, a Human Factor Specialist

In this part, we let a field practitioner introduce the discipline, explain what it's based on, and what it brings to all kind of projects, including innovative ones.

I am referred to by several names : "ergonomist", "human factor specialist", "human factor engineer", "human and social factor engineer",… all those names are about one and only one practice. I obtained a Master's degree, in 5 years of university studies. I learned a lot about human characteristics and functioning, in order to apply them to work situations. Most often, the people I meet only know the adjective "ergonomic", designating at best an expected quality (ergonomic mattresses where we would dream better, ergonomic chairs, etc.) or the notions of work environment, dimensioning of workstations, postures.

This represents an extremely limited view of what my job is.

I am part of a community supporting this profession, where practitioners share their experiences, successes, failures, methods, innovations,… This community forms a very active network, carrying knowledge as well as ethical values.

Our profession is relatively recent; it developed after the Second World War. We are scientists, we apply multiple knowledge to a particular object, work. But until now, we have not been able to share efficiently what our job is, even if it is quite well known in certain sectors of activity or certain areas of intervention (e.g.: reliability in high-risk industries , integration of disabled people into work situations, adaptation of working positions, organization, functioning in the team, etc.).

These few pages aim to better communicate on the subject and to demystify it. My job is actually quite simple: it's about adapting the work to the human who has to do it.

Our business contributes to developing machines and tools, without being competent on the technical characteristics of these. We design means of transport, planes, trains,… without having specific skills in aeronautics or railways. We design industrial processes, without having skills in metallurgy, chemistry, electronics,… We design workspaces, buildings, without having architectural skills, we design shift work organization without having physician skills, etc.

We carry one of the dimensions of design, the one linked to human functioning. In all the cases cited, the human is one of the components of the system. The human factor is identified as one of the causes in many industrial accidents, such as in transport, health, etc. I have to underline that it depends on the characteristics of the system, compliant or not with the human.

The rise of ergonomics began in aviation, in relation to "human errors" that led to accidents. A very large part of human errors has been analyzed as the result of design flaws. These defects were not technical, but were in the relationship between the machine and the human. This was later called the Human-Machine Interface.

Indeed, Human/Machine compatibility cannot be decreed. To be operational, the situation must meet the operating requirements of all its components. An engine running too fast, or without oil, would cause damage or an accident. A human operator who would work beyond his physical capacities, in situations that are physiologically or psychologically too demanding (e.g.: enslavement to an excessive machine speed), stressed, subjected to repetitive gestures, will lose his efficiency and probably develop pathologies, work at the cost of damage to his health.

Humans are extraordinarily complex. We know how to adapt to an incredible variety of situations. We know how to deal with unforeseen events and solve new problems. This has a price, we are not infallible and can make mistakes. My job aims to integrate human capacities and limits in the design of working situations. The challenge is to guarantee the effectiveness of the situations constructed and to preserve the health of the people involved in this situation.

To achieve this, two conditions:

- **Mobilize knowledge about human functioning.** There has been a proliferation of knowledge in recent decades. We have models applicable in physiology, anthropometry, cognition, sociology, psychology, etc. These models have both value for the interpretation of mechanisms in work situations, and an ability to predict the effects of the changes made. They provide criteria for design or re-design.
- **Use appropriate methods.** A working situation is an intertwining of multiple factors. The teams immersed in such situations are constantly adapting, and their practices go well beyond what is written in the procedures and instructions. To understand how people adapt, why, what are the effects and limits of these adaptations, what are the risks, it is necessary to immerse oneself in the concerned situation. This is what practitioners call “observation”. If supported by models relating to human functioning, observation will provide keys to understanding pathologies, incidents, accidents, etc. and will provide levers to modify the factors concerned. These observations will often be usefully supplemented by interviews with the people who carry out the work. These people provide the meaning of their activity, the compromises they make, the constraints to which they and the team have found solutions. The answer to the question "why did you remove the safeties from the machine", if it can be asked, provides a great deal of information appropriate to change the working situation. And this answer contains the expertise of the person.

These two conditions are important. Moreover, even when a requesting company expresses a particular need, such as treatment for Musculoskeletal Disorders, the investigation work must take into account all the possible factors, before focusing on the responses to be provided. Indeed, in the example taken from MSDs, we know today that it is a multifactorial pathology, and that tendon or muscle alterations can be linked to the organization of work, to management, to a deterioration in relationship to work...

It is the same for all the other treatments to be carried out in our practice. We are always surprised by the links between the factors in a specific working situation; the analysis will bring out, before any transformation action, what it is useful to act on. The more the analysis will be precise, the more the solutions will be numerous, the greater the perspectives for improvement will be.

As professionals, our capacity for improvement is usually placed on the individual workstations, on the technical systems to be exploited. But the spectrum of solutions is much broader than that. In particular, on the collective aspects of work, on the fact that no activity can take place without cooperation, and that the organization is a level of human functioning which is to be taken into account like the others.

Beyond that, analyzes and changes are carried out with the people concerned, in all layers of the organization. This is a condition for the understanding of the reason for the changes to be shared, as well as the solutions. This also ensures that solutions are tailored to the detailed workings of the situation.

Our society is once more at the verge of new important changes, with the so called “Industry 5.0”. It is necessary to remind the previous design mistakes and successes in the past changes. I regularly attend to technical congresses. Too often, I hear from my partners foreigners of my discipline: “to analyze and forecast the future human functioning with my innovation? What use could it be? My system is totally reliable, and resistant to human errors”.

Experience shows that this is never true, and can lead to very serious incidents. My community has a lot to say and do about human/systems compliance, reliability health, development,…

B. ERGONOMIC NATURE OF THE PRINCIPLES

Principles 1, 2, 3, and 4 outlined in the document can be considered ergonomic principles in essence because they align closely with the core goals and approaches of ergonomics as a discipline. Here's a detailed explanation of how each principle relates to ergonomics:

Principle 1

This principle directly resonates with the fundamental ergonomic approach of designing systems, products, and environments to fit the capabilities and limitations of the human users. Ergonomics recognizes that humans have physical, cognitive, and psychosocial constraints, and designs should accommodate these constraints to ensure safety, efficiency, and well-being. By explicitly including the human operator's capacities and limitations in the design process, this principle embraces the user-centered approach that is central to ergonomics.

Principle 2

This principle highlights the importance of leveraging the practical knowledge and experiences of the people who are directly involved in the work processes. Ergonomics emphasizes the need to understand the context and realities of the work environment, which can often be best understood by those who perform the tasks. By recognizing the value of operator expertise, this principle aligns with the ergonomic approach of involving end-users in the design and improvement processes, as they can provide invaluable insights into potential issues, risks, and opportunities for optimization.

Principle 3

This principle directly promotes participatory ergonomics, a widely recognized approach in the field of ergonomics. Participatory ergonomics involves actively engaging workers and teams in the design, implementation, and continuous improvement of their work systems, tools, and environments. This principle recognizes the importance of incorporating the perspectives and experiences of those who will be directly impacted by the changes, which is a core tenet of ergonomics. By including teams in the design process, the resulting solutions are more likely to be well-suited to the actual needs and constraints of the work environment.

Principle 4

Technology cannot solve all problems and may lead to delusion

While this principle may not seem overtly ergonomic at first glance, it reflects a fundamental understanding in ergonomics: that technology alone cannot address all human factors and organizational challenges. Ergonomics recognizes the complex interplay between humans, technology, and the work environment, and understands that technological solutions must be implemented with consideration for the human element. This principle cautions against the potential pitfalls of overreliance on technology without accounting for human factors, which can lead to unintended consequences, such as increased stress, decreased job satisfaction, and even safety risks.

In essence, these four principles align with ergonomic principles because they prioritize the human element, emphasize user-centered design, promote participatory approaches, and recognize the limitations of technology-centric solutions. By incorporating these principles, organizations can develop systems, processes, and environments that are better suited to the needs, capabilities, and limitations of the people who will be using them, which is the core goal of ergonomics.

C. ABOUT THE CONNECTION OF FOUR ERGONOMIC PRINCIPLES WITH HUMAN CENTRIC APPROACH OF INDUSTRY 5.0

Principles 1 and 2 align closely with the human-centric approach that is a core tenet of Industry 5.0.

Principle 1

This principle directly supports a human-centric approach by ensuring that the design of equipment, installations, and processes takes into account the capabilities and limitations of the human operators who will be using them. Instead of designing purely based on technological capabilities, a human-centric design considers how the technology will interface with and support the human operators. By incorporating ergonomic principles and an understanding of human factors, the design can be optimized for the people who will be using it, reducing physical and cognitive strain, improving safety, and enabling the operators to work efficiently and effectively.

Principle 2

This principle also aligns with a human-centric approach by recognizing the value of the operators' practical knowledge and experience. Instead of treating operators as mere recipients of top-down changes, this principle advocates for actively involving them in the process of defining requirements and designing solutions. The operators' expertise, which has been developed through years of hands-on experience, can provide invaluable insights into the realities of the work environment, potential pitfalls, and opportunities for improvement. By incorporating this expertise from the outset, the solutions that are developed are more likely to be well-suited to the actual needs and conditions of the workplace, ultimately leading to better outcomes for both the organization and the workers.

In essence, both of these principles place the human operator at the center of the design and implementation process, rather than treating them as an afterthought or a mere recipient of predetermined solutions. This human-centric approach not only improves the chances of success for Industry 5.0 initiatives but also aligns with the broader goal of creating sustainable and fulfilling work environments that support human well-being.

By incorporating ergonomics, human factors, and operator expertise, the technology and processes of Industry 5.0 can be designed to augment and support human capabilities, rather than replacing or diminishing the human role. This approach recognizes that humans and technology can work in synergy, with each playing to their respective strengths, to achieve outcomes that would be difficult or impossible to achieve with either one alone.

Principles 3 and 4 also strongly reinforce the human-centric approach that is central to Industry 5.0.

Principle 3

This principle directly embodies a human-centric approach by actively involving the operators and workplace teams in the design and development process. Rather than having solutions imposed on them from the top-down, the teams who will be directly impacted by the changes are given a voice and an opportunity to shape the solutions.

By including teams in the design process, their firsthand knowledge, experiences, and perspectives can be incorporated, leading to solutions that are better aligned with the realities of their work environment and more likely to be accepted and adopted. This collaborative approach fosters a sense of ownership and buy-in among the teams, increasing the chances of successful implementation.

Furthermore, by valuing the teams' input and expertise, this principle recognizes the inherent value and agency of the human element in the industrial process. It treats the teams not as passive recipients of technology, but as active participants whose involvement is essential for developing effective and sustainable solutions.

Principle 4

This principle serves as a counterbalance to the potential over-reliance on technology and a reminder that the human element must remain a central consideration. It recognizes that while technology can be a powerful tool, it should not be treated as a panacea that can solve all problems or replace the need for human judgment, adaptability, and oversight.

By acknowledging the limitations of technology and the potential for delusion, this principle reinforces the importance of maintaining a human-centric approach. It highlights the need to carefully consider the social, organizational, and human factors that technology interacts with, rather than treating technology as an isolated solution.

This principle also aligns with the goal of creating sustainable and fulfilling work environments. If technology is implemented without considering its impact on human factors, it can lead to unintended consequences, such as increased stress, alienation, or a disregard for human well-being.

Together, Principles 3 and 4 emphasize the need to strike a balance between leveraging technology and preserving the human element in industrial processes. They reinforce the human-centric approach by ensuring that the teams and operators are actively involved in shaping the solutions, and that the limitations and potential pitfalls of over-reliance on technology are recognized and addressed.

This holistic perspective, which considers both the technological and human aspects, is essential for achieving the goals of Industry 5.0, such as sustainability, resilience, and a human-centered approach. It recognizes that true innovation and progress cannot be achieved by focusing solely on technology but must involve a deep understanding and integration of human factors, experiences, and perspectives.

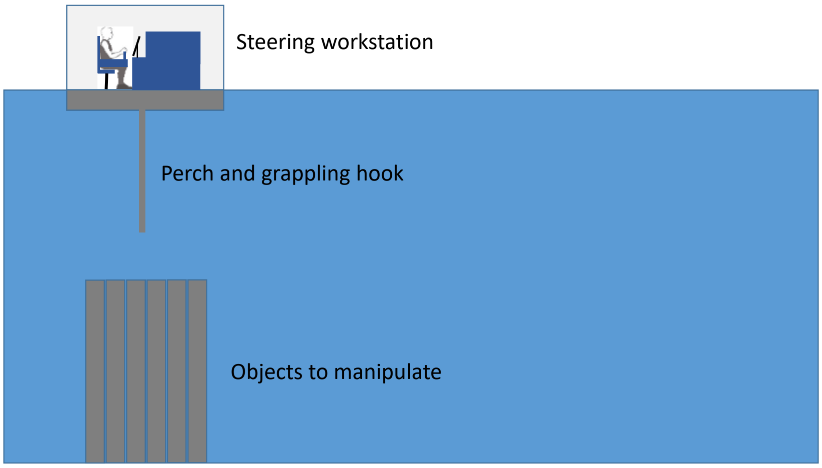
D. Change in industry : return of experience

1. Example 1 : movement automatization

This example is taken from a sensitive industry. The equipment concerned is a means of handling dangerous objects under water. The service that was requested of us consisted in understanding why a set of incidents had occurred, and the reasons for the rejection of the innovation by the operators.

Project and objectives

Before the implementation of this innovation, the operator controlled all the movements, in X, Y and Z, by the controls located on his steering workstation, as well as the positioning of the grapple and the attachment of the object to be handled.



Problems in the outcome

After the installation of the new equipment, the operator was still in charge of approaching the grapple and hooking it, but all the other movements were controlled by an automaton, from the starting point of the object to the point of delivery. The operator only had to exert a continuous pressure on the "run" command, and the automaton took care of the rest, by determining the possible movements with regard to the information produced by the various sensors. The expected result was better reliability in movement and increased speed. This result was achieved, but only in nominal situations. From the first operations, two major problems emerged.

A machine that "does as it pleases"

When moving the gripped object as when returning to the mass to be handled, the sensors could send false information to the automaton (environment generating strong interference). In these cases, the automaton used this information without being able to identify the error, and actuated the advance commands. When the machine was without obstacle around, the operator could stop by detecting the anomaly. But there was no time when the machine was close to obstacles that should have been avoided. This resulted in several plasters of the manipulated objects, with deformations for some, which was serious. These incidents were blamed on the operators, who were instructed to stop in the event of an anomaly. But this was impossible for them, for the simple reason that the displays informed them of the movement made, and not of the movement to come. When we pointed out to the supplier that for the expected role of the operator to be fulfilled, forecast information of the movements was necessary, he objected that it was impossible, because all the programming was designed in this way. We are here in an "ironie of automation" [5]

A machine that "does not understand what is happening to it"

Another major problem was produced by the inertia of the handling machine. Under the effect of the mass moved, of the residual speed, the machine could stop its course outside the planned indexation ranges. In these cases, no more movement was possible automatically. The only solution for the operators was to switch the machine to manual mode, reposition the device within the indexing ranges, then switch back to automatic. While switching from automatic mode to manual mode was not a problem, it was another matter to reactivate automatic mode. It was actually totally unplanned; the designers had thought of the manual mode only for their interventions. As a result, we have seen operators tamper with programming lines from a laptop PC connected to the system, to re-parameterize conditions recognized by the system before being able to restart. Of course, the risks were major at these times; these non-specialists could enter many errors into the machine, having impacts on subsequent operation.

What missed

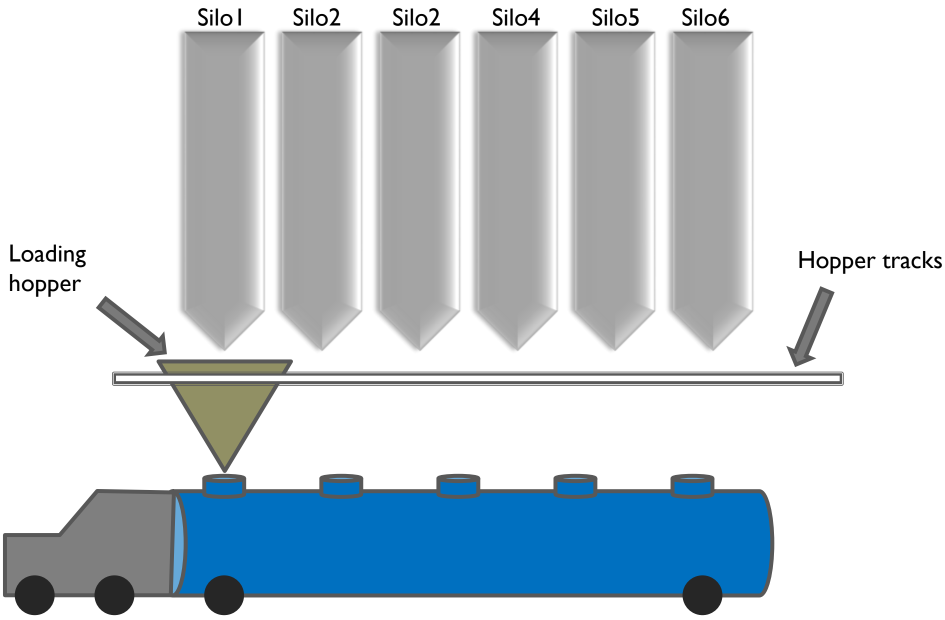
The lesson to be learned from this story relates firstly to monitoring. Regardless of the cobot made available and its level of assistance, the operator needs information on its status, its failures, the commands it will issue, and this in a form appropriate to the task to be performed. Without this monitoring, the machine is a "black box" for the operator, and the question of distrust of this machine, which does as it pleases, will quickly arise.

Secondly, the teaching relates to the underestimation of the variability of the operating situations of this Cobot. When does the operator have to “take control”, what does he need for this? How to put the system back in a safe configuration? For this too, it is impossible to do without methods such as feedback in a reference situation (which we carried out later)

2. Example 2 : automatization for filling trucks

Project and objectives

During an intervention relative to the modernization of an animal food manufacturing plant, the project encountered a technical obstacle for the design of a loading bridge.



Problems in the outcome

The challenge was to set up an automaton allowing autonomous loading by delivery drivers. The silos could contain pellets of different types, this content changing according to the needs of the customers and the productions. The delivery drivers only had to enter the product indicated on the loading order sheet, then the automaton had to take over the search for the right product in the different silos, to then give the hand to the delivery driver for unloading in the compartment truck target. This made it possible to overcome the risk of user error.

The constraint put forward by the engineer in charge of the project was that of the effect of temperature variations on the reliability of the positioning of the hopper under the silo. Before each movement, the hopper had to make a "Point 0" at the front end of the rails, to benefit from the positioning metric. But with the mass of the hopper, the slips related to the cold in winter, this metric could not be reliable, and other devices of the rack type were not possible in this situation.

What HFE brought

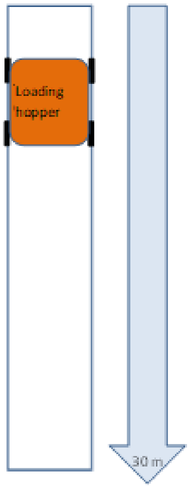
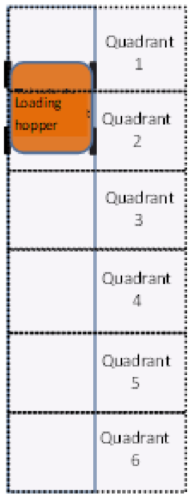
We found the answer by working with the engineer. **We have replaced the metric approach with a topological approach**. Here is an extract of the most important exchanges (I=Engineer; E=Ergonomist):

- E: is there a way to detect the position of the hopper on the rails, even approximately?
- I: yes, I can place braces, which will be activated by the passage of the hopper, and I can know if the hopper is between such and such a brace
- E: Then, for a selected product, when the hopper goes for example towards silo 5, the automaton can know when silo 4 has been passed; he can send the order to slow down or stop at the hopper?
- I: yes, but with the braking and sliding effects, I cannot know if the hopper will stop in the right place, i.e. under the spillway
- E: And if we place an additional pair of braces, in an acceptable location interval so that the dumping is done well in the hopper, we can know if the hopper is well positioned?
- I: I can place them, but I have to calculate the maximum positioning uncertainty, and the upper opening of the hopper must have the width corresponding to this uncertainty

Further work showed that this solution was feasible, and it was implemented. This small example aims to show the importance of the methods that we use in our way of structuring the information of a project. As specialists in the human sciences, or even “soft sciences”, according to some, we are very rarely on the scales of analysis and metric construction. To make a brief reminder, our civilization is built from 4 scales, nominal, ordinal, interval and ratio.

- **Nominal:** In this scale, we first define discrete classes of facts and criteria allowing us to know whether or not an observation belongs to a particular class. The processing of observations is done by counting the apparition in each class constituted
- **Ordinal:** Here, we can order values according to a dimension: we can establish relations of inequality between the different values of a variable. It is necessary for this to have a criterion allowing to establish transitivity in the set of values.
- **Interval:** In certain cases, one can compare the intervals separating the ordered classes. For this, it is necessary to have a criterion guaranteeing their equality. For example, we can say that there is the same noise difference between two sounds of 10 and 20 decibels and two sounds of 50 and 60 decibels
- **Ratio scale:** These scales are still at a higher degree of precision. Their use supposes that one can determine a zero degree in the observations, and that one has criteria making it possible to establish reports. For example, we can say that Jean, who weighs 50 kilos, is twice as light as Pierre who weighs 100.

The figure below show the functionning of the two approaches, and the related leeway for conception.

Metric approach: measuring the distance traveled by the revolutions of the hopper wheel	**Topological approach:** evaluate the position of the hopper by detectors and accept an uncertainty
	

The solution with the quadrants is a pragmatic innovation, which does not need sophisticated equipment. The emergence of this idea was possible because human factor specialists are able to apply to technical questions methods, means, different from technical specialists, and to bring a look that may offer new levers to the solutions. To use common words: “we went out of the frame”. The fact that we are very often at a strong difference in point of view with other specialists does not only have drawbacks. This becomes a strength for the project team, because the possibilities of combining and recombining the elements of the problem are increased. The obvious condition is to be aware that the different points of view are based on **mental representations** by specialists, and that it is necessary to put them “on the table” in order to go further.

This solution lowered the costs, made the organization possible, and was easy to maintain. This is a consideration to have in mind towards complex and expansive systems.

3. Example 3 : shortening the tune phase of a production line

Project and objectives

- The context: a small company in Aveyron, about 200 people
- Activity: surface treatment of parts for perfumery
- The request: support an evolution in the workshops, aiming to install masked time in the recalibration of equipment occurring during manufacturing changes
- The challenge: the production series have been reduced over time, and the time consumed by the recalibration of the production tool has become an economic impediment
- The problem: very strong physical demands in this part of the workshop, situation generating MSDs, very strong fears of operators with regard to the possibility of intensification

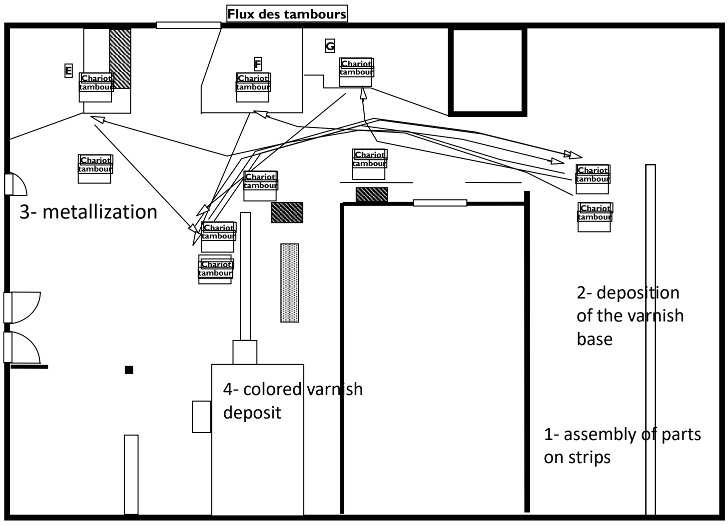
Implementation of "masked time" in a surface metallization workshop

- Small factory of 200 employees
- A size of the productions series which have shrunk over the years.
- Equipment recalibration requirements over the variety of productions
- 3X8 teams

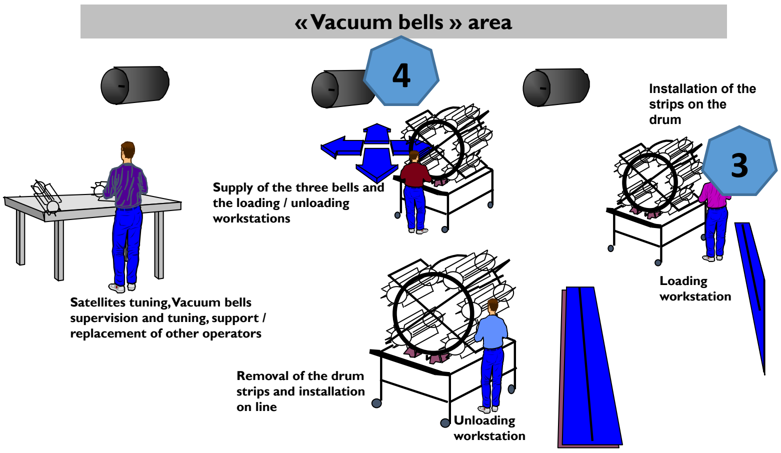
All the staff meet the masked time requirement , except the « vaccum bells » team, says the management

« It's too hard, we can't do it! »- say the employees

All segments of the line were ready for the accelerated production changeover. Only the part of the "empty bells" posed a problem. The overall steps are as follows:



Workshop overview

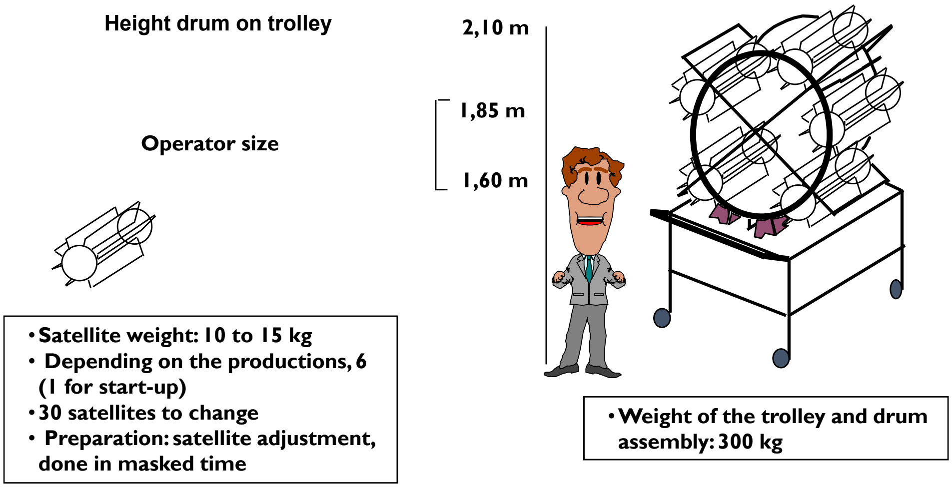


Vacuum bell area

1. the parts are placed on the strips by operators
2. driven by the conveyor belt, the strips pass through a varnishing machine
3. an operator picks them up and places them on a drum, itself placed on a trolley. Once the drum is full, it is brought to one of the 3 vacuum bells entered into the machine, and the metallization cycle is triggered.
4. the drum on a trolley is brought to a deposit area, where an operator feeds the conveyor belt to another varnish deposit machine

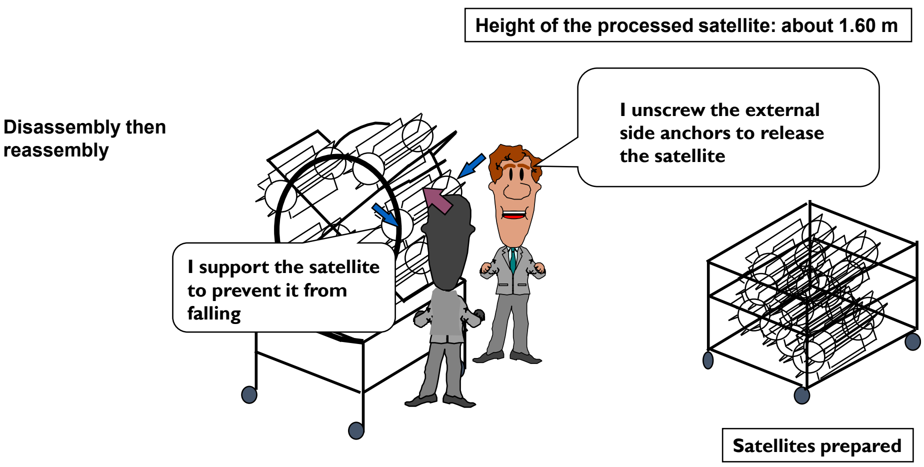
The functioning for the team in charge of the tuning is described below :

Dimensions and weights



Equipments to be tuned and operators

Procedure



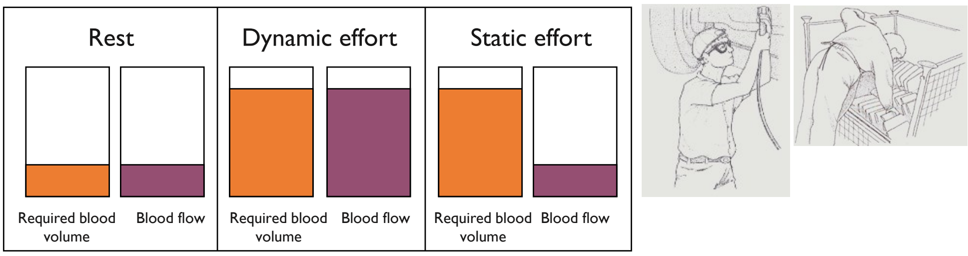
Realization of the operation

1- an operator stands in front of the satellite to be dismantled, and supports it
2- a second operator unscrews the two side anchors
3- the released satellite is placed in a container
4- one of the two operators takes a satellite prepared in another container, and presents it on the drum, while the second operator screws the side anchors

Problems in the outcome

The source of the problem was on the workload; in fact a specific type of workload, which we name “Static effort”. The model is shortly explained below :

The level of functioning concerned: our physiology



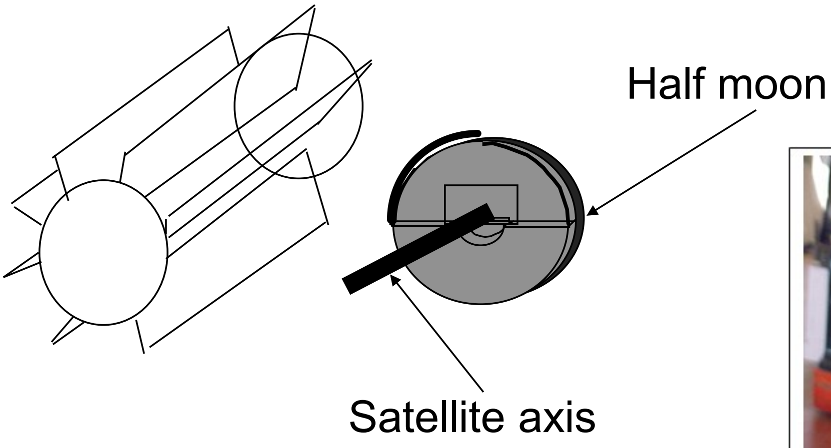
- When the effort is static, the blood circulates more difficultly, the metabolic waste produced by the contraction of the muscle is not eliminated effectively
  - ➔ production of muscle fatigue
  - ➔ Risks of premature wear

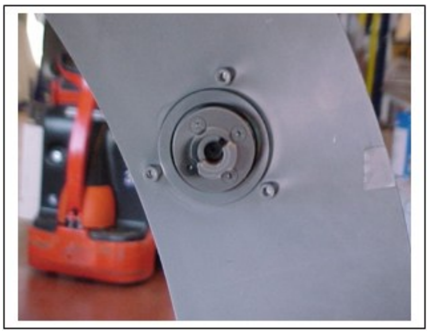
<u>The solution</u>

Before the intervention of the human factor specialist, the company studied a lot of very expansive solutions, using automated equipment.

But considering the source of the problem, a more accurate solution appeared, implementable in a short delay :

The solution





With this solution, the operators had only to unscrew the satellite, this one being held by two lateral supports, not requiring any muscular effort. Once unscrewed, the operator has to manipulate the satellite, in the same way it was previously.

This solution appears simple, and fitted to the need. It was effectively much more cheaper than the other solutions offered by suppliers. It needed some research and development with the maintenance team, and the first idea, delivered by the human factor specialist, was operationalized integrating the technical requirements.

The result is summarized below.

Costs and gains

Falling satellites

During handling, the satellites fall and are degraded

Average:
- Satellites fall 156 times each year
- The cost is around 120 € / piece

=> Cost: 19K € / year

Production potential

Production was interrupted 20 minutes for the format change

- Number of format changes X number of pieces / minute

=> Potential of 270,000 more pieces

Cost of the service

Service covering a set of points in the workshop (not only this one)

=> 25K € HT

Operators exhausted and angry

The painfulness of the operation is very severe; "We can't do more"

Identified MSDs

- 12 male operators (3 teams X 4 operators)
- 7 operators> 50 years old
- 4 of which with shoulder TMS

Cost of modifying drums

Anchor support on the drums
Satellites axis

=> 29 K € HT

An added value : identifying a criteria for investments

During this project, one point particularly interested the business manager. He had acquired the third vacuum bell a year earlier, in view of production requirements. This equipment was the most efficient, and observations showed that the operators had to disengage the machine: it triggered evaporation too quickly. More than speed, the operators' logic was to synchronize the inputs and outputs of the drums in the bells, in relation to the speed of the chain. This logic also met a quality objective: the parts should not be left exposed to dust for too long after metallization. His exclamation was: *"but when I bought this machine, my criterion was its speed!".*

In fact, the investment could have been reduced significantly: instead of €1 million, €500 thousand would have been sufficient. The effect on the return on investment of such job knowledge was easy to calculate.

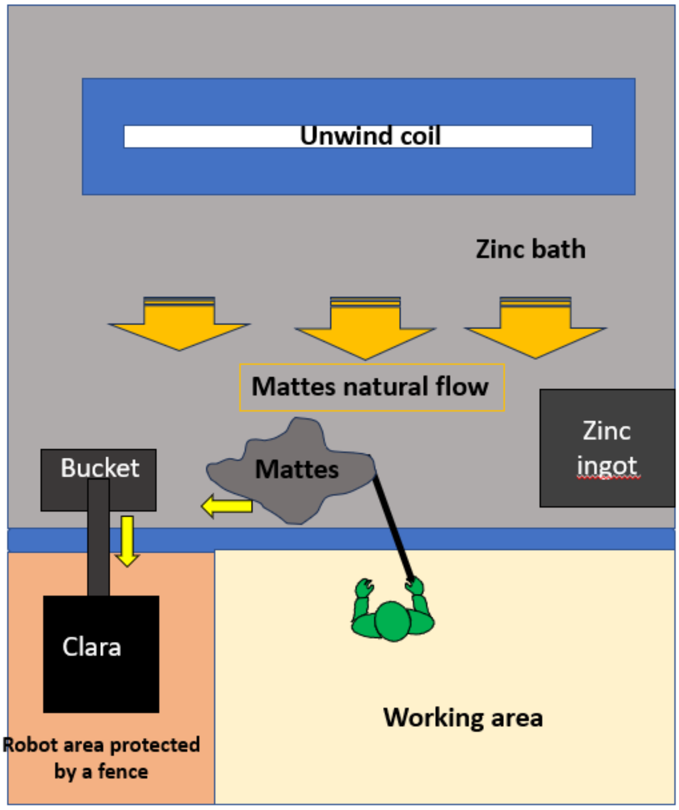
4. Example 4 : Product removal automaton (Remove the mattes)

This example is taken from a steel coil galvanization factory. The perimeter concerned is the molten zinc crucible in which the unwind coils are run through in order to be galvanized. During the process, steel particles get mixed into the molten zinc bath. Those particles go up to the surface where they agglomerate and solidify to form steel icebergs called "mattes". Mattes need to be removed from the bath as they will end up covering the whole surface and might lead to mechanical issues of the moving parts and / or a drop of the bath temperature.

Project and objectives

The removal was previously done entirely manually using long steel tools. The operators developed several tools with different use. They are all based on the same shape : a long straight bar (from 200 cm to 320 cm of length to access every part of the crucible) ending with a head. Several heads are used for different situations : a slotted spoon is used to gather and scoop the mattes while letting the molten zinc flow through the holes when a thinner spatula is preferred to access and scrape the sides edges of the crucible. With the change of the crucible and in order to protect the health of their employees, the factory has recently integrated a removal automaton named "Clara".

The goal was to set up an automaton that would help the operator to remove the mattes with an articulated arm equipped with a bucket. It was decided from the beginning that it would not be entirely autonomous. The robot was installed in a corner of the crucible for the operators to gather and push the mattes toward its bucket.



The request was to understand why the robot was rejected by the operators and to help the company find short and long term solutions.

Problems in the outcome

The rejection of the equipment was due to a deterioration of the working conditions after the crucible was changed and the robot integrated, when they should have been made better. This deterioration was based on several issues :

- **A greater height from the top of the zinc bath to the platform** : With the former crucible, the height was about 10 cm. With the new one, it has been increased to around 40 cm. This led to an increase in postural constraints during the gathering of the mates.
- **Robot's reliability** : on the first weeks after the installation, the robot used to breakdown several times a day, causing the operators to remove the mattes manually (this issue has been greatly reduced since).
- **Difficulty to clean the others areas of the crucible** : The robot was designed to collect the mattes created in the front area of the crucible, but mattes also tend to gather on the side and back edges of the crucible. Those areas are difficult to access even with long tools, requiring the operators to get close to the bath (with a safety harness) in difficult positions.
- **Physical constraint to push the mattes toward the robot :** the robot being on the side of the crucible and surrounded by a safety fence, operators have to perform a pushing motion from right to left in order to "feed" the bucket, putting more physical constraint than they needed to remove the mattes in the former situation (the motion requires a unilateral spine twist).
- **Robot removing performance :** As mattes are semi solids and float on the zinc bath, they tend to slip out of the bucket during the removal motion as the excess of liquid zinc goes back to the bath. This leads to a manual "feeding" of the bucket, by placing it just above the bath to fill it manually with mattes using the gathering tool (slotted spoon head).

The initial situation (before the new crucible and the robot) contained strong physical constraints but the crew kept them bearable by developing suited tools and operative strategies. Now they are in a situation where their know how can't keep the constraints bearable, which is tougher to deal with because they were told that their working conditions would be better, hence a strong rejection of the equipment.

What missed

Here we can see the main issue was that integrating Clara and a new crucible led to new work situations which were not anticipated. This issue occurred mainly because the designing process was based following the written operative processes, which are a good source to start understanding work situations but lack information concerning the operative strategies the operators need to build to deal with the constraints in order to achieve their tasks.

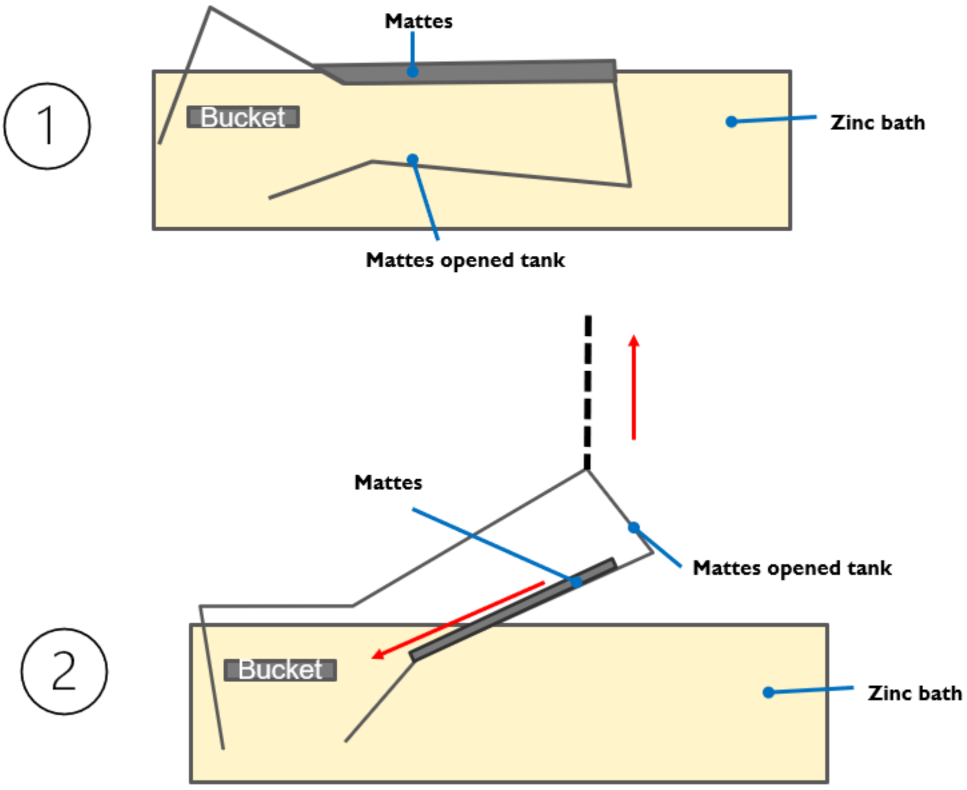
Two lessons are to be learned here :

- First is to precisely identify every operations done manually in the initial situation. This way the company can identify which operations can be replaced by the automaton, which are left to be done manually and anticipate any new operation needed in the process. This only can be done by going in the factory to observe directly the work situations.
- Second is to make sure the designers are able to ensure an acceptable level of performance for the main task the automaton is designed for by taking into account all the variables. Clara's motion works well but its performance is worse than expected as the fluid characteristics of the molten zinc were not anticipated. This could have been seen beforehand by running simulations, per example with a manually handled bucket.

What HFE brought

With no leeway on short terms solutions concerning the robot itself (neither on the bucket accessibility or on its functionalities), we developed an iterative process with the company to find short and long term solutions. First we went observing and interviewing the operators around the crucible to collect data on the reality of their work situations. Based on those data, we established a diagnosis exposing precisely the constraints, their causes and consequences in term of health and productivity for the operators and their needs to work in good conditions.

Based on the diagnosis, we started the iterative process needed to define the solutions. First we worked with the operators to discuss the first solution ideas. Those ideas were then discussed in meetings with the engineers, to whom the diagnosis was presented. A representant of the operators was also invited. This way, the engineers could evaluate the technical and maintenance feasibility of the solutions and eventually bring evolutions or even new ideas, which could be evaluated by the operator in term of functionality. For example, the first idea was to design an immerged tank which could be lift up to gather the mattes in the bucket area. The bottom of the tank would have been open to let the liquid zinc flow through :

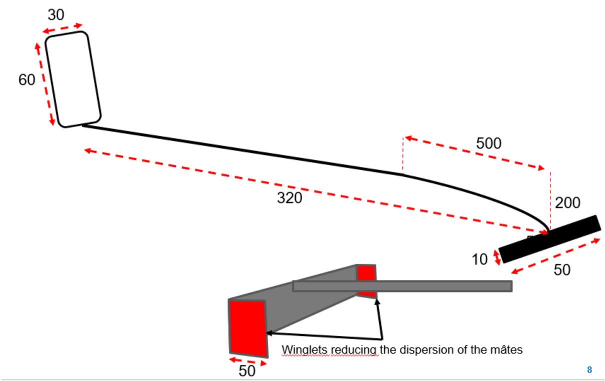


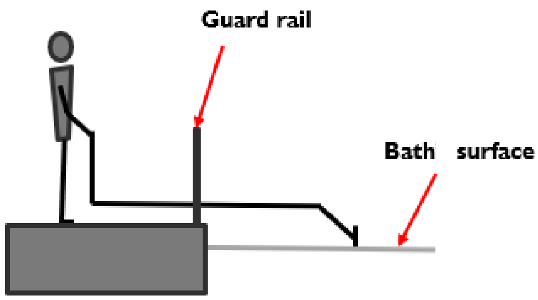
Front view of the bath

This idea worked well in term of functionality as it ensured to condense the mattes and blocked them from escaping the bucket area, but the engineers evaluated that the risk of a technical failure due to the long term immersion and the lack of accessibility to the device would be too complicated in term of maintenance. Yet, even if the idea was rejected, the concept of a device allowing to condense the mattes around the bucket made its way and laid the foundation for another device. At this point, two short term and one long term solutions are in development :

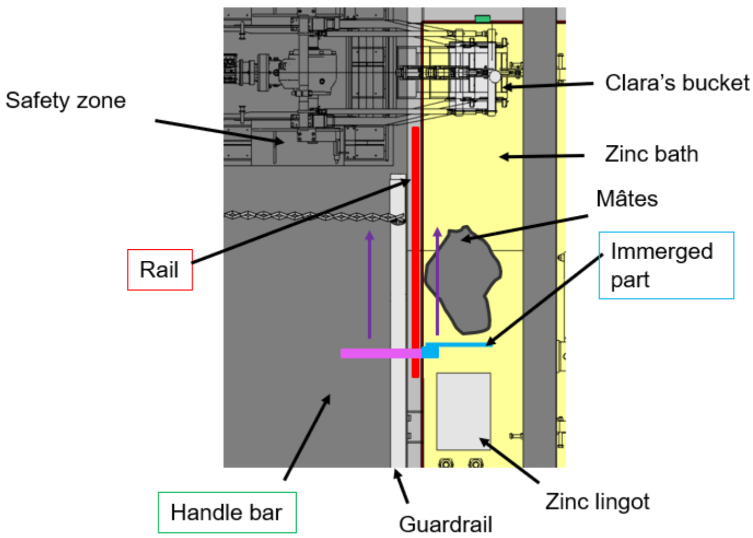
Short term :

- <u>Designing a new steel tool</u> : We helped the company redesign the steel tools used to move the mattes in order to reduce physical constraints during the gathering operation of the mattes and optimizing the quantity of mattes gathered in one motion by :
  - Adding a curve toward the end of the bar to compensate the 40 centimeters between the platform and the surface of the bath allowing the operators to stand straight while using it.
  - Adding a large handle allowing the operators to change the tilting angle without moving their arms in a harmful range of motion.
  - Adding winglets to the heads to limit the dispersion during the gathering.





- Designing a mattes pushing device : As it was identified that the most difficult task was to push the mattes toward the bucket. The main issue was the lack of accessibility to the bucket inducing strong physical and postural constraints. We worked with the operators involved in the situation to develop the concept of a mechanical system that could ease these. Once the functionalities were clarified, we worked with the engineers in order to evaluate the technical feasibility. First idea was to design The designing process is still running but the idea is to use the guardrail to mount a sliding system that can be pushed with a pushing bar from the platform. The pushing bar would be connected to a metal post which would have a slightly immerged part that would push the mattes toward. As the new steel tool is more effective at gathering mattes, the iceberg is more dense and reduce the dispersion in the molten zinc during the removal motion, increasing the amount of mattes removed at each motion.



- Long term : Helping the company to develop a robot able to perform the operations currently done by hand. At this stage, we wrote the functioning specifications for these operations. The next step will be to work with the robotics engineer to evaluate the technical solutions they will design in an iterative process, to ensure an improvement of the working conditions around the crucible, as well as an improvement of the productivity. As we have seen HFE is best put to use when integrated upstream of the designing process and with a more human-centric 5.0 industry, should be considered more than ever as a reliable resource of development for the industrial world.

E. Ergonomic principles in a nutshell

This part of the with paper summarizes each principle in one short page

1. Principle one : to include in the design of the equipment / installation the human operator with his capacities and limitations

Definition
Human operators are the ultimate barrier against industrial accidents. Their experience, capabilities, flexibility in front of unforeseen situations are more effective than any machine. They can make mistakes particularly if the machines are not adapted to them

Utility
The role of the human operator in the design of equipment and installations is crucial, as they are often the key factor in system performance and safety]. This requires a deep understanding of the operator's capabilities and limitations, which can be achieved through the application of ergonomic criteria in the design process. The human operator should be seen as a vital link in closed-loop control systems.

Bringings to Industry 5.0 projects
Ensuring that equipment design matches human characteristics and functions, in order to improve worker efficiency, safety and comfort. Ergonomics deals with adapting the work environment, tools, equipment and systems to human abilities and their limitations.

2. Principle two : there is a huge expertise at the workplaces, developed by the operators. Understand it, use it before any change!

Definition
The expertise of operators is a major resource. The issue is about reliability, safety, health, but also the relevance of investments, the cost and delay of adaptation for the teams

Utility
The expertise of operators at workplaces, refined over years and often surprising, must be thoroughly analyzed and understood prior to defining technical development requirements, as it impacts not only reliability, safety, and health, but also the appropriateness of investments and the cost and time required for team adaptation. It is essential to analyze and understand it before defining the requirement sheets for technical developments.

Bringings to Industry 5.0 projects
Understanding the expertise developed by operators in the workplace and its use before any change is a key for the compliance of the new systems with the existing expertise, for the "just investment", for the efficiency and sustainability of the future process.

3. Principle three: to include the teams in the design process

Definition
Participation is an important key to success. If the operators contribute to the construction of specifications and the development of solutions, they will bring their "know how" knowledge to the project

Utility
A crucial factor for success relies in active participation, wherein operators' input in formulating specifications and developing solutions leverages their workshop expertise, ensuring a comprehensive understanding of the forthcoming system and necessitating meticulous, project-integrated methods for genuine engagement.

Bringings to Industry 5.0 projects
"3ou never adopt a change as well as when you have contributed to it". This operators participation, which must be rigorously constructed, mobilizes the operators concerned by the change, their expertise, and is a motivating factor

4. Principle four : technology cannot solve all problems- it may lead to delusion

Definition
While technology providers often highlight the potential of their products, it's crucial to analyze the existing operations in a workshop before investing, as the effectiveness of the technology depends on its alignment with the needs, and promises only bind those who believe in them.

Utility
Often problems at the source of change processes are poorly defined. This opens up for too loose interpretations. Whilst diversity of perspectives is fundamental for the understanding of problems without effectively listening to these different perspective we are simply collecting noise. This inevitably leads to the definition of the problem through the lens of the solutions at hand. No single manager (or anyone at any other position in a company) can ever hold the knowledge and understanding of problems to a satisfactory degree. Continuous "listening to different perspectives" is a fundamental cornerstone for decision making.

Bringings to Industry 5.0 projects
No problem faced today by industry can be considered to have "ONE SOLUTION". Furthermore, technology is far from being the solution as often promised. Before making any decision for a change, the knowledge about the existing functioning is a strong requirement.