ABSTRACT

Industry 4.0 Demands the Co-Evolution of Workers and Manufacturing Operations

Looking Towards the Future: What we're seeing. What we're wondering. What we think others might be wondering.

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To say that Industry 4.0 and the Industrial Internet-of-Things (IIoT) is changing the way things get done in manufacturing is an understatement. Fueled by the rapid rise of smart technologies, manufacturers are bringing together IIoT, connected machines, robots, sensors, smart devices, generalized compute technologies, and a steady stream of real-time data analytics to automate many of the mundane — and not so mundane — tasks of the factory and the larger manufacturing system.

These technologies are poised to change just about everything in the factory. But they are doing more than just increasing industrial automation, they are helping create "intelligent" factories which are marked by autonomous production, hyper-agility, and real-time analytics that provide operational transparency and make data a transformative force for the business.

The march toward the intelligent factory has long been under way. However, transforming into an intelligent factory is neither easy nor quick. The key to achieving true intelligent factory status is to integrate every process and system into a holistic "system of systems" that is run by real-time data and IIoT connectivity.

Successfully making the transition to the intelligent factory takes more than just technology smarts. Successful adoption of the underlying IIoT-enabled technologies requires comprehending the co-evolution of the many systems in manufacturing environments and the behaviors, goals, motivators, and needs of the people who work with them in order to anticipate how to successfully design this transformation.

As we undertook this project, we wondered what workers from the factory floor to the boardroom expected in the intelligent factory of the future. Likewise we also wanted to uncover pain points, desires, concerns, and expectations of these individuals as they and their companies pursue the promise of the intelligent factory. To answer these questions, we turned to the workers and leaders who are in the midst of today's changing manufacturing environments. We recruited 145 individuals from a broad range of manufacturing

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settings for this project. While this work was done in the context of intelligent factories, what we learned should have broad generalizability to introducing technology in manufacturing settings.

Digital Intensity and the Intel Experience

The promise of the intelligent factory is of particular interest to Intel. As a manufacturer ourselves, we have factories all over the world, each precision-tuned for efficiency and quality. Our traditional automation systems are augmented with IIoT-enabled capabilities, such as data-driven materials handling and advanced analytics. Examples of how Intel is using IIoT include:

- Big data analytics help us detect the potential failure of critical testing units before they wrongly categorize "good" devices as "bad"
- Image analytics speed up the once hours-long manual task of segregating true rejects from marginal units
- Machine learning helps us visualize and automate the control of equipment performance and anticipate maintenance needs before failures.

These and many other IIoT-enabled efficiencies are teaching us how to use our data to increase uptime, accelerate output, generate higher yields, and lower mean time to repair — all typical benefits of the journey toward a fully intelligent factory.

However, Intel's manufacturing prowess is a double-edged sword. With our decades-long experience in semiconductor manufacturing, we must constantly remind ourselves that the Intel experience may not map to other manufacturing environments. Thus, we needed a framework to describe various manufacturing environments. We created a framework based on digital intensity – the degree to which computer-based technologies (e.g., machines, equipment, services) do the work and often substitute for humans when it comes to manufacturing tasks (See Figure 1). We used this framework to help participants in our study better describe their own operating environments and tasks, and to anticipate challenges in their journey to the intelligent factory.

To explore the impact of digital intensity relative to the opportunities and threats of further digitization, we relied on participants' subjective perception of manufacturing digitization and our assessment of the technology they shared during the research. Not surprisingly, most people were a long way from the vision of the intelligent factory.

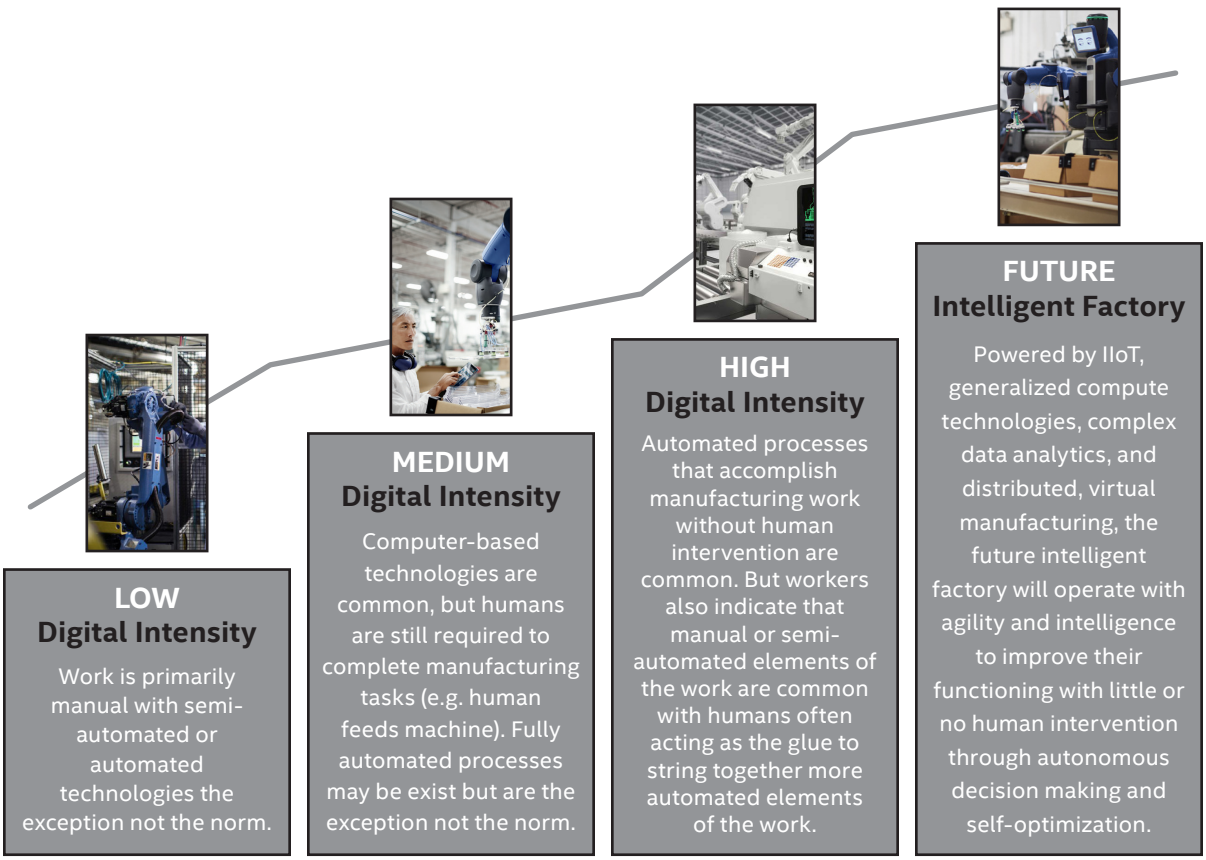

Figure 1. Digital Intensity Continuum Today and in the Future

25% of participants worked in settings with low digital intensity where work was predominately manual, or as one participant said, "technology isn't the worker here … <the> operator has to do the majority of the work". 46% worked in medium intensity environments, and only 29% indicated they worked in high intensity settings, where automated processes were common. Table 1 summarizes the human aspects of digital intensity differences. We believe that a deep understanding of these differences will be necessary to successfully navigate the digital journey ahead.

Manufacturing Systems are Evolving, But What About the Workers?

As part of the research, we looked to identify key groups of leaders and workers with similar behaviors, goals, motivators, and needs — aka personas of potential "users" — that will be critical for successful adoption of IIoT capabilities, both today and in the next 3-5 years. They provide a shared framework and language for thinking about the accompanying co-evolution of workers and manufacturing operations.

Digital Intensity	Low	Medium	High	Future
Top Challenges	1. Process includes too many manual tasks and too much paper	1. Information challenges – (a) not collecting needed data and (b) not trusting as inconsistent information coming from different sources	1. Information and communication challenges – do not collect data I need or collect it but cannot easily use it as (a) not available real-time or (b) difficulties making sense of it	1. Technology changes faster than company makes decisions or can keep up with skill-wise
	2. Equipment upkeep and maintenance	2. Wasted labor time due to poor planning or insufficient information	2. Old equipment still in use	2. Increased transparency of work and communication may make visible information workers or company don't want shared
	3. Information challenges – (a) not trusting as too many people touch during collection or processing, (b) not in an easy to use format, and (c) information hoarding by others	3. Labor variability (e.g. staffing differences, or quality differences for the same work)	3. Unpredictability of technology and equipment maintenance	
Tech Impact on Work in next 3 – 5 years	1. Work faster and more efficiently 2. Work is increasingly automated	1. Work faster and more efficiently 2. Work is more strategic	1. Work faster and more efficiently 2. Work is more strategic	1. Increased work transparency 2. Less manual work
Top Change Obstacles	1. Limited tech financial resources 2. No commitment to change in the organization	1. Cost of technology 2. Skill gap among today's workforce	1. Cost of technology 2. Insufficient training investment	Our pace of change is too slow to achieve envisioned transformation in a competitive time frame for our industry
Top Change Motivator	Reducing time to complete a task	Increasing productivity	Increasing effectiveness and overall productivity	Improved quality especially process & information

Table 1. The Impact of Digital Intensity

Persona Family	Summary Description
Hardcore Doers	Keep the factories running and are at the heart of manufacturing – operating machines, checking quality, and supervising shifts. Their focus is on getting things done as efficiently and safely as possible. (Example roles: line workers, QA technicians, factory supervisors, operations)
Factory Influencers	Focus on the big picture of the organization – from maintaining company reputation to planning its strategy. Even when drawn into more day-to-day matters, the big picture is never far from their minds. (Example roles: CEO, CIO, CTO, Information Security Directors)
Customer Champions	Aim for happy and satisfied customers whether they provide technical support, create new markets, or design products that customers will love. (Example roles: marketing, sales, product designers)

Table 2. Three Key Persona Families

During our analysis we quickly realized that each persona needed a unique name, which encapsulated multiple job titles. We believe that this approach captures the essence of the key types of inhabitants in the factory ecosystem. Table 2 highlights the three broad persona families we identified. We distinguish between personas today and those in the future.

As the vision of the intelligent factory is realized, the personas are expected to transform with their taglines below reflecting this transformation. The shift from today's reality to the envisioned intelligent factory was so substantial that a new set of future personas were required, with some of today's personas merging into a single persona and individual personas experiencing fundamental shifts in the nature of their work and even their motivators.

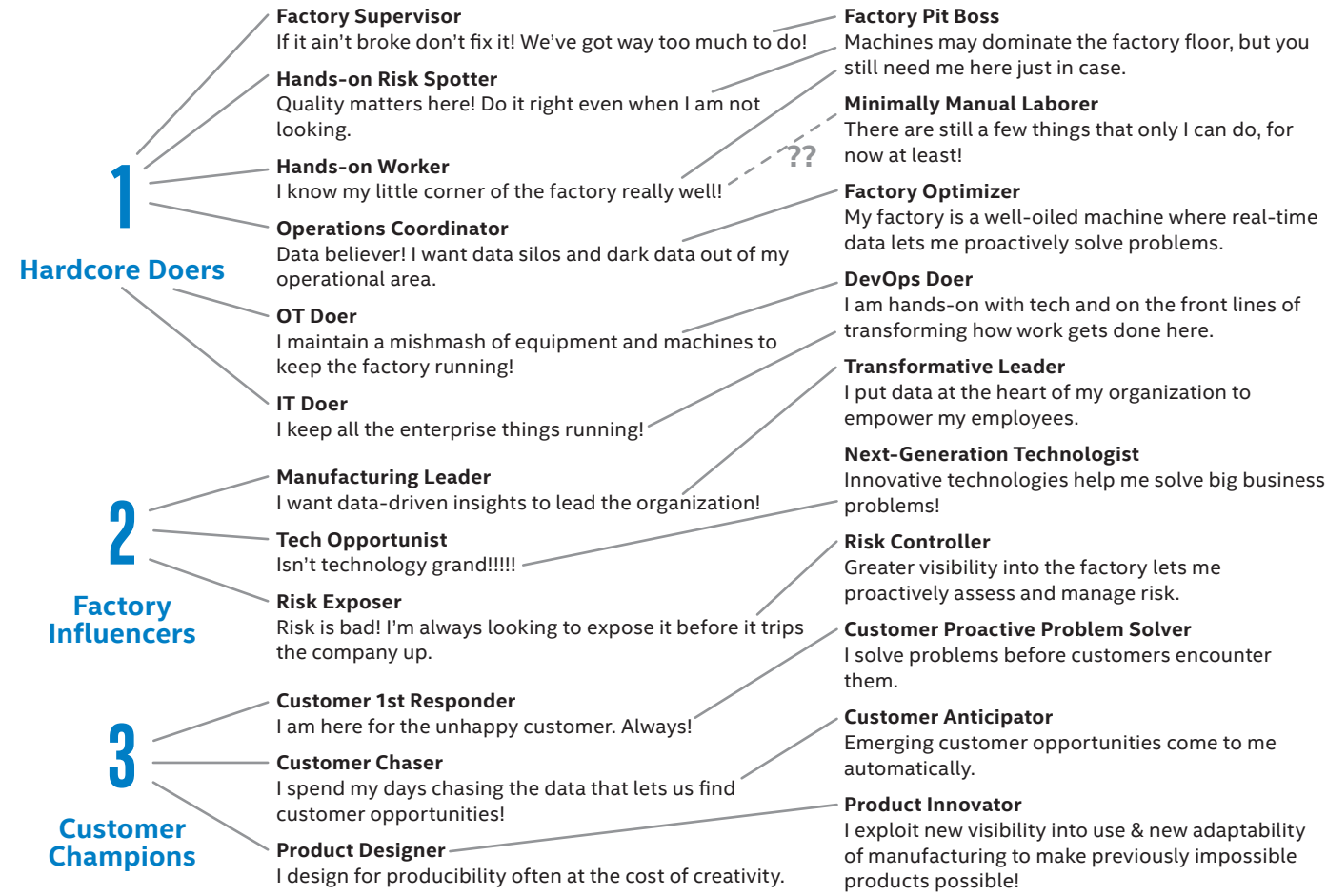

Figure 2. Persona Landscape – the Leap from Today to the Future

What We Learned about the Coevolution of Workers and Manufacturing Operations

As we looked across the 145 manufacturing participants and the 133 companies that they came from, we discovered shared motivators, accelerators and potential threats to adoption of IIoT and successful transition to the intelligent factory. We hope by sharing them here, we can help you think about where you are on your journey toward the intelligent factory and enable you to better anticipate implementation and communication needs. We believe these are particularly relevant since 76% of participants were between 18 and 40 years of age — the future leaders and inhabitants of the intelligent factory.

(1) The Journey Starts with Today's Pain Points

When describing their work and its challenges participants overwhelmingly started with their pain points today, rather than with a technology solution. Manufacturing pain points came in all shapes and sizes — product rework or damage, physical discomfort or injury, inefficiency or just basic communication breakdowns. These many obstacles are ideal problems to potentially solve with IIoT solutions. The most frequent types of reported problems are shown here:

26% **Information challenges** related to difficulties getting needed information for work tasks. When participants drilled into the reason behind these challenges, they indicated that (a) needed information was not collected, (b) collected information could not be easily used (e.g. hard to find, wrong format, not available real-time), or (c) not trusting the quality of the information collected (e.g., too many versions of the truth, manual nature of data collection)

24% **Equipment maintenance and upkeep** including unplanned downtime, reactive rather than proactive management, difficulties diagnosing problems, and maintenance costs

19% **Communication challenges** related to the lack of effective coordination across the factory (e.g. between teams, sites, or functions)

18% **Safety hazards** such as environment air quality, temperature, noise levels, and ergonomic issues (e.g. lifting heavy object)

17% **Equipment not a good fit** for work whether the complexity of changeovers, age of equipment, or not using it for intended purpose

(2) People are at the Heart of a Successful Transition

When we envision intelligent factories of the future, we often put technology in a starring role, but technology alone will not ensure a successful transition to an intelligent factory.

Fully 56% of the obstacles raised related to the culture and leadership of the company — whether workers were concerned with the slow pace of change at their factories, leaders concerned with resistance to change from their workers, or workers recounting C-Suite-level distrust of new technology and resistance to technology adoption despite the fact that it would increase efficiency for their companies.

When transitioning to the intelligent factory, leaders are often seen as decision-makers and workers seen as being along for the ride. But in this research, it was not just the manufacturing leaders or managers who proclaim influence. It was also operations and logistics coordinators, quality specialists, maintenance technicians, and hands-on line workers. 56% of participating workers and leaders saw themselves as decision-makers at some level about the future of manufacturing at their companies. Fully 98% of the workers who participated believed that they had direct or indirect influence over technology adoption and implementation decisions. These individuals are potential allies in the path to the future, if only we can harness their interest in change.

Worker participants who embraced technology and coming changes were often motivated by the desire to adapt as a way to stay relevant and employable over the long-term. Likewise, they want their factories to change in order to stay in business before they do not have enough capital to adopt new technology. Leadership participants who embrace technology are often concerned about the potential financial losses from poor adoption and delays from implementation. There is clearly a subset of leaders who appear to be more risk averse than workers on the floor when considering new technology changes.

(3) Organizations Must Bridge Both An Understanding Gap and a Skills Gap

The intelligent factory is exacerbating the resource and skills gap that many manufacturers are already wrestling with. Leaders are rightfully worried about their increasing inability to find and keep skilled labor, particularly as the skills required for manufacturing keep changing.

However, an even bigger — and often unrecognized — obstacle to the adoption to smart technologies is the understanding gap. For most participants, "Industry 4.0." and "Manufacturing 4.0" were at best buzzwords, with leadership response to these terms during interviews mixed. Overall, participants demonstrated a widespread lack of awareness about using a 4.0 framework for conceiving and planning changes in their factories. Despite that, many demonstrated awareness of and interest in solving today's problems in ways evocative of 4.0 technologies. However, they framed their interest in terms of piecemeal changes, process changes, and improvements to particular work, not large-scale manufacturing transformation. So to successfully navigate the transition, you must be able to translate the grand vision into changes that workers care about, namely solving the problems they face today.

For many, technology (and their envisioned intelligent factory) remained a black box, despite a hunger for all-in-one, out-of-the-box solutions to solve a variety of today's problems. Participants rarely referenced wanting a specific technology in their free-form musings about needed changes, but they did do plenty of magical thinking regarding smart 4.0 technologies. While it demonstrates the participants' openness to these technologies, it also demonstrates a lack of concrete information about how these technologies work, what they are, and what they can or cannot do. This magical thinking represents a formidable obstacle to the successful implementation and adoption of such technologies in the factory.

In no small part due to magical thinking about technological possibilities, participants struggled with how to operationalize new technology possibilities. They often had concerns about the new technology fitting in with existing equipment and lacked the time to learn more. They saw themselves as being at risk potentially if they failed to navigate the transition, but need help learning to make transformation concrete through practical, proven steps.

(4) People Don't Trust the Intelligent Factory

If we want manufacturing to truly benefit from the rise of the intelligent factory, we need to get workers and leaders to trust it.

In this research, workers and leaders at times exhibited distrust when it came to 4.0-like technologies. Even those who are the closest to and seemingly most ready for 4.0 seem afraid of letting go of human control in manufacturing processes. They saw the dark potential of these technologies becoming difficult to control, from losing control over quality or data, to losing the ability to respond flexibly to volume fluctuations, to losing control of personal information, or even fully losing physical control over the factory itself. In fact, one intelligent factory future persona exists largely because of the participant sentiment that the future factory, even if run by robots, still needs humans on premise — just in case.

They also had concerns about the reliability of 4.0-like technologies once installed. Even with current technology, there are widespread concerns around preventative maintenance lapses and repairs that take too much time away from production due to hard to come by parts or need for specialized support. Technology today is often adopted without any plan in place to keep it updated. Some have ended up with new machines and old computer interfaces, new data streams and old servers, or other combinations due to a lack of systematic planning. With the increase in automation, this concern becomes even more pressing as many workers and leaders feel that they would need to rely more on the technology with less human intervention and potential lack of needed skills in-house.

(5) The Future Intelligent Factory May Be Closer Than You Think

Industry is often viewed as being very conservative and resistant to change. As a result, the transition to the intelligent factory is expected to be a long one — many expect the journey to take nearly a decade to achieve for most companies. We were surprised by the extent to which participants' free-form imagining of next 3-5 years aligned with the long-term vision of the intelligent factory. This suggests that the timeframe for the expected intelligent factory may be sooner than anticipated.

Participants saw the automation that comes with the intelligent factory as potentially freeing them from the more onerous aspects of their job (e.g. repetitive manual tasks, paper wrangling). Many relished the thought of being able to focus more on value-add tasks that were uniquely human and having freedom from today's constraints of manufacturing. They looked forward to transparency in work and communication, where they could access information about anything from anywhere, leading to an organization that was more in-sync and data driven. They believed that the future factory would still need people — although maybe fewer of them and in vastly different roles.

Your Journey to the Intelligent Factory

Your journey to the intelligent factory begins with a vision — one that you can incrementally implement over time. As you learn more along the way, the vision matures. Our work here suggests that this vision should consider the co-evolution of manufacturing environments and the people that work within them.

Current manufacturing workers at all levels have expressed a hunger for change and believe that they can and should play an important role in that change. Harnessing this enthusiasm, coupled with their deep hands-on manufacturing expertise, will lead to solutions that are powerful, that have buy-in, and that can be communicated in a way which presents the changes as solutions to the problems workers care about today.

Our study respondents believe that change is necessary to stay competitive, both for themselves and for their companies. The personas shared here will help you better understand your workforce, consider how your workforce may experience the transition, and craft communication that explains the value of operational transparency.

The Intel Role

No single company makes this journey alone. Intel seeks to be an advisor, solution provider, and co-traveler on this journey. In sharing these research findings with the broader industrial community, Intel hopes to help refine the dialog about what it means to operate in an Industry 4.0-like environment. We wanted to focus a spotlight onto the organizational and worker concerns that often are overlooked (or underplayed) in wide-sweeping technology changes.

We intend that this work should be ongoing and look to grow our understanding of this transformation by actively partnering with those engaged in the journey. We envision active partnerships taking many forms including workshops, management roundtables, individual company engagements, and sharing learnings through industry forums.

For more information

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