



Laura Juliano: We've been talking about the factory of the future for a long time. It's been decades down the road, but now it's days down the road. Some industries are actually implementing these technologies and changes today and seeing real value from them. Others need to start thinking about it.

Daniel Kuepper: The real constraint is of not the technology itself and its maturity. It has been evolving so fast over the last two to three years. It is rather whether companies are ready to update their ambition and act on it to ensure future competitiveness.

Georgie Frost: Welcome to *The So What from BCG*, the podcast that explores the big ideas shaping business, the economy, and society. I'm Georgie Frost. For decades, companies have optimized manufacturing around low-cost labor. Now, advances in AI could change all that. The implications go far beyond the factory floor with the potential to reshape supply chains, global competitiveness, and the future of work.

Joining me today are Daniel Kuepper, leading BCG's Manufacturing & Physical AI team; and Laura Juliano, BCG's North America Operations practice lead. Daniel, Laura, welcome to you both. Daniel, we've been talking, it feels, about the factory of the future and industry 4.0 for many years now. What is different about this moment?

Daniel Kuepper: So for me, and that's the difference, three key tech evolutions. Number one, physical AI expands what we can automate. Number two, agentic systems change how the factory is orchestrated, and the scalable technology backbone changes how quickly successful solutions can be deployed.

Laura Juliano: And I'd add one more, talent, and the generational differences of the frontline workers.

Daniel Kuepper: We have been talking about a factory of the future and industry 4.0 for many years. The ambition was always clear. Factories that are more productive, more flexible, and increasingly self-controlled. What feels different now is that the technology has finally caught up with the ambition. Today, I see three things coming together. First, physical AI can now sense, reason, and act through robots, machines, and material handling systems.

That is a big shift. Robots can adapt and learn in ways that were not possible before. And because many of these systems can be trained virtually before they are installed on the shop floor, the economics are improving, the business cases are improving. In our work, we see that roughly 50% more work can be automated compared with just three years ago. And robot training and setup effort can be reduced significantly, in some cases by roughly 70%.

Second, agentic systems. We are no longer talking only about AI optimizing one machine or one task, we are talking about AI helping to orchestrate the entire factory. For example, one agent might continuously optimize the production schedule based on incoming orders and constraints while another monitors machine performance. They feed information back to each other so the factory can continuously adjust.

And then finally, the third topic: we now have the technology backbone to scale. Technologies like unified namespace, modern platforms, edge computing, standardized connectivity all play a role in this. In simple terms, we are finally able to create a common data layer for the factory.

Laura Juliano: We're getting to a point now where new graduates and the entry level of organizations, the machine operators, the folks that actually have to be driving the back office are coming in with a base level of understanding of how to interact with an agent or a chatbot, what it means to have a machine learning algorithm that underpins the work that is happening, how a robot or basic physical automation interacts with humans.

It is drastically different to the starting point of where Daniel and I were. I won't say how long ago, but it was a lot longer than a couple of years. The learning had to happen immediately on the job site versus now that base is there to build from.

Georgie Frost: Laura, how significant a shift is that?

Laura Juliano: Fairly significant, and certainly the progress over time has been in fits and starts. Over the last ten years, I would venture to say 80% of the progress towards physical automation has been in the last two or three years. The factors that Daniel just mentioned are really increasing the slope of the curve at a very rapid pace.



Georgie Frost: Daniel, Laura there talks about humans and workers. I'm hearing a lot about so-called lights-out factories, which doesn't sound as though it has a lot of room for humans involved unless they want to work in the dark. What exactly are these things, and why are they getting so much attention right now?

Daniel Kuepper: I would say lights-out factories are the extreme version of a factory of the future. It is basically a factory that tries to operate with significantly less human operators, and that is possible in some places. My personal definition of a lights-out factory is that we still have indirect manufacturing labor. We still need maintenance technicians to support whenever there is a breakdown, a physical breakdown to a certain equipment.

Georgie Frost: Laura, is that vision realistic across manufacturing?

Laura Juliano: It certainly depends, but I'd say the vision itself holds for the most part. What it really boils down to is how automated can a process be, whatever the physical process is that needs to happen to create whatever good is coming out the back end, and how much do logistics costs matter in the calculation of the business case?

In some instances, there are some sectors and industries out there where the actual moves that need to get made, or the volume that gets pushed through a factory is so small or so specialized that the creation of the technology to have physical AI and robots conduct it is still a ways away, from a development perspective.

In other cases, it's a financial issue. The business case just doesn't close. The investment that it would take in order to create a lights-out factory does not outweigh from a benefit perspective because say there's a local-for-local setup where everything that you are making is proximate immediately to the customer that you're delivering it to.

And therefore, in order to build a lights-out factory, if you have to get farther away, the logistics costs outweigh that benefit, or perhaps the technology is just so expensive. Think of high reliability industrial environments like satellites or other technology, or med tech where the human touch is still so important and modeling that in an automated fashion is not quite there.

Now, I say quite because I think everything is moving towards that direction. So as we progress over the next few years, there will be aging assets in manual factories that make a lot less sense to replace with other manual machines versus upgrading to more of a lights-out or physical automation setup.

Georgie Frost: You mentioned a number of industries there, Laura. Are any really, really far ahead?

Laura Juliano: Certainly, places around physical technology, and those that are heavy in regions outside of the US actually in Asia tend to be the ones that have put in the investment, have the high volume, low mix line speed that are so conducive to this type of investment. And Daniel, I'm going to actually pass it to you, because I know that's the space that you work day in and day out.

Daniel Kuepper: Investing in the factory of the future, first of all, is always in competition with just relocating to a lower cost location, right? And for me, the rule of thumb is always if the impact that you can achieve by investing in the factory of the future is high, and if you operate in a sector that comes along with significant logistics costs, so shipping from a distant location to the customers is expensive, if those two things come together, then that is a sweet spot for where it makes sense to double down on implementing the factory of the future.

Georgie Frost: I'm curious to follow this thread a little bit further and look at the implications of what AI advancements will do for where companies choose to manufacture. If AI changes that equation, what does it mean for regions?

Daniel Kuepper: There have been significant changes over the last 25 years. Both the US and Western Europe have each lost 11 percentage points of their share of global manufacturing value add, shedding over nine million jobs combined, while Asia and China in particular has gained 28 percentage points, representing now 55% of global manufacturing value add.

And without a broad implementation of AI and the factory of the future that we are discussing here, the current trajectory will continue. We expect or we see in Europe alone more than \$1 trillion of



manufacturing value at risk of being relocated and we see more than 400, \$440 billion at risk of being relocated from the United States. So AI-powered factories can fundamentally alter this equation.

By reducing labor intensity in factories, AI reshapes the cost structure of production, but there is no universal arm by whether AI can reverse the best option where to produce varies by sector and location as we have that. Just to give you two examples, Western European chemicals, automotive manufacturer investing in AI-powered factories can be equally competitive with China when we account for logistics and the proximity to customers.

But in battery cell manufacturing or smartphone assembly, for example, cost disadvantages are deep enough that even a full implementation of the factory of the future leaves a meaningful gap.

Laura Juliano: Daniel mentioned in China, there is aggressive moves towards factory of the future to defend its position in automation as this labor cost advantage equation starts to shift. South Korea has the highest robot density of manufacturing in the world, and continues to pour technology and research and development as well as on the ground implementation learnings into what they are doing.

Even in the US, we're seeing that tariffs are starting to further motivate the need to bring more production on shore where economically possible and industries like automotive are able to make decisions about their entire company future off the back of this capability.

Georgie Frost: One thing I wanted to, we've taken a look at the broader picture here, global economies. Let's bring it back down to companies. I want to explore where they are currently finding value from AI and automation.

Laura Juliano: Let me give a few examples, because these are ones that are in place and happening every day right around the corner from each of us. So industrial equipment, think pumps and valves, HVAC type equipment. These are places where the combination of automation on the line, plus the advanced utilization of data and technology infrastructure to predict what maintenance will be necessary to increase the runtime of assets that are

on the floor is allowing, not only to reduce total labor, but to most importantly reduce the churn from labor that comes from the training that is necessary in these roles, and the turnover delays that get driven when attrition happens in the workforce.

It's taking significant points off of conversion cost, allowing these companies in what in many cases are a hundred years old and have operated the same way, and allowing them to think very differently about their operating costs.

Another space, aerospace and defense for example, this is a supply chain that often has to be on the cutting edge of design, incredibly important and mission-driven sector. There, it's less about taking labor out because the value of the individual is so important at a high value add job, but it's more about consistency and yield, reducing non-conformance. And so there's significant value there that's not on the reduction of cost, but rather the increase of what you can do with what you have.

Daniel Kuepper: Western economies with high labor costs, they would typically try to optimize for labor productivity, right? When you have the same discussion, for example, in India, typically no one ever asks for labor productivity, right? They are all over asset productivity and a question of how can we better utilize our assets and also product qualities and the predominant theme.

How can we make sure that we get to a better quality, a more consistent quality to be able to serve international markets? So it really depends on what to optimize for, but the factory of the future has exactly that in mind, and can benefit much more than just the cost equation.

Georgie Frost: Laura, you spend a lot of time helping manufacturers through these kinds of transformations. What do you see are perhaps the biggest mistakes that leaders make when they get started?

Laura Juliano: One mistake is looking at it as a technology-only solution and situation. I know when a client comes to me and asks for what should our AI transformation be, that I'm in for a long conversation because my question back is what problems are you trying to solve? And that's the case in manufacturing as well.



What element of your cost base are you unhappy with or has increased significantly recently? Where are you seeing the biggest constraint when it comes to labor capability? What is it that is causing excess effort or rework in your production process? These are the types of questions that need to get asked instead of where can I use a robot?

The second one is underestimating the people element. I mean, Georgie, you mentioned this earlier. We talk a lot about the technology, yet every time that I do, the people become that much more important. Yes, the profile is going to be different of what the labor force looks like at a company that is highly automated versus not. But as Daniel mentioned, things like maintenance, prediction, decision making power, these are all elements that still have a human touch to them.

And in this interim period before many companies get to the lights-out factory, there's going to be a hybrid setup and you need to focus on first of all, how do we mine people's knowledge for the areas that are going to be most effective to utilize this technology? And then how do we design a solution that augments and increases the value of what our labor force is providing, and takes away the low value-add areas?

And then the third one I'll mention is a mistake I often get, "Okay, well give me the playbook. What is the playbook?" It's different for everyone. I mean, obviously Daniel and I have gigabytes of playbooks that we can provide, but the question is, again, what is the problem you're trying to solve? What is the unique setup and situation of your assets? Again, many of which have probably been around for 50 years.

Your supply chain, the map of suppliers you're using, your customer base, what they need and the service levels that have to be delivered, and how do we apply the capabilities to those in a way that creates the perfect map for you? What a German auto plant requires in this way is going to be very different from what a New Jersey biopharma line looks like at the end of a transformation.

Georgie Frost: Daniel, what does it look like from your perspective?

Daniel Kuepper: I would say what is becoming more important in these days is to acknowledge that the two decisions of where to produce, and how to produce, that means with or without what we discussed as being the factory of the future, cannot be separated. Those two questions belong together, and that is different from what we have seen in the past.

And that is something that decision makers now, when they discuss their overall footprint, always need to keep in mind. And then the question is already how much of that reshoring is already happening? I would say real reshoring is still rare, right? So is a decision not to move production to lower cost locations. It's simply the more certain response in the eyes of many decision makers, given that we are only at the very beginning of using the latest AI advancements and change manufacturing economics at scale.

Georgie Frost: Daniel, you say that we're at the very start. Is there a benefit to the first movers in this space, or the watch and sees?

Daniel Kuepper: I mean, there are definitely benefits. So I would argue we are ready to deploy and we are deploying it for many of our clients. There's still, from my perspective, though, a gap in the awareness at many manufacturing leaders so many of them still look at automation through the lens of what was possible a few years ago. Expensive, rigid, hard to program, difficult to scale, but some technology has moved very fast.

Physical AI agentic systems and scalable data infrastructure have changed both what is possible and what is economically attractive. And then sometimes I also believe there's a lack of courage. Companies need to move beyond isolated pilots, and define a more ambitious target picture for how the factory and ultimately the factory network should operate.

And thirdly, I would say companies need to invest behind it, not blindly, but with conviction in automation, in the data backbone and capabilities and in change on the shop floor. And yes, this investment will not always pay off in one or two years. That is clear.



So what I would say is the real constraint is of not the technology itself and its maturity. It has been evolving so fast over the last two to three years, we discussed that. It is rather whether companies are ready to update their ambition and act on it to ensure future competitiveness.

Georgie Frost: Laura, courage and conviction.

Laura Juliano: Absolutely. I mean, I would say just to summarize what Daniel said, moving forward, leaders need to define what problem they're trying to solve, set a vision, and then what the first step is going to be because a vision without that first actionable step with the investment is never going to get off the ground. And a first step without any vision associated is going to stall.

Georgie Frost: Well, you've led me beautifully to the next and final question, which is the "now what?" What is the first step if I'm a manufacturing leader that I should be taking tomorrow?

Daniel Kuepper: Well, for me, the first step tomorrow morning is simple. Update your view of what is now possible, define a bold but practical factory ambition anchored in your highest value opportunities, and invest behind it. The factory of the future is no longer, for me, just a vision or a collection of pilots. It is becoming an executable transformation agenda, with significant implications for productivity and competitiveness.

Georgie Frost: Laura?

Laura Juliano: Said beautifully, Daniel. I would just add to it, evaluate your people, listen to your people, and understand together how you're going to go on this journey.

Georgie Frost: Laura, Daniel, thank you so much, and thank you for listening. If you'd like to find out more about this subject, you can read the article *How the Factory of the Future is Reshaping the Economics of Manufacturing Competitiveness*, just find the link in the show notes.