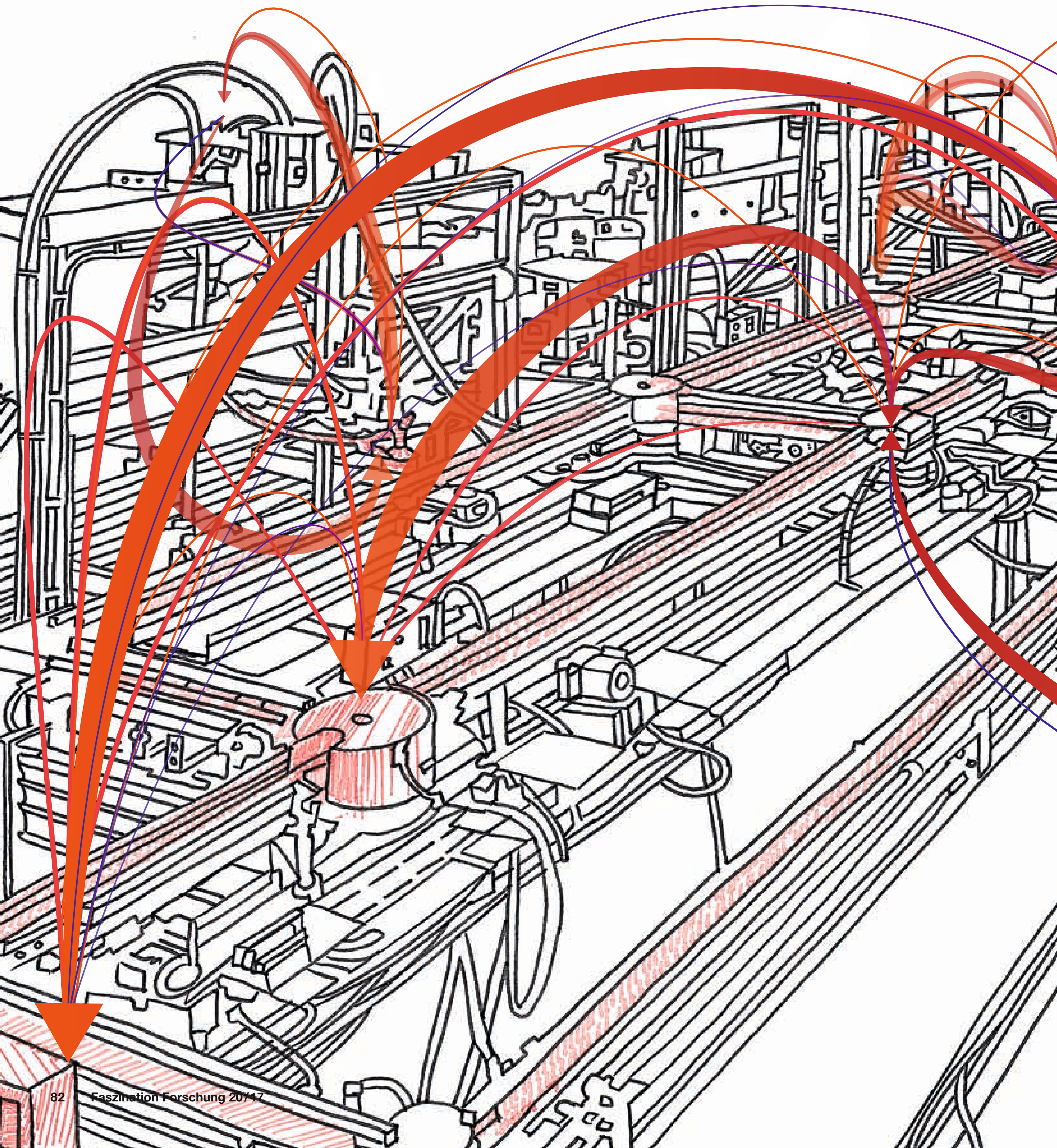
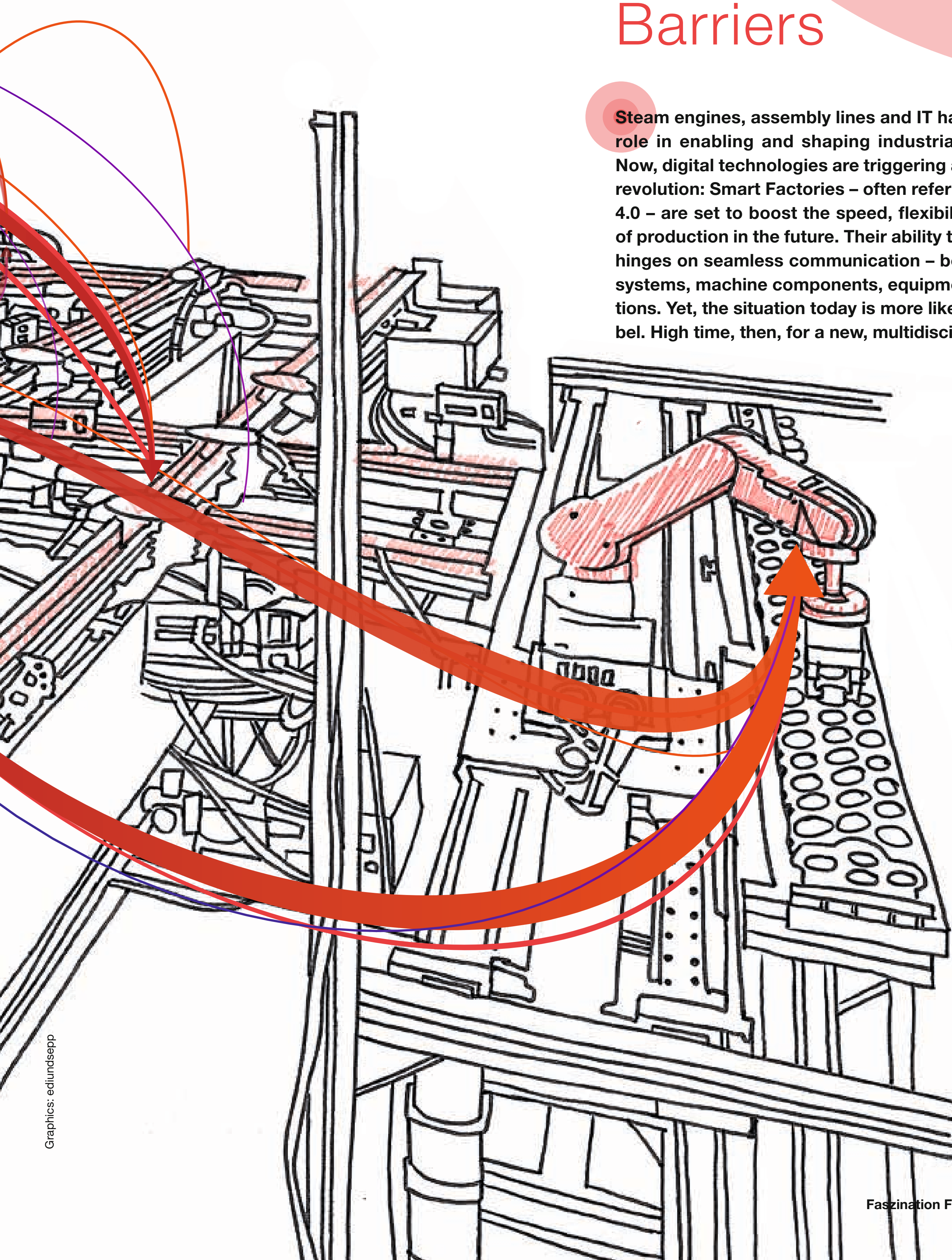


# **Overcoming** Communication Barriers

**Steam engines, assembly lines and IT have each played a role in enabling and shaping industrial manufacturing. Now, digital technologies are triggering a fourth industrial revolution: Smart Factories – often referred to as Industry 4.0 – are set to boost the speed, flexibility and efficiency of production in the future. Their ability to do so, however, hinges on seamless communication – between operating systems, machine components, equipment and organizations. Yet, the situation today is more like the Tower of Babel. High time, then, for a new, multidisciplinary approach.**



Graphics: ediundsepp

*Monika Weiner*

# Modularität überwindet Sprachbarrieren

**Anlagen, die schnell auf Kundenwünsche reagieren, sich selbst steuern, effizient produzieren, stets optimal ausgelastet sind und Produkte in höchster Qualität liefern – Industrie 4.0 macht's möglich. Zumindest theoretisch. Praktisch steckt die Vernetzung von Verfahren, Prozessen und Produkten noch in den Kinderschuhen. Noch fehlt es an Standards und Plug-and-Play-Lösungen; der Fluss von Daten und Informationen kommt häufig schon an den Schnittstellen zwischen Maschinen zum Erliegen; Softwareprobleme machen das Austauschen eines Förderbandes oder Barcode-Scanners zum unüberwindbaren Hindernis.**

**Prof. Birgit Vogel-Heuser erforscht am Lehrstuhl für Automatisierung und Informationssysteme der TUM, wie sich der Informationsfluss verbessern lässt – zwischen Anlagenbau, Elektrotechnik und IT, zwischen den einzelnen Komponenten einer Anlage, aber auch zwischen Auftragseingang und Systemsteuerung. Damit überschreitet sie Grenzen – sowohl zwischen Fachdisziplinen als auch zwischen Technologien.**

**Der Schlüssel zum Erfolg der Industrie 4.0 ist nach Ansicht der Ingenieurin ein modularer Aufbau von Produktionseinheiten: Jeder Greifer, jedes Förderband, jede Abfüllstation wird als eigenständige Einheit betrachtet, als Modul, das eine gewisse Intelligenz besitzt, das weiß, was es kann, und das sich im ständigen Austausch mit den anderen Einheiten befindet. Dass dieses Konzept funktioniert, beweist der MyJoghurt-Demonstrator im Erdgeschoss des Instituts: Die Anlage steuert sich selbst. Geht ein Auftrag ein, prüft sie ohne menschliches Zutun die Verfügbarkeit der Zutaten und die Kapazität der einzelnen Module. Das System ist so flexibel, dass während des laufenden Betriebs Softwareupdates durchgeführt und Komponenten ausgetauscht werden können.**

**Der modulare Ansatz hilft Unternehmen, die in Zeiten immer kürzerer Produktzyklen schnell auf die Anforderungen des Marktes reagieren müssen, und auch Zulieferern und Dienstleistern, die unter dem Druck der Globalisierung neue Möglichkeiten suchen, ihre Effizienz zu steigern.** □

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Electric motors whir, conveyor belts emit a low hum. With a quiet click, a robotic hand places a small glass container on the belt. The yogurt jar starts its trip by heading to a switch, which guides it around the corner, before a second belt picks it up and transports it past a barcode scanner towards the filling unit. Here, a light barrier registers the incoming jar. The conveyor stops, and little red balls from a plastic container immediately tumble into the opening. After two seconds, the jar advances again to the next stop, where water then pours in. At a third station, yellow balls are added to the mix. “These might be strawberry pieces or chocolate chips – we don't like using fresh ingredients in the lab, because they're perishable,” explains Prof. Birgit Vogel-Heuser. The Chair of TUM's Institute of Automation and Information Systems keeps a critical eye on the processes in the “MyJoghurt” demonstrator. Everything runs like clockwork: robotic hands and conveyors, switches, scanners, light barriers and filling units are perfectly synchronized.

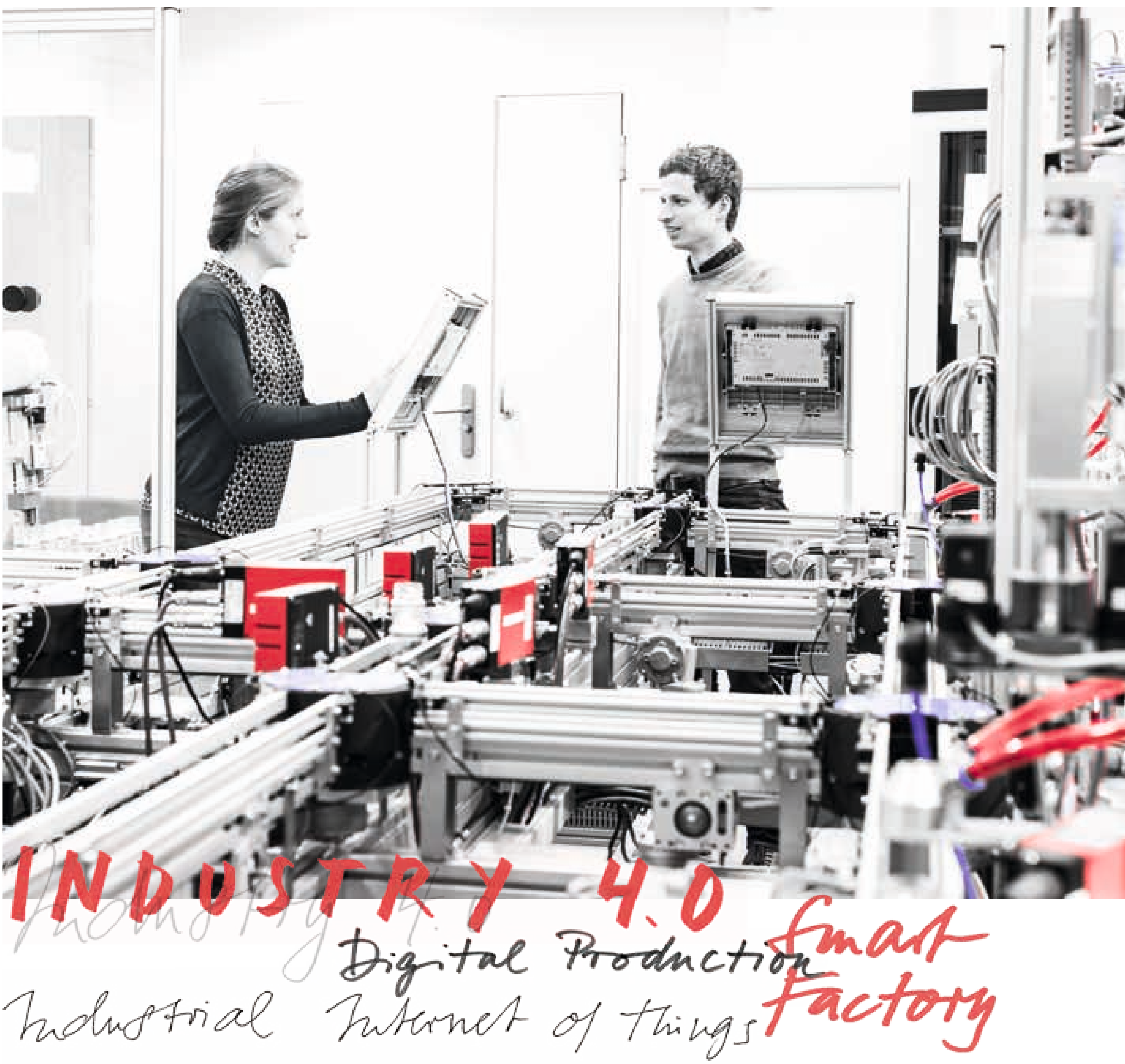
What you don't see, however, is the fact that the system is running itself. When an order comes in – a customer requests chocolate yogurt with strawberry topping, for instance, which has not been produced or designed before – requests are sent to the various modules: Are sufficient amounts of these ingredients available? Are the filling unit's tubes wide enough for chocolate chips and strawberry pieces? Can the conveyors transport the jars fast enough to execute the order on time? Is the price right? Once all the modules have checked and confirmed their capabilities, production can begin. A minor miracle of predictive planning and efficiency.

We could, in fact, be looking at the future of industrial production. MyJoghurt is a demo system for Industry 4.0 – the fourth industrial revolution following in the footsteps of the steam engine, the conveyor belt and IT. “Industry 4.0 has now become a buzzword. Everyone wants it, but everyone means something different by it. There are currently few standards and hardly any plug and play Industry 4.0 solutions that can smoothly integrate equipment from different manufacturers,” clarifies Vogel-Heuser, explaining that the definition of Industry 4.0 is thus relatively abstract. It entails connecting data, goods flows, production processes and people in order to improve the speed, flexibility, overall equipment efficiency and quality of manufacturing in the future.

The MyJoghurt system shows how these aims can be realized. Researchers are using the demonstrator to develop new concepts – for instance, to enable communication between separate areas or units. “We can run software updates and even replace components with new ones featuring different connectors in live mode without needing to completely shut down the whole system,” outlines the engineer. “As it stands, that is almost impossible in current industrial production plants.” ▷

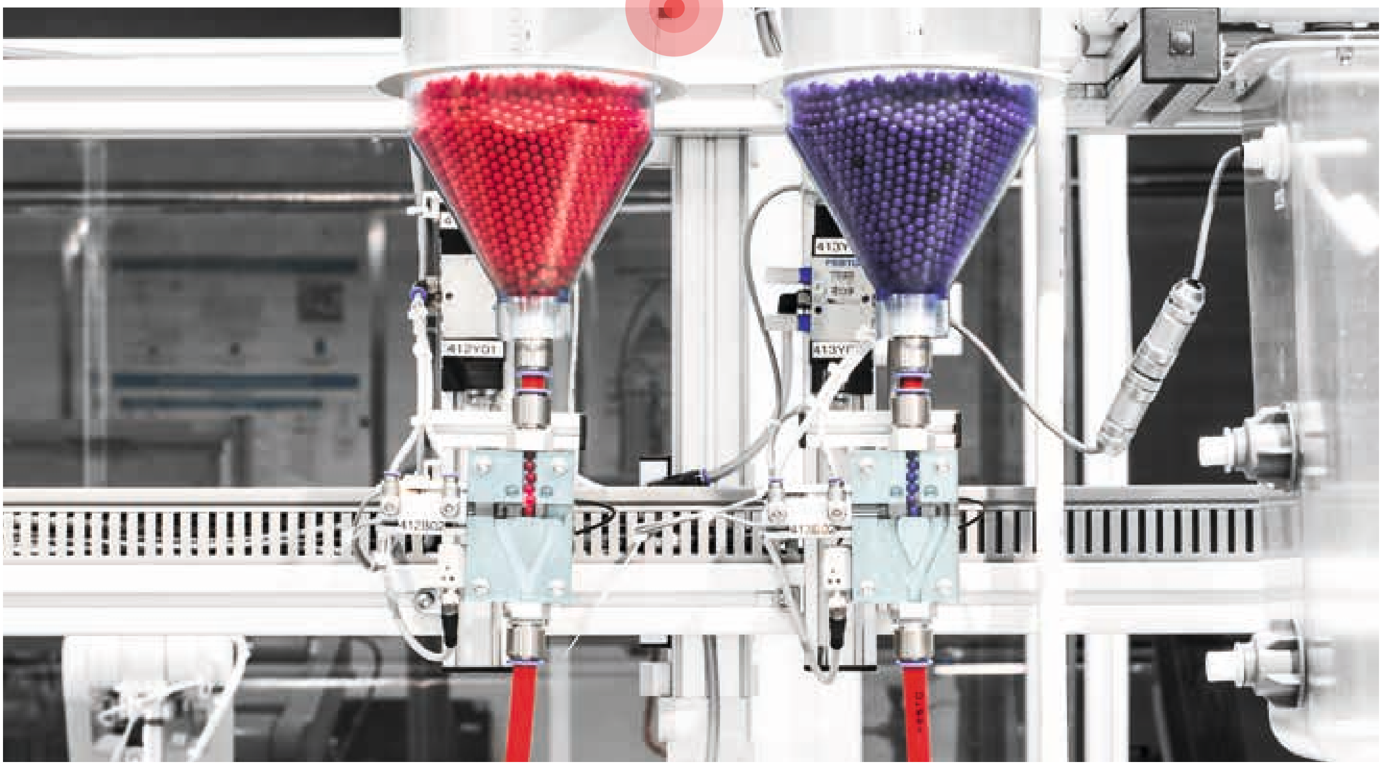
**MyJoghurt – a demo system for Industry 4.0**

The MyJoghurt demonstrator is intended to showcase the possibilities of Industry 4.0 and how they can best be leveraged. A key focus lies on networking geographically distributed production facilities which may even belong to different companies. This way, the filling unit may collaborate with the packaging system or purchasing organization on an automated basis, for example. MyJoghurt consists of a yogurt filling system located at TUM, a yogurt processing facility in Magdeburg and another one in Stuttgart, a lid labeling facility in Hamburg and other, virtual systems run by various partners. Prof. Birgit Vogel-Heuser was responsible for initiating and setting up MyJoghurt, with five other research partners also participating while the project continues to grow.




Graphics: ediundsepp; Picture credit: Bauer

## Material supply
**with metering device**



## Robotic arm
**picks up containers and places them onto belt**

## Beyond digital Babel

But why is that, in fact? Vogel-Heuser doesn't need asking twice. She knows the situation on the ground. For ten years, she was involved in plant engineering herself, and she has worked with industry partners on dozens of projects as a researcher. "Within an enterprise, there is often no clear semantics of communication between production units. Conveyors and scanners, filling equipment and packaging machines all come from different manufacturers and use diverse control systems." She explains that there often isn't even a seamless flow of information within the engineering, meaning the overall technical solution comprising electronics, software and mechanics: "The conveyor belt controller doesn't know, for example, when the motors have reached their load limit because design data the plant engineer created in a CAD tool is not compatible with the tools used by the electrical engineers. And these, in turn, are not recognized by the tools supporting software design."

A survey of sixteen German plant and machine manufacturing companies conducted by Vogel-Heuser and her team also bears this out. Many companies work with equipment acquired over time from a variety of manufacturers. The manufacturers themselves, after decades of operation, are often not adequately informed about which software their customers are using. Similarly, they do not know to what extent the customers modified the programs or even the hardware that they supplied. "Changes within production lines thus tend to be extremely complex," reports Vogel-Heuser. "Integrating a new component in an existing production facility means determining the current version of the old software, then adapting the interface before finally importing the new software." And identifying the system's previous software status is frequently no easy matter. Some solutions evolve several times over a longer period and manufacturers often only maintain very rudimentary variant or version management. "Some systems have been running for a good thirty years," Vogel-Heuser points out.

Her aim is to remove these barriers and pave the way for workflow and system efficiency at both the engineering and operational stages – not only in factories, but also among suppliers and service providers. "In the long term, for companies to hold their ground in the face of global competition, they will have to adapt quickly to new market requirements," forecasts the engineer. "To do this, we need a seamless flow of information and plants that can process incoming orders as autonomously as possible. Since product cycles are also becoming ever shorter, systems either have to adapt automatically or allow for rapid reconfiguration and redesign."

Picture credit: Bauer

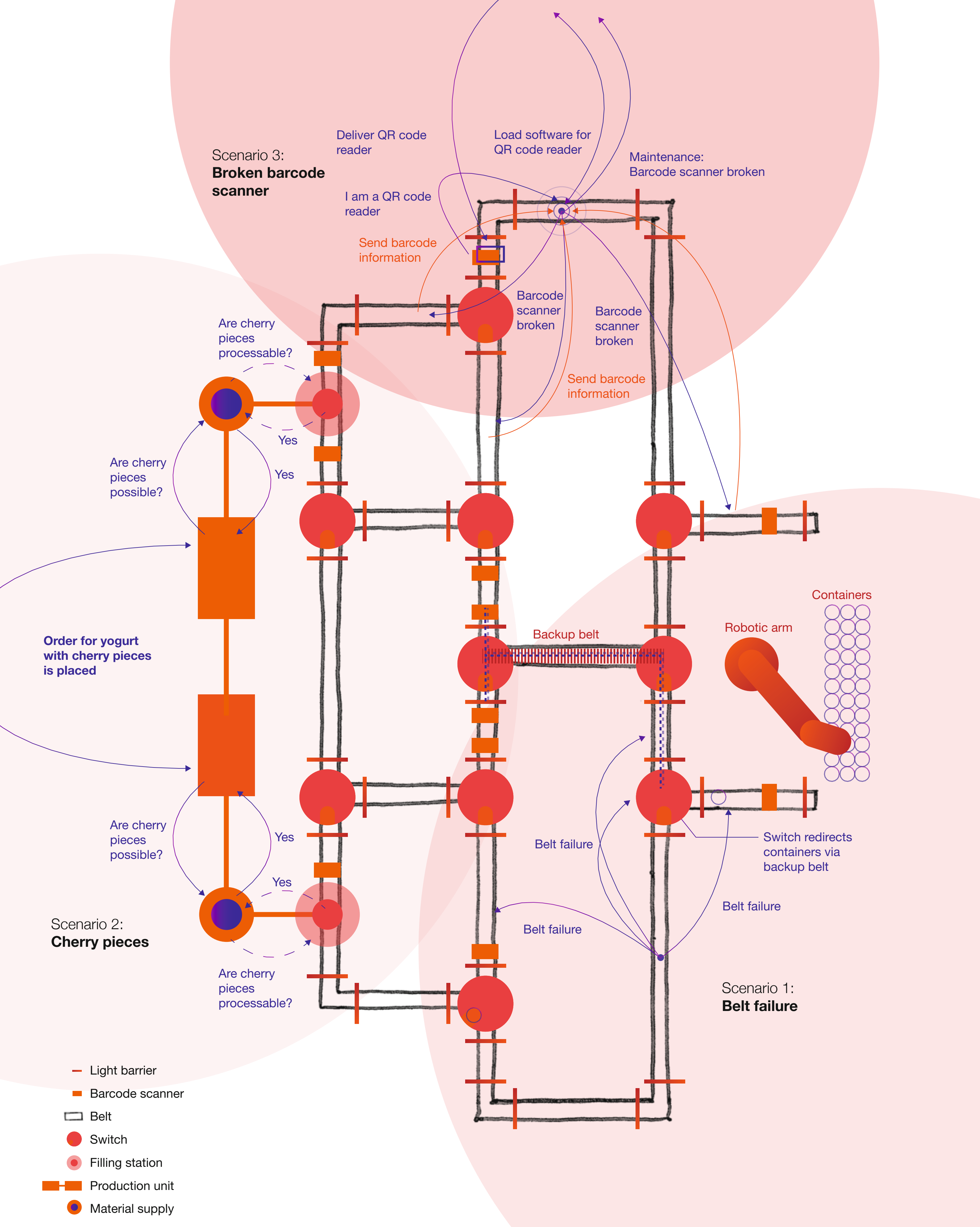
*"We can run software updates and even replace components with new ones featuring different connectors in live mode without needing to completely shut down the whole system. As it stands, that is almost impossible in current industrial production plants."*

*Birgit Vogel-Heuser*

## Intelligent modules

The key to success here lies in a modular approach, Vogel-Heuser is convinced. A module is a self-contained unit – in the MyJoghurt demonstrator the robotic hand, scanner and conveyor belt are, for example, independent modules. Within any given module, all the information relating to its tasks – technical data, operating data, programming – is available at all times. This becomes possible when mechanical engineers, electrical engineers and software developers all use a common description with defined semantics. This allows information to flow freely between the different disciplines of both a single module or a combination of modules. The module is aware of its own capabilities and knows when its limits are reached.

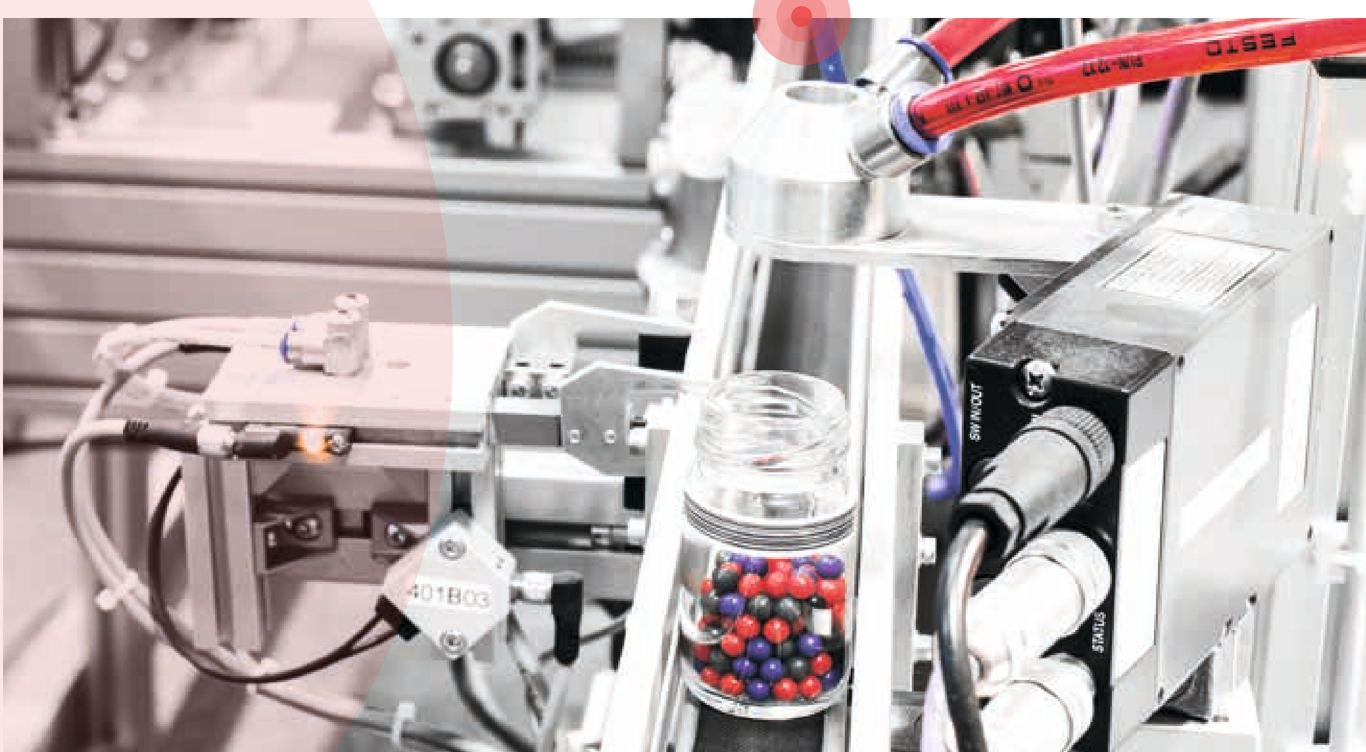
Modules can thus work together to make intelligent decisions. While the yogurt filling system is still adding chocolate chips and strawberry pieces to the jars, for instance, the system can check the next incoming order. Say a customer would like yogurt with cherry pieces. The first thing is to determine whether the system can process the relevant in- ▷



Scenario 3:
Broken barcode scanner
Deliver QR code reader
Load software for QR code reader
Maintenance: Barcode scanner broken
I am a QR code reader
Send barcode information
Barcode scanner broken
Barcode scanner broken
Send barcode information
Are cherry pieces processable?
Yes
Are cherry pieces possible?
Yes
Order for yogurt with cherry pieces is placed
Containers
Robotic arm
Backup belt
Are cherry pieces possible?
Yes
Yes
Belt failure
Switch redirects containers via backup belt
Belt failure
Belt failure
Scenario 2:
Cherry pieces
Are cherry pieces processable?
Scenario 1:
Belt failure
Light barrier
Barcode scanner
Belt
Switch
Filling station
Production unit
Material supply

Switch
**with light barriers**

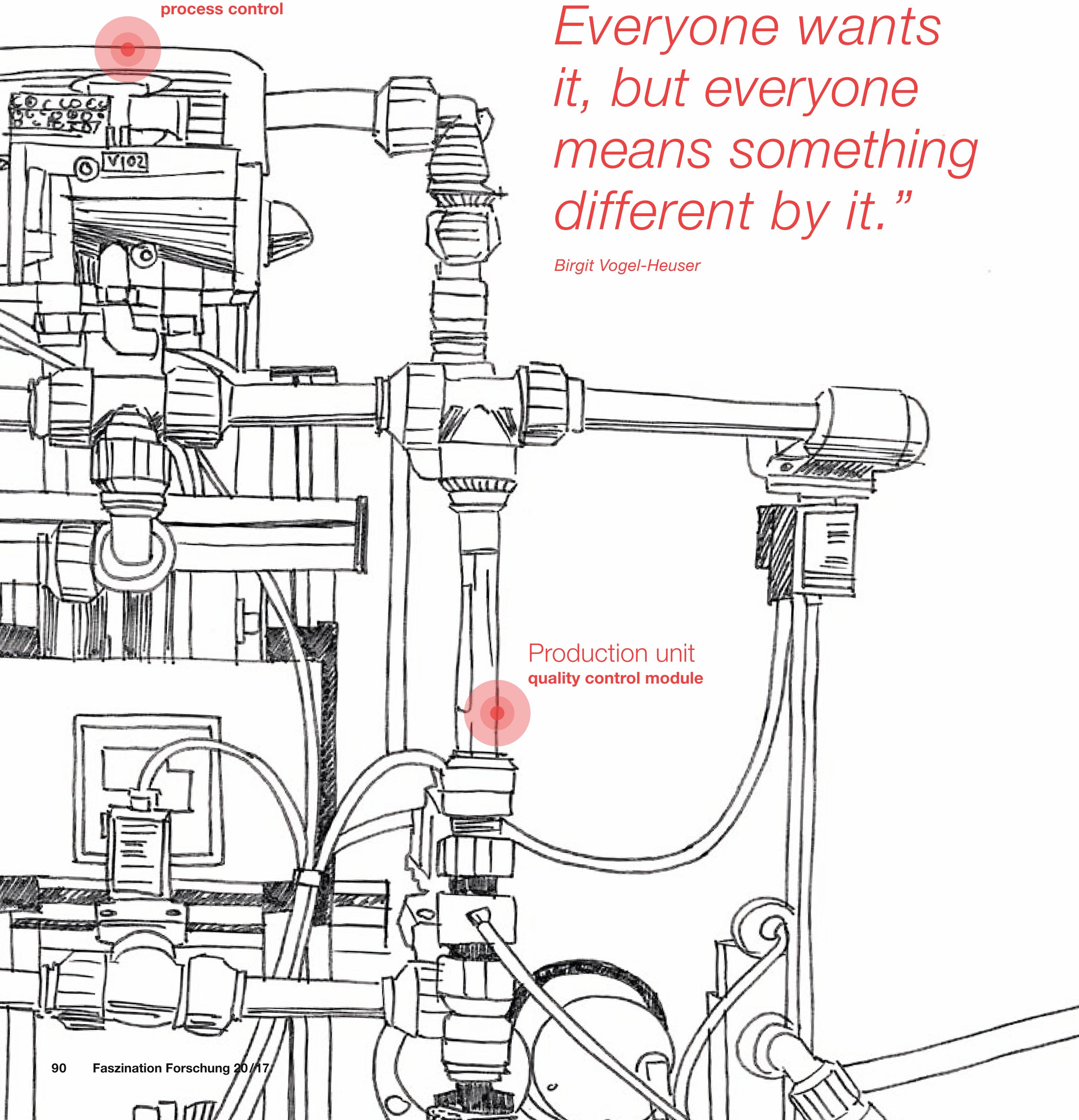
Filling station
**with mixing unit**



Graphics: ediundsepp (source: TUM); Picture credit: Bauer

*"Industry 4.0 has now become a buzzword. Everyone wants it, but everyone means something different by it."*

*Birgit Vogel-Heuser*



**Prof. Birgit Vogel-Heuser**

## Interdisciplinary from the outset

Birgit Vogel-Heuser likes to bridge boundaries – both geographical and, above all, technical: “We can only advance Industry 4.0 with an interdisciplinary approach.” Indeed, she has constantly crossed the borders between various disciplines in the course of her own career. Having earned her degree in electrical engineering at RWTH Aachen University, she then transferred to the Faculty of Mechanical Engineering to pursue a doctorate focusing on software-oriented automation. She thus laid the foundations early on for the triad of mechanical engineering, electrical engineering and information technology that still informs her research today.
After obtaining her doctorate, Vogel-Heuser spent ten years in industry, working first with Siempelkamp Group and later with ATR Industrie-Elektronik. Alongside this, she established the Automation Technology professorship at the distance-learning University of Hagen (FernUniversität Hagen). She then made the leap back into research in 2000, first becoming Chair of Automation Technology and Process Informatics at the University of Wuppertal (BUW). She then held the Chair of Embedded Systems at the University of Kassel from 2006 to 2009, before moving to Munich in 2009 to take up the Chair of Automation and Information Systems at TUM.
In recognition of her work, Vogel-Heuser has received the Adam Opel Award, the GfR Sponsorship Award, the Borchers Medal from RWTH Aachen, and the Initiative D21 Special Award (“Get the Best”).
Vogel-Heuser is spokesperson for the German Research Foundation’s Collaborative Research Center 768: “Managing cycles in innovation processes – integrated development of product service systems based on technical products”, a member of the Deutsches Museum Board of Trustees, and a member of the German Academy of Science and Engineering (acatech).

gredients in the first place. The size of the cherry pieces is automatically compared with the diameter of the filling tubes. “For us humans, that is simple and straightforward, but it can lead to problems with machines – for instance if the supplier sending the cherry pieces provides measurements in millimeters, while the tube diameter is stored in inches. But defined semantics clears this up, by providing a common understanding,” emphasizes Vogel-Heuser. The next step is to check whether all ingredients will be available in the right time frame, and whether the capacity of the robotic hands and conveyor belts is sufficient to carry out the order on time. All of this must be ensured before the order is accepted. Thanks to defined semantics, communication between the demonstrator’s modules, even newly added ones, is available in real time and reliable. Special software agents take care of this coordination in real time, while the plant is running. If a component – such as a filling level sensor – is updated with a newer version, each module recognizes the new hardware from the information available and integrates it automatically. But what happens if a new yogurt variety is to be produced and the system’s software has to be modified to allow it? Can approaches be developed here that could be used in similar systems around the world? Vogel-Heuser is currently working with industry partners and as part of a German Research Foundation (DFG) priority program to develop targeted methods for evolving software over decades. These efforts center on optimized module structures to enable systems to adapt with as little effort as possible to new requirements and thus, ideally, continue to evolve themselves. In her TUM institute, a demonstrator set up in Vogel-Heuser’s lab shows how this might work, with a conveyor belt transporting boxes past an old-style barcode scanner. “Here, we have created a scenario that corresponds to actual practice in intralogistics,” explains the engineer. “Our aim was to replace the old scanner with a new one without interfering with system functionality of the logistics system.” This relies on a clever trick: “Taking the old software interface as our basis, we developed a new one that is outwardly identical. So the software works as a kind of adapter, ensuring that the system doesn’t even notice that a component has been replaced and updated.”
These new Industry 4.0 solutions certainly work well in the lab. But how long will it take for the modular concept to catch on in the real world? “Looking ahead, Industry 4.0 is coming one way or another,” responds Vogel-Heuser. “But the road to intelligent plants and equipment is rocky, so we need to move forward slowly and surely. We always need to consider each individual scenario and look for solutions together with the company involved – there is no quick fix.” That said, German companies, in particular, have a good chance of benefitting from the new research findings sooner rather than later: “There is no country where research and industry are more closely intertwined, or where findings are transitioned to concrete applications more quickly.” *Monika Weiner*

Graphics: ediundsepp; Picture credit: Bauer

# E-bikes and the domino effect

*"This example shows what enormous reach innovations can have."*

*Birgit Vogel-Heuser*

What happens when customers want to cycle further? The electric bike rental case study shows how complex the interplay between innovations, businesses and consumers can be. Let's say a rental service offers electric bikes with a range of thirty kilometers. But an increasing number of customers want to ride longer distances. An ambition with far-reaching consequences: First, the rental company contacts the e-bike supplier. They determine that their batteries are not powerful enough. As a result, they need to switch to a different battery technology. This, in turn, also changes the way the battery is mounted to the bike, as well as the interfaces between mechanics, electrics and software. And the battery production facility has to be reconfigured for the new technology. As soon as the batteries are delivered and attached, the bike software needs updating to provide customers with information about points of interest in their new, extended surroundings. The hitherto successful companies which provide the pick-up service may now also prove unsuitable, since more vehicles with greater capacity are required to collect the bikes. "This example shows what enormous reach innovations can have," explains Prof. Birgit Vogel-Heuser, spokesperson for the German Research Foundation's Collaborative Research Center 768: "Managing cycles in innovation processes – integrated development of product service systems based on technical products". The researchers set out to represent the interdependencies between service providers, products, and production facilities in the different models. Using these models to run through a wide variety of scenarios allowed them to find the best solution for the overall offering, spanning both the bike itself and accompanying services – in other words, the complete product service bundle. The identified dependencies between the different models are then presented to the decision-maker – such as the rental service. This familiarizes them with the factors and levers leading to the suggested solution and significantly boosts their confidence in the outcome. The researchers have developed a special visualization method showing how small changes – like customer demand in bike rental, as outlined above – result in a domino effect spreading through the entire system. Projecting these interactions beforehand allows businesses and service providers to cooperate in advancing the necessary innovation cycle, to their mutual benefit.

This is no mean feat, since each innovation cycle involves dozens of stakeholders, all with their own approaches. The software engineer sees things differently to the electrical or mechanical engineer – they each have a different mindset. "In the Collaborative Research Center, we are working to make these mindsets underlying the various fields more transparent," confirms Vogel-Heuser. "There are often semantic issues – different terms used for the same idea, or various ideas referred to by the same term. Only once we are aware of these differences can we reduce misunderstandings and work together to find solutions."


**Longer distances for rental e-bikes requires larger batteries,** new interfaces between mechanics, electronics and software. Visualizing the interactions between involved businesses helps to anticipate how an innovation will affect the whole system.

Picture credit: Bauer