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At the end of the line

How automakers can embrace flexible production

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EXECUTIVE SUMMARY

The automotive industry is currently undergoing the greatest transformation in its 100-year-plus history. Customer demand and regulatory pressure mean the number of electric vehicles made, including hybrid models, is expected to increase[1] by 466 percent by 2027, and cars will become increasingly autonomous and offer more connectivity. The setback to car-sharing and ride-hailing services caused by COVID-19 will be temporary, and we expect shared vehicles to account for around one-third of the market in Europe by 2030 and a greater proportion in the US and China.

At the same time, profitability is being squeezed: Investments in electric and autonomous cars need to be made, yet sales at the world's biggest carmakers are expected to fall[2] by between 13 percent and 24 percent in 2020 as a result of the pandemic and ensuing economic shock.

To keep pace with all these changes, automakers (OEMs) and their suppliers must invest to transform the way they make vehicles. In our 2018 analysis of the market[3] we identified two distinct production models that will be required: First, highly automated "plug and play" plants producing almost identical mass-market vehicles, predominantly for car-sharing services; and second, the "flex champion" – technologically-advanced flexible plants producing high-end, driver-owned customized vehicles.

1. https://www.strategyand.pwc.com/de/de/studien/2020/e-mobility-sales-review-q3/e-mobility-sales-review-q3.pdf
2. https://www.strategyand.pwc.com/de/de/studie/2020/zuliefererindustrie.html
3. https://www.strategyand.pwc.com/de/de/studien/2018/transforming-vehicle-production/transforming-vehicle-production.pdf

> "In the near future, premium OEMs can only survive if they incorporate flexibility as new imperative for factory design – digitization and a set of basic technologies will be essential enablers for the flex champion factory."

In this study, we will focus on the “flex champion” because the need for greater flexibility has accelerated. There is growing demand for a range of engine technologies, for new models to be available faster, and for customized models to be delivered more quickly. There is also supply-chain uncertainty due to trade tensions and the disruption caused by COVID-19 lockdowns. Both highlight the need to be able to respond quickly to unforeseen shocks. Our key findings are:

- The current trend towards more models and the mix of electric and conventional powertrains means machinery that can only be used for one distinct group of models is not being used to its maximum capacity, making it less economical.

- Technology that enables OEMs to meet these demands has matured to the point that it is affordable, shifting the balance between the cost and the benefit of flexibility.

- Assembly lines will be less important and may disappear from flexible factories. Instead, car bodies and components will travel along individual routes, in a flexible sequence, to modular assembly stations that can be configured to carry out the task at hand. Materials will be ordered and delivered using self-organizing automated systems.

- The current production order-control principle of sequencing (‘pearl chain’) also comes to an end in the flexible factory – new forms of more autonomous, self-organizing order control are required.

- OEMs that are already making some new models in this way say investments are paying for themselves within a year and help to speed up production (case studies below).

In this study, we will look at the technology behind “flex champions”, as well as two of these factories in production at Porsche and AMG in Germany. We will explore how OEMs can achieve three different types of flexibility: Variant flexibility, which enables manufacturers to produce as many different models as possible on one line; volume flexibility, the ability to handle a wide range of production output in an efficient manner; and changeover flexibility, which makes it possible to change a line from making one series to another within a few days. Volume and changeover flexibility are growing in importance due to supply-chain and market uncertainty.

There have long been various concepts for small-scale, flexible production, however the technology to do it at scale is now available and more affordable. One of the key elements we will look at is driverless transport systems to move parts and vehicles around the factory, replacing a fixed assembly line. Historically, they have been associated with high cost, space requirements and complex control systems. However, they can now be equipped with more sophisticated artificial intelligence (AI) at far lower cost, enabling a high degree of autonomy.

We will also examine the design and technology of the control systems for highly automated and flexible factories. This includes the traceability of decisions taken by AI. Control concepts are also vital to expanding flexible production into the supply chain, with self-organizing systems ordering and delivering parts as needed, for example.

We aim to help senior operations executives assess the right degree of flexibility for their organization, and strike the optimum balance between the cost and the benefits of flexibility.

OEMs are spending more on production, but not in the most effective way

As OEMs weigh up the costs and benefits of making radical production changes to achieve greater flexibility, it is important to bear in mind the investments they are already making to keep pace with the shift towards new technologies such as battery and fuel-cell engines. In addition, OEMs are also adapting to more complex manufacturing and shorter lifecycles of new models. We analyzed spending on technical equipment and machinery at German OEMs between 2013 and 2018, and found spending outpaced production increases (*see Exhibit 1*).

EXHIBIT 1

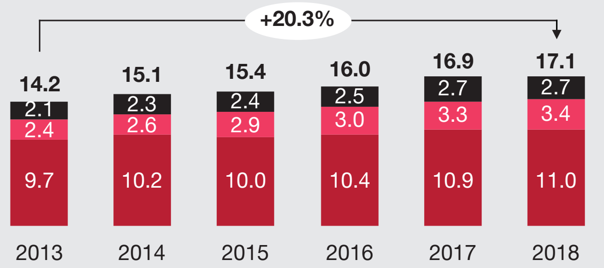
Increasing production volumes are accompanied by a disproportionally high increase of technical equipment and machinery

German car makers: Total vehicle production[1] and net technical equipment and machinery[2]

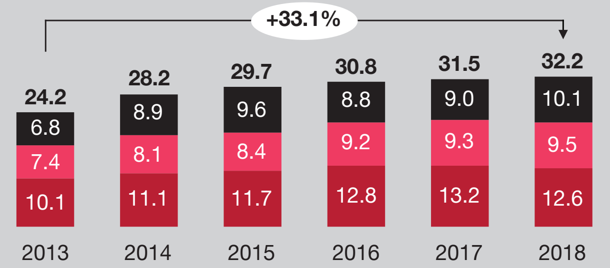
Between 2013 and 2018 total production (units) increased by 20.3% with a CAGR of 3.8% while technical equipment and machinery (in € bn) increased by 33.1% with a CAGR of 5.9% in the same time.

As a consequence, the financial value of technical equipment and machinery increased 50 percent more quickly than the number of vehicles produced.

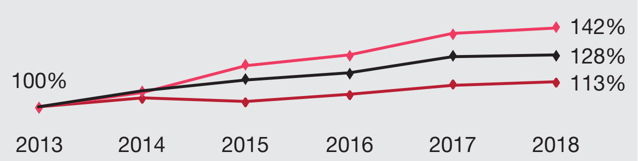
Vehicle production[1] of German OEMs (in mn units)



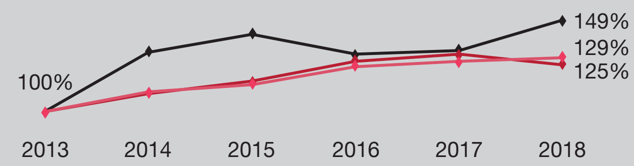
Net technical equipment and machinery[2] (in € bn)
Not adjusted for inflation



Indexed production of German OEMs (2013 = 100%)



Indexed technical equipment and machinery (2013 = 100%)



BMW AG | Daimler AG | Volkswagen AG

1. Including motorcycles for BMW AG; including trucks, vans and buses for Daimler AG
2. Carrying amount at end of year
Source: Annual reports from 2013, 2014, 2015, 2016, 2017 and 2018 from BMW AG, Daimler AG and Volkswagen AG, Strategy& analysis

The total number of cars in use in Europe is expected to peak in 2025, according to Strategy&'s Digital Auto Report[4]. If investments in technical equipment and machinery continue to increase, as indicated by the rising values shown in Exhibit 1, they will need to be paid for from a smaller number of vehicle sales, with a greater amount of variation within them.

So, can the money be spent more efficiently, to better equip OEMs to meet future market demand? We believe it can – with a greater variety of models being produced, inflexible conventional equipment will not be used to maximum capacity, resulting in further inefficiencies. Instead, more adaptable equipment and processes are required.

Below, we set out the potential changes to production models, the technology needed to do it, and the costs and benefits involved. We also look at OEMs that are already doing it successfully.

4. https://www.strategyand.pwc.com/gx/en/insights/2019/digital-auto-report.html

> A "flex champion" type of assembly is enabled by various elements of smart manufacturing – modular machinery, a flexible flow of the material, an AI-based production control with elements of self-organisation, and tools to support a flexible work organization."

Putting flexibility into practice

In the ideal “flex champion” factory, the key differences from the assembly-line model are modularity and flexible flow. Modular plants have no fixed installations: Workstations are mobile and can be adapted to the task at hand. Flexible flow makes use of driverless transport systems that deploy automated guided vehicles, or AGVs, to carry the car body itself, sub-assemblies or pre-commissioned parts to the assembly station and other equipment from station to station. Both concepts are underpinned by a self-organizing control system (*see Exhibit 2*).

EXHIBIT 2
Flex champion

Drastic change of job profiles towards higher qualified employees (massive reduction of classical “operators”/ logisticians compared to today and massive increase of job profiles around data science)

Fully integrated and digital manufacturing execution system (MES)

All assets are real time connected based on a digital factory twin, e.g. for predictive maintenance, performance management

Local Edge Clouds, virtually merging into a central Data Lake

Integrated, real time factory, material and logistics planning supported by control tower concept

CO_2 neutral factory – onsite energy production through renewables

Flexibility is key – assembly will be organized with assembly stations instead of an assembly line (no monuments!)

Self optimizing processes relying on parts dimensions as input and machine learning

Source: Strategy& analysis

Modularity

The core idea is to install machines and systems that can be used to carry out the full range of production and assembly tasks, instead of specialized production facilities, some of which require their own infrastructure, e.g. monorail overhead conveyors. Modular ways of working also dispense with special installations on the hall floor or on a conveyor system.

Instead, production systems are configured to carry out manufacturing or assembly tasks and can be quickly reconfigured for new tasks if necessary. This naturally requires versatile hardware, e.g. robots and robotic manipulators, but above all, it needs suitable control technology, including software and communication technology (*see Exhibit 5, page 12*).

It is not necessary for a complete assembly line to be modularized in this way – the overall goal is to use flexibility where it is advantageous, in a system with a directed rather than an entirely free flow. Assembly modules are only implemented where it is technically and economically possible and beneficial. They make sense for tasks where the amount of time taken varies considerably depending on the model variant that is being built – the roof of a convertible compared to the roof of a standard model, for example – or where further variants, e.g. new powertrains or levels of automation, can be expected in the foreseeable future.

Flexible flow

A key element of flexible production sites are automated guided vehicles (AGVs), which can now be equipped with greater amounts of artificial intelligence, enabling a high degree of flexibility. Conventional conveyor systems are struggling to cope with the greater range of time it takes to complete different models. Sometimes mechanics are standing idle waiting for colleagues to finish at the previous station, or logjams build up after tasks completed faster than average. When the material flow is organized by AGVs, each car body takes an individual route through the assembly hall via different stations. Each station is replenished by AGVs delivering pre-picked baskets of parts.

Achieving this requires continuous online tracking of car bodies, parts and the AGVs transporting them, as well as new forms of decentralized manufacturing control. This allows each AGV to “decide” its own optimum route, instead of a centralized control system coordinating the overall flow of vehicles.

Conveyor technology on several floors, as in today’s car factories, becomes unnecessary, and track-bound vehicles are being largely eliminated. Today’s mostly outsourced logistics, with external supplier warehouses, supermarkets, route trains to supply the conveyor belt and Kanban racks on the belt, will be replaced with sets of parts picked and put into baskets for each vehicle in commissioning zones, before being delivered by AGV to the assembly station.

Modularity case study: AMG M139

AMG's M139, the world's most powerful series-produced four-cylinder turbocharged engine, is assembled on a new, flexible assembly line in Affalterbach, Germany. Using a completely redesigned line, the Mercedes-AMG team has kept its "One Man, One Engine" manufacturing principle, in which a mechanic manufactures an engine completely by hand. But at the new plant, this way of working is combined with Industry 4.0 solutions.

The assembly line is completely free of racks, forklifts or route trains. Instead, freely movable assembly trolleys are used, and driverless transport systems carry all the parts to be assembled to the right place. Employees are able to change their position on the belt and even overtake other fitters. Fluctuations in the number of engines in the workshop can be dealt with by bringing in more or fewer employees, and new engines can easily be introduced. This type of assembly allows for maximum variant flexibility. It also opens up new possibilities in terms of volume and changeover flexibility.

"Variant flexibility was the top priority when planning the line," says Fabian Jenuwein of Mercedes-AMG. "Every euro we invested in flexibility has paid for itself after only one year."

The assembly trolley (*see photo below*) on which the M139 is built is an important component of the modularization. All the necessary tools and resources are organized in the most ergonomic way on and around the trolley, which makes work easier, minimizes distances travelled and increases efficiency. The integrated tablet computer supports the fitter with precise instructions in clearly understandable language. Order papers, manuals or guides can all be called up electronically, meaning the assembly process is paper-free. New cordless screwdrivers are immediately to hand and no longer need to be carried from station to station, attached to the hall ceiling by a cable.

Each fitter is followed by a driverless transport vehicle carrying a 'shopping basket' which contains all the parts needed to produce an AMG engine. The system guides itself through the plant with the aid of indoor tracking system. This means that the shopping basket moves autonomously to where the mechanic is currently working. The shopping baskets are filled up at the Mercedes-AMG Marbach Logistics Center and delivered to the production line "just in sequence".

The locating technology and pre-picking of the parts make the traditional pre-arranged, fixed sequence of tasks unnecessary. This allows flexible and efficient assembly of the different engine variants, and the throughput time is on average 20 percent shorter than on conventional assembly lines.

Assembly trolley and 'shopping basket' on an automated guided vehicles

Flexible flow case study: Porsche Taycan

The Taycan is the first purely electric Porsche. More than €700 million will be invested in establishing Taycan production in Zuffenhausen, Germany.

Three basic principles are at the forefront in the implementation of the smart factory – the "factory of the future": smart, lean and green.

Here, "smart" stands for versatile and intelligently networked production. A high degree of adaptability will be absolutely essential in the future due to constant changes in the mix of variants.

The new so-called "Flexi-Line" dispenses with assembly lines that are permanently integrated into the foundation of the building and relies on driverless transport vehicles (*see Photo below*) in the production of the Taycan, which allows major adjustments to be made without high investments simply by introducing new AGVs.

This type of assembly allows maximum flexibility in terms of variants and changes, and reduces investment costs.

"By using AGVs instead of the classic assembly line, we have created an important technical flexibility reserve. In the future, this will enable us to react more easily to major changes in factory layout or assembly sequence, or to implement flexible sequences in operational control," says Albrecht Reimold, member of the board of management of Porsche AG, responsible for production and logistics.

Lean end-to-end planned processes and systematic data consistency were important enablers for factory planning, which was mapped in a complete digital model from the very beginning.

The new production system also sets standards in terms of resource efficiency and sustainability, in line with the third basic principle: "green".

Automated guided vehicles

Self-organization

To transform production to a modular system with flexible flow, the technological control system must also change from a centralized to a decentralized one.

In our view, the communication technology and algorithms required for this are already available today. These tools enable self-organization by creating a detailed digital ‘map’ of all the physical processes, assets such as tools, and modular assembly stations, so all parts and processes are in communication.

The “flex champion” vision includes using reinforcement-learning algorithms to enable autonomous, decentralized decision-making, either on the shop floor or in the supply chain. Depending on the scenario, the algorithms can perform combinatorial detailed scheduling or optimize worldwide supply relationships, while taking into account uncertainties and risks.

So rather than production planners deciding days in advance what will be made in the factory during a particular shift, with no possibility of changing that even if there are delays in deliveries or changing sales patterns – or deciding which machine will be used for a task on a particular day – AI-enabled decision making uses real-time data to decide on the optimum use of production facilities. This makes planning cycles much shorter and more responsive, ensuring the most efficient use of employees’ time and of equipment and materials.

Distributed decisions are also possible: Each participating agent – which could be a person or a piece of software – has a local action space in which to observe the system status and make changes. The agents act co-operatively and work to deal with unexpected changes faster at a local level, instead of searching for a global optimum.

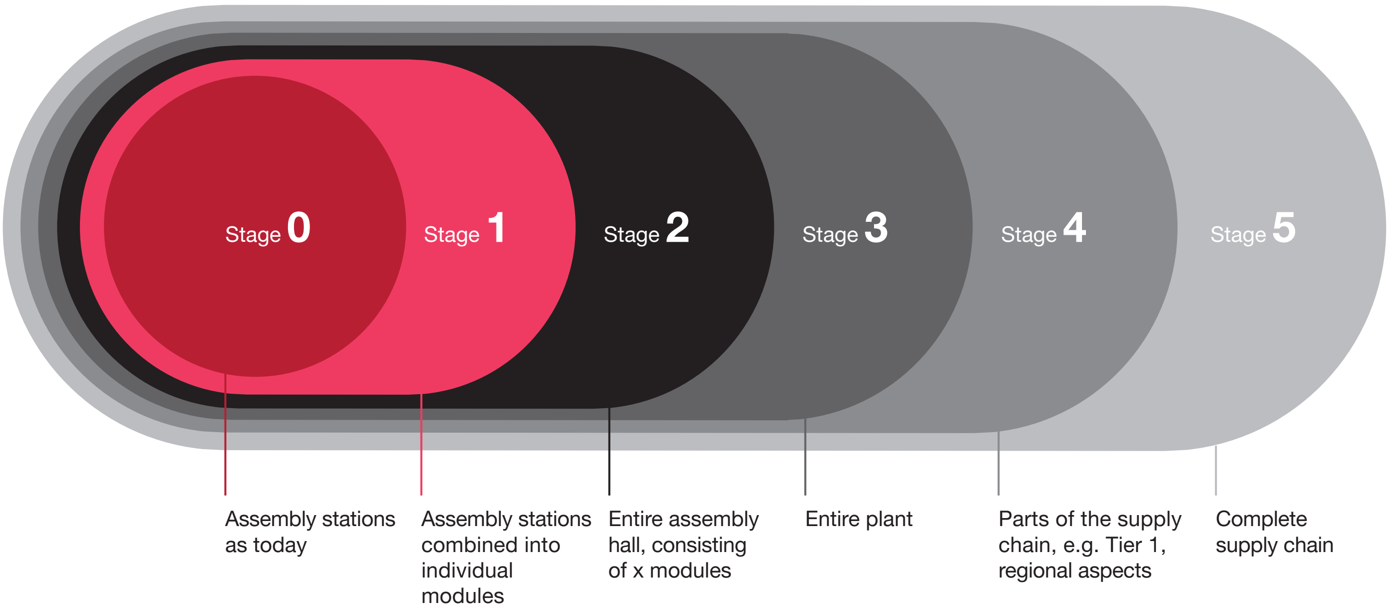
Self-organization could be scaled up to cover a whole production facility, from the moment parts are delivered to the time the completed car leaves the factory. It can also be used in defined areas of the factory or for specific tasks, and this is close to becoming a reality in many assembly plants.

The role of suppliers

It is important to note that becoming a "flex champion" will impact supplier relationships. We expect suppliers to take an increasing share of value in this model, supplying greater numbers of entire modules, such as the front end of cars, also on a "just in sequence" timeline. As a result, there will need to be greater sharing of information and materials between OEMs and suppliers. Modules will need to be able to communicate with the OEM's control system so they can be located and traced along the flexible manufacturing route described above. Suppliers may also become directly responsible for module assembly inside the OEMs' shops (*see Exhibit 3*).

EXHIBIT 3

Stages of flexibility

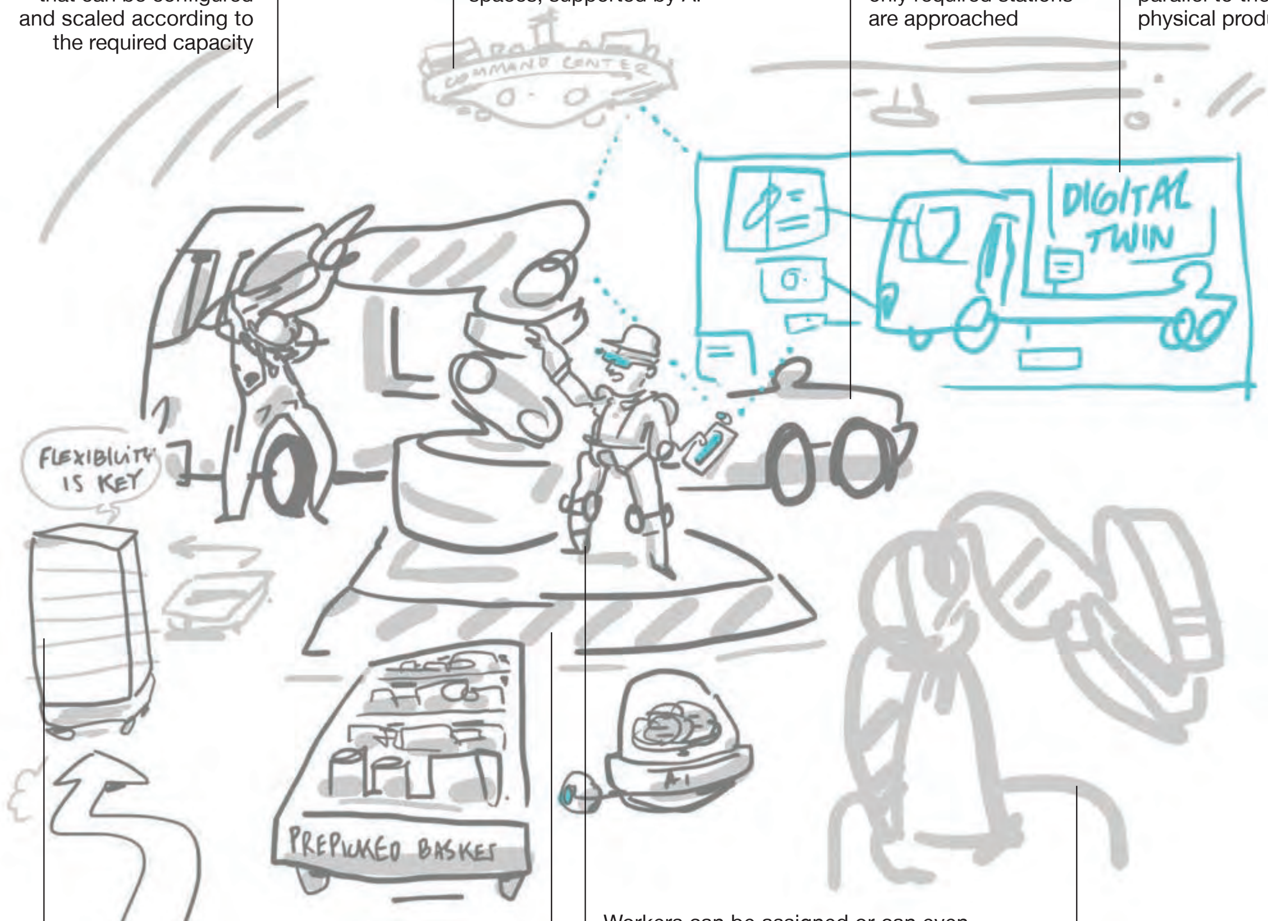


Source: Strategy& analysis

Our vision for the flex champion of the future

EXHIBIT 4

Our vision for assembly



Source: Strategy& analysis

EXHIBIT 5

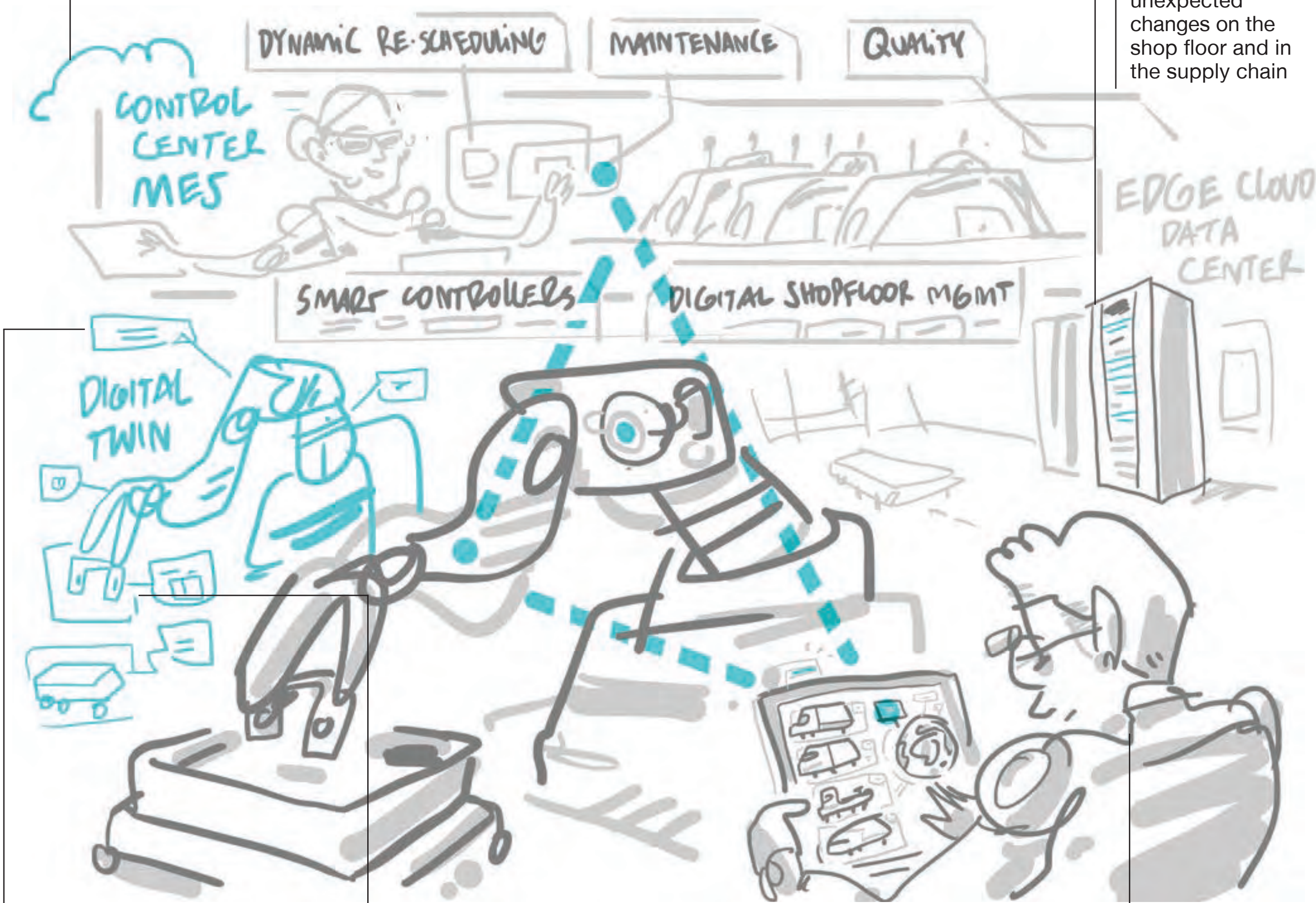
Our vision for a factory control center

Interoperable enterprise resource planning (ERP) and manufacturing execution services running on platforms enabling data sovereignty in accordance with GAIA-X in the supply chain

Indoor and outdoor identification, localization, and tracking of raw material, parts, and car bodies, e.g. via 5G

Decentral communication between equipment, machines and IT-tools, e.g. via OPC UA and interoperability enablers

Online scheduling, simulation, and swarm intelligence supported by artificial intelligence and machine learning to react and predict unexpected changes on the shop floor and in the supply chain



Digital asset management all assets are real time connected based on a digital factory twin e.g. for predictive maintenance, performance management

Digital twin of the factory

Edge Cloud data centers allowing real-time processing and fusion of any type of sensor and machine data based on a standardized semantic

Source: Strategy& analysis

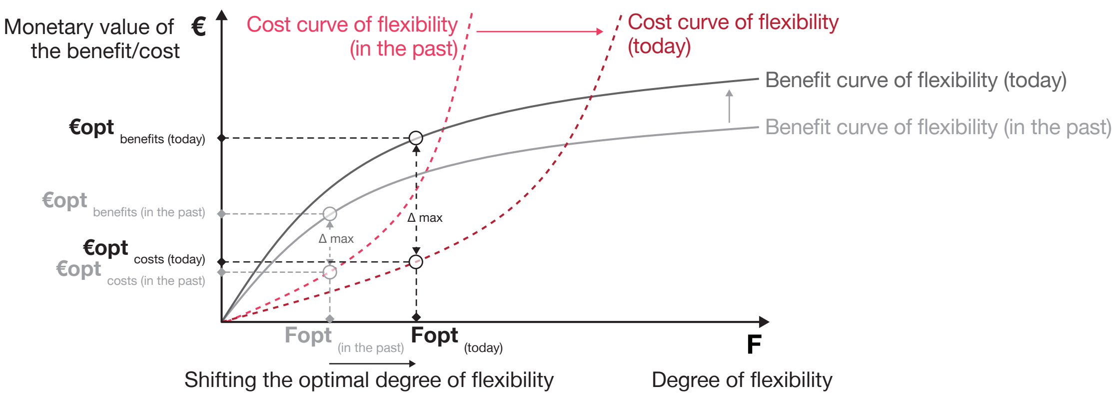
SECTION 3

Assessing the benefits, costs and added value of flexibility

The flexible approaches described above hold considerable promise for OEMs and suppliers as they seek to respond to a transforming market. However not everything that is technically feasible is economically viable. The following chart shows how the benefits, costs and added value of flexibility are changing over time (*see Exhibit 6*):

EXHIBIT 6

Added value of flexibility



Source: Strategy& analysis

Our assumption is that there is an optimal degree of flexibility where the difference between benefits and costs is maximized. As the benefit and cost curves have changed over time, the optimal degree of flexibility has also shifted and will continue to do so. Accordingly, production must be further adjusted to achieve this optimum. In order to find the way to the optimal degree of flexibility, OEMs must therefore ask themselves three questions:

1. What benefits does flexibility bring me?
2. What costs are associated with flexibility?
3. What degree of flexibility does my company have?

In the rapidly transforming mobility market, greater manufacturing flexibility is key, especially at the high end, where customers expect greater choice and a faster turnover of new models. Introducing greater production flexibility in advance of launching new models is indispensable for established OEMs – after all, new competitors don't have the overhang of long-term investment in existing sites, but have the luxury of a relatively blank page.

Yet established OEMs have shown they can work in this way with great success, and changes in the cost and benefit curves mean all automakers have the opportunity to make their equipment spending more effective with greater flexibility.

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