enterprise iot insights

report series

DIGITAL FACTORY SOLUTIONS:

industrial LTE &5G

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how incoming cellular technologies will transform smart manufacturing

by James Blackman

Editor, Enterprise IoT Insights

KPMG

Everything inside the factory of the future will be fluid, except for the floors, walls, and ceilings. Industrial assets – including machines, devices, and vehicles – will be animated by 5G networks and made intelligent by edge and cloud analytics. Factory owners will be able to swap-around their production lines to meet changeable demand.

So says German industrial giant Bosch. The concept is plain, of course: factory operations have come full circle, from craft production in the first industrial age, through mass production in the global age, and a new compulsion towards hyper-customisation and the idea of a 'lot-size of one'.

"That's the vision – that the customer tells us what to produce, whether it's more umbrellas because it's raining, or a new shampoo because a celebrity's using it," says Stefan Bastian, global director of sales and marketing at Bosch.

The idea is the whole supply chain – from the sales channel, through the production line, back to the source – wags in response to demand, whether for a sudden surge or a single SKU. But this contradictory trend towards both greater individualisation and greater productivity pulls production in two directions at once. How can manufacturers, in the middle, respond?

Bosch is betting on 5G as a means to connect reconfigurable production systems, which can be torn up and down according to real-time analysis of demand, itself driven by LTE and 5G systems in combination with edge compute and machine learning. But, actually, this concept of a fold-away factory is just one version of industrial revolution.

Car maker Audi is pursuing a variant that hinges on an equivalent principle of "modular assembly". The assembly line is dead, it reckons. "You need to think in extremes to make technology possible," comments Henning Löser, head of Audi's production lab.

Audi wants 'assembly islands', instead of assembly lines. Increasing model diversity is hard to master in a rigid process, it reasons; a fixed tempo leads to inactivity on certain sections of the line, typically engaged for 'optional extras' on a small proportion of cars. These losses accumulate, especially as factories engage in more heterogeneous production.

Its concept breaks the line into production stages, attended by a couple of workers and served by automated guided vehicles (AGVs), which bring the car pieces to the relevant stations in an orchestrated loop – so AGVs arrive in and out of sequence, so long as the build allows and the space is available.

"Rapid-transit cellular networks and beefy edge-compute functions create a new digital platform for factories to cascade performance gains into smartly-orchestrated supply chains"

The conveyor belt vanishes altogether, and the 'line' concept goes with it. Unlike with Bosch's vision, the work stations are fixed, and wired with ethernet. It is a nearer-term view, in practical development already; Audi has been testing at a battery plant in Brussels, in Belgium, and an engine plant in Győr, in Hungary.

At the same time, it is a staging post on a rapid innovation path. 5G is required in order to make it work. "We can't run lots of AGVs on wi-fi – that's where cellular will help," says Löser. It may yet mutate into a free-form Bosch-style arrangement, he says. "Once the wireless network is there, with the right availability and throughput, we don't need cabling anymore."

Nokia offers a third vision, and a wider-screen view, which considers the broader economic impacts of smart industry, imagined in the twin factory scenarios from Audi and Bosch. It ties-in, as well, with other functions in the industrial supply chain, as described in the umbrella / shampoo example. The point is faster production will bring manufacturing home again.

Rapid-transit cellular networks and beefy edge-compute functions create a new digital platform for factories to cascade performance gains into smartly-orchestrated supply chains. "The idea is to be more productive, more efficient – to have better services," says Manish Gulyani, vice president of enterprise marketing at Nokia.

The dream is to reverse the migration of industrial work to cheaper labour markets, and to make businesses distinguished and profitable because of its products and manufacturing. "If I bring technology into play, it becomes less about labour arbitrage and more about tech innovation," says Gulyani. "That's the big story; that's what is supposed to happen – that we can go beyond how we've done it for 30 years, to make it smarter."

Fold-away factory – the Bosch vision of future factories sees everything in motion, except the walls and ceilings; the above image shows the company's Hannover Messe 20-19 demo of AGVs and AI 'assistants' powered by the floor itself

€1bn
per annum – Bosch's Industry 4.0 sales target by 2022

THE FUTURE IS WRITTEN

Cellular is written into the future of industry, then. But what about today? How should factories make use of LTE and 5G technologies, now? Because this 'fourth industrial revolution', leveraging various comms-and-compute combinations, is not new. Just ask Bosch. The German outfit has earned €1.5 billion in four years from the implementation of so-called 'Industry 4.0' techniques. It has an incremental revenue target of €1 billion per annum by 2022 from supplying these inside and outside of its own facilities. "Industry 4.0 pays off," says Rolf Najok, board member at Bosch.

The company started connecting its manufacturing and logistics back in 2012. Its plant at Blaichach in southern Germany has increased production volumes for antilock braking system (ABS) units by 200 per cent in six years, without expanding or buying facilities.

Bosch has flowed its new factory-tech through its supply chains, as well. "Manufacturing and logistics have to be thought of as one element. This is the only way for Industry 4.0 to succeed in practice," says Najork, raising the umbrella/shampoo scenario again. It seems like Bosch has cracked it, and yet it has made ground with little or no

Industrial network control: *Whose line is it anyway?*

"5G gives carriers a chance to reinvent themselves. They're still focused on consumer 5G and beating their competitors. [But] behind closed doors, they want to capitalise on private LTE and 5G in the enterprise space. Consumer 5G is too costly; the returns will take too long. They won't have the same issue with enterprise 5G, and will demonstrate incremental value to customers.

"Some carriers will offer 5G as an enterprise solution, and some enterprises will manage responsibility themselves, just as they have managed their wired and wi-fi networks. In the end, it will be a mix, but operators will have a clear role.

"Some smaller enterprises may want control and some bigger players may want operators to manage it for them. Running private 5G in a single plant won't be so different from running a localised wi-fi network, whereas a manufacturer with 40 plants across a large geography will find it much harder – and probably require a whole organisation to operate the network. So there is justificaton both ways. The 'bigs' might do it themselves, and the 'smalls' might too. There's not enough clarity, yet, to know which way it will go."

Greg Corlis, National IoT Leader, KPMG

cellular connectivity at all.

It is not the only one. Audi's parent Volkswagen said last month it will build its own 5G networks from 2020. But Audi's experiments with industrial-grade cellular are just that: lab tests, in anticipation of step-by-step cellular deployments.

"Right now, our equipment is all connected. Period. Where it's moving, it is running on wi-fi – and we have an actively managed wi-fi network with dedicated channels and slices to work around the limitations of wi-fi, and have high availability throughout our factories," says Löser.

But manufacturers, we hear, are at the limits of even the most highly-tuned wi-fi networks. Is that the case with Audi? "Yes, definitely," Löser responds, stating as well that wi-fi is pushed to keep pace with the security demands of industrial computer connectivity.

"If you want to run PROFINET over wi-fi, it doesn't really work. You can't rely on a security message being routed in a 10 millisecond range, say – so something turns off. If you open a gate to enter a robot cell, you want to be sure the robot stops. These things rely on cabling now."

Consultancy KPMG reckons cellular, at large, has failed in factories. Ethernet is the go-to technology for critical communications, wi-fi is the compromise for moving parts, and cellular remains a public network on the fringes. Cellular has been tested, and found wanting, it says. "It is quite limited within the manufacturing floor today," says Greg Corlis, national IoT leader at KPMG.

"It's been tried, from 2G through to LTE. There's a lot of interference in these large manufacturing plants – in terms of noise, heat, friction, you name it – which really corrupts the transmission on the cellular network. So most factories these days – probably 90-plus per cent – are still running on ethernet, with some wi-fi on the floor."

But industrial networking requirements are developing, as digital solutions multiply and advance. "Everything we do is getting more and more real-time; we want to be able to react as quickly as we can. We have so many processes where you need to react in milliseconds," says Bastian at Bosch. He suggests remote control of a welding machine as an example, with millisecond latency between command and response. "You need a technology, whether it's over-the-air or via cable, that can do that," he says.

Automated vehicles – remote controlled transport vehicles require wireless comms, and wi-fi networks are at capacity

"Everything we do is getting more and more real-time; we want to be able to react as quickly as we can. We have so many processes where you need to react in milliseconds"

Stefan Bastian, Global Director of Sales and Marketing, Robert Bosch (pictured)

Löser gives the parallel example of a glue pump, one of the industrial setups Audi has at its labs for testing 5G. The discipline is to "teach the settings" so pressure in the pump goes down at corners, so the glue does not go over the edges. "You want the same amount of glue all the way around. These are tricks and tweaks that are our process experts do every day. Right now, we are used to setting these points to the millisecond, exact, with cables. You can't do it with wi-fi. The test is to see whether we can do the same with 5G. If we can, then we can eliminate the cables."

5G DONKEY-WORK

Timing is important. "2019 is the year of the 5G smartphone", says Qualcomm. The cellular focus on industry is sharpening, but the consumer sector remains in the middle of the picture, momentarily. Patience, says the California chip maker; the donkey-work will be done in the service of every-day punters.

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"The smartphone ecosystem will allow those of us more interested in the industrial space to mature the technology," comments Gerardo Giaretta, senior director of product management at Qualcomm Europe. "We will start deploying 5G for industry at the end of 2019 and start of 2020, when we already have 12 months of interoperability testing and network optimisation." In the meantime, the line from Qualcomm is that, as the ground is laid for industrial 5G-proper, enterprises should look to LTE to develop their digital capabilities.

Giaretta talks us around. "How do things change with 5G? Do you always need it? No, it depends on the use case. There will be some that need high bandwidth, low latency, and ultra reliability – and demand 5G. But many others will work right now with LTE."

Nokia, with LTE gear to sell, perceives a 'moment in time', as the clamour from industry for private cellular networks grows. "It comes from a need. If you look at factories, today, there are no wireless comms – there aren't even any decent comms. Yes, there are highly automated cells, but there's no data coming out of them. Early adopters realise what they've got, currently, is not good enough. It is like cellular is the missing link in the digital transformation journey for industry. It has been overlooked until now," says Gulyani.

Why so? There is as much hype around private LTE, designated for industry, as there is around industrial 5G, and LTE has been around for yonks. Besides this heady brew of connectivity and compute functions, the liberation of spectrum in various markets has made independently-managed cellular networks viable, suddenly. The mood has been set by the reallocation of the CBRS band (3550-3700 MHz) for private and shared usages in the US. It has been stirred even more by the German government's precedent to free part of the C-band (3700-3800 MHz) for its big beasts of industry. Audi, Bosch *et al* are in the wings.

Giaretta at Qualcomm describes these spectrum policies and the domino-like

Fist bumps – German chancellor Angela Merkel with the latest factory robots at Hannover Messe (2018, left; 2019, above); her government has prioritised 5G for industry

"Do you always need 5G? No, it depends on the use case. There will be some that need high bandwidth, low latency, and ultra reliability – and demand 5G. But many others will work right now with LTE"

Gerardo Giaretta, Senior Director, Product Management, Qualcomm Europre

Industrial network control: *Whose line is it anyway?*

"Everything's on the table – that's the message. Right now, the technology is still developing. We need to figure out what it can actually do. We don't even know all the use cases that will come up in the future. Okay, the technology is really cool, but we first need to know the problems it can solve – which we couldn't solve before.

"[It is clear that] to get to these very low frequencies, we need to manage it locally. The question is whether enterprises will really do it themselves, or hire a company to support them. Whichever, it's their network, and the data stays on the premises. That's something we want as well, for sure.

"Would we let an operator manage our network? Why not? We have contracts with companies that help us operate our wi-fi networks, and we will most likely do the same with 5G. Because it's not our business to operate a cellular network. What we want is the ultra-reliable low-latency communication; then we'll figure out who will make us the best offer to operate a network like that... And we'll most likely have a contract that goes for a couple of years, and look for a new supplier every couple of years."

Henning Löser, Head of Production Lab, Audi

decisions expected from telecoms regulators in other markets as "fundamental for small and medium industry" to move forward with 5G.

Importantly, the work by the likes of Nokia and Qualcomm on MulteFire, for running standalone LTE in unlicensed and shared spectrum, including in the global 5 GHz band, appears to be coming back 'in-house', having existed outside of 3GPP circles until now. A late-2018 work item in 3GPP proposes a pathway to make 5G work in the unlicensed 5 GHz and 6 GHz bands, as well.

Gulyani at Nokia calls it a "perfect storm" of the "right ingredients". He says: "The technology needed to work, the spectrum needed to be available, and people needed to feel the need – to actually digitise and not just talk about it." But questions remain about the suitability of LTE, even as 5G is given the run-out in lab environments.

"Manufacturers have tried LTE and it has failed miserably. The market is waiting for 5G – because you can get closer to the equipment than you can with LTE, at least without lots of extra work. The clients we've spoken with, anyway, are not going to do anything with LTE; they'll wait for 5G, and what 5G brings to market," says Corlis at KPMG.

"Manufacturers have tried LTE and it has failed miserably. The market is... not going to do anything with LTE; it will wait for 5G, and what 5G brings to market"

Greg Corlis, National IoT Leader, KPMG

90% ***of industrial use cases can be served by LTE, says Deutsche Telekom***

THE VALUE OF LTE

So what's the truth? Is there a place for LTE in factories? Deutsche Telekom, with new hybrid public-private 'campus' networks to promote, thinks so. The clamour for 5G factories is not actually based on concrete demands, it reasons.

"The industry says, 'telecoms operators don't build networks for us'. That is wrong. We do; but we need to know their requirements. They say they want private networks, they want 5G networks. 'Well, what are your requirements around bandwidth and latency?' And they don't know the answer," says Herbert Schüttler, vice president of 5G corporate customers at Deutsche Telekom.

The answer is being worked out in 3GPP, in development of Release 16 of the 5G New Radio (NR) specification, as well as in new cross-industry groupings like the 5G-ACIA, which has most of the interview subjects of this article as members.

The telecoms community and the industrial set have to put their heads together, says Schüttler, and scope out factory requirements for networking before bowling headlong into 5G deployments. Much of the work can be carried on LTE networks, says the telecoms community.

"Ninety per cent, perhaps even 95 per cent, of use cases can be served today with LTE. It is only ultra reliability and high bandwidth that really demand 5G. It is not always a discussion about technology. Both sides need to learn what it means to use cellular in the industrial space, because neither side has any experience with it," says Schüttler. *(As an aside, Deutsche Telekom says private networks are easy to talk about and hard to manage, in response to the perceived jeapordy for operators in the industrial 5G debate – a discussion continued in the 'Whose line is it anyway?' boxes in this article.)*

Industrial software specialist PTC, another company with a vested interest in gearing-up digital factories, says industrial revolution is happening today – before industrial 5G devices are available and industrial-grade 5G networks have been fully specified – and not tomorrow. "Wi-fi is a perfectly fine way of doing it," says Howard Heppelmann, vice president and general manager of connected solutions at the Boston firm, putting the industrial cat among the telco pigeons.

"It depends on the experience, and the scale of it. But there is not an inhibitor, where everything stops and stalls. You won't notice an experiential difference using our technology in a sort of standard deployment today versus 5G in the future," he says. "It may be easier to connect your entire factory with 5G

Ethernet cable– most industrial plants will continue to rely heavily on wired connections, waiting to swap-out production or build new factories before investing in new 5G networks

Mixed reality – Microsoft's HoloLens 2 is being promoted as an industrial tool, more than as a consumer gadget; it requires high bandwidth,low latency networks

than with current methods – which involve running cables to machines. But it doesn't change what we do today. We will welcome 5G with open arms, but we just keep going."

PTC has form. It is a 25 year-old business with $1.3 billion turnover, and fresh funds and new opportunities after Rockwell Automation ploughed $1 billion into it last summer. It has built a serious-looking IoT and AR business in four years. PTC was on stage at the launch of Microsoft's HoloLens 2 AR headset, a $3,500 play-thing for industry, at MWC 2019. Its Vuforia unit, acquired from Qualcomm, has a 60 per cent share of the AR space. PTC will post more in new sales in 2019 from IoT and AR than from its old CAD and PLM lines; they should combine next year as its primary income source.

Heppelmann says: "Don't get me wrong; we're excited about 5G. Ten years from now, 5G will be semi-pervasive, and as relevant to connectivity as Linux is to operating systems. It is a critical step, which unlocks opportunities, and we are ready. But we're not held up by it."

Like Schüttler at Deutsche Telekom, and every other new digital sage skirting around the industrial space, Heppelmann urges caution. There are gnarlier concerns for digitally-minded manufacturers than whether or not 5G is currently worth a punt. "The bigger challenge is how to get data out of proprietary drivers, so it can be consumed somewhere else. Even with 5G, you need to figure out how to translate the data. The whole system needs to be constructed in the right way," he says.

"You won't notice a difference in a standard deployment today versus 5G in the future... Don't get me wrong; we're excited about 5G. Ten years from now, 5G will be semi pervasive, and as relevant as Linux is to operating systems... But we're not held up by it."

Howard Heppelmann, Vice President, Connected solutions, PTC (pictured)

APPLICATION DEPENDENT

But Audi is at capacity with its wi-fi network and hemmed in by its ethernet cabling, as we have heard, and Bosch is already betting on industrial 5G for the next phase of its transformation drive. The question remains: is cellular connectivity a must-have for factories, and does LTE cut it as a supplementary or in-between tech? "It really depends on the use cases," says Heppelmann, restating a line we've heard before.

On this, everyone agrees. "It's not black and white. It comes down to use cases. LTE has some viability, 5G just has more utility in every aspect," comments Michael Flaherty, director of tech enablement at KPMG, and specialist in IoT and private networks.

Corlis, his colleague at KPMG, says the same: LTE works for certain non-critical factory functions away from the production line itself, but has limited appeal over existing well-tuned ethernet and wi-fi networks. "Some carriers tried to go the private LTE route and garner interest from manufacturing and other sectors, but it was just a hard slog. And manufacturers, already wired to ethernet, are not going to rip out and start again, unless they're deploying a new plant

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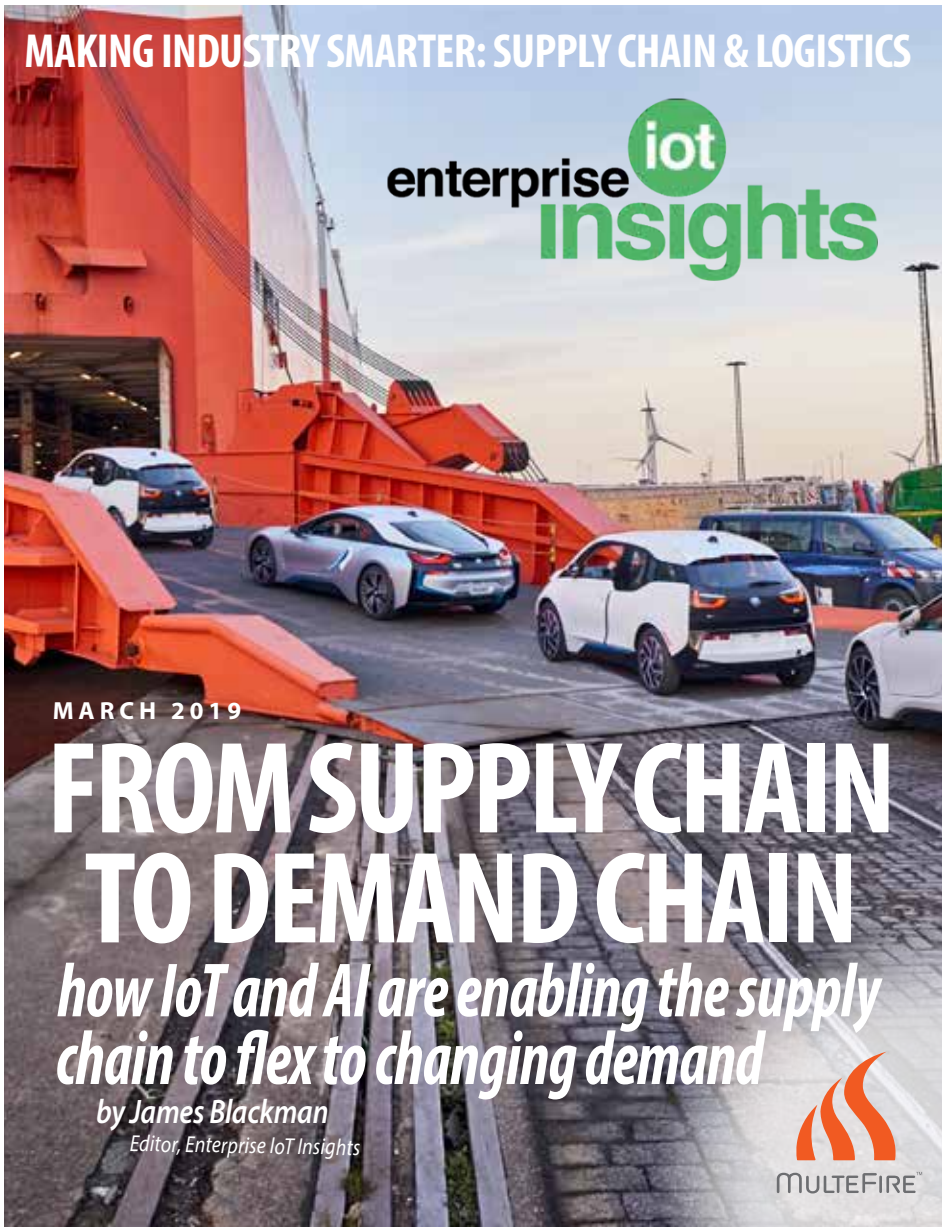

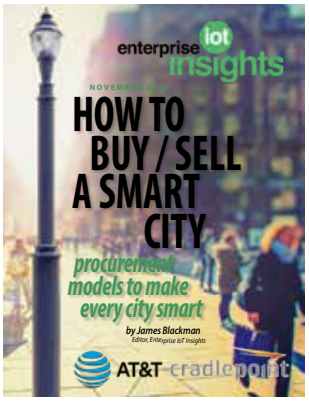

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or re-tooling the line. In those cases, there's an opportunity to put 5G in there."

He goes on: "That's one of the big reasons private LTE hasn't been adopted, because wi-fi and ethernet can serve most purposes – so LTE offers less value in these environments. 5G is different, because it brings an opportunity to rip out and eliminate ethernet on the factory floor. That's where 5G starts to have appeal. LTE just doesn't offer the same throughput as an ethernet solution."

Nokia insists LTE is an advance on wi-fi, at least. "I can put some number of high-definition cameras on wi-fi, but I'll saturate the cell. I need a network that will support that very high-density environment – one cell here and one cell there is not feasible. That's the problem with wi-fi," says Gulyani.

But it is also the problem with LTE, at some point, if the digital factory goes far enough. As per the march of technology, it is also the decisive reason for a 5G factory. Nokia has a decent cross-analysis of industrial performance requirements and cellular performance metrics, and finds most production processes lend themselves to URLLC-level 5G reliability, in fact.

Motion control, mobile robots, and robot controls require so-called 6x9s (99.9999 per cent) network availability, it says, with cycle times, payloads, cell saturation, and service areas varying according to the number and intensity of the machines in each case. "LTE gets you to 4x9s and 5G gets you to 6x9s," he says.

Equally, 4x9s (99.99 per cent) availability goes a long way, he says, at least for non-critical factory operations, including general communications, and limited AGV and AR functions. Network redundancy can be carefully designed with private LTE, as well; certainly better than with public LTE networks.

But the deal-breaker for factories is time-sensitive networking (TSN), which supports time synchronisation and dual connectivity, and gives deterministic performance. Certain characteristics have been introduced in LTE, notably fast uplink access, flexible numerology, mini-slots, and fast acknowledgment. But TSN is a URLLC specification, set out in Release 16 and available with standalone 5G from 2020/21.

It is almost like networking from 20 years ago, suggests Gulyani, harking back to when time-division multiplexing (TDM) afforded equivalent guarantees about traffic delivery. "That section was yours, and that was yours, whether you use it or not," he says. The arrival of packet-switched data, allowing the same path to be shared by many users, made this model of independent transmission signals seem "wasteful".

But industrial users want better than best-effort communications; it needs the gaurantees of independent channels. "Good-enough is not good enough in process automation," says Gulyani. At Hannover Messe 2019, Bosch and Nokia demonstrated a high-definition camera, a pressure sensor, and an emergency stop button. "If the camera doesn't give full resolution for a

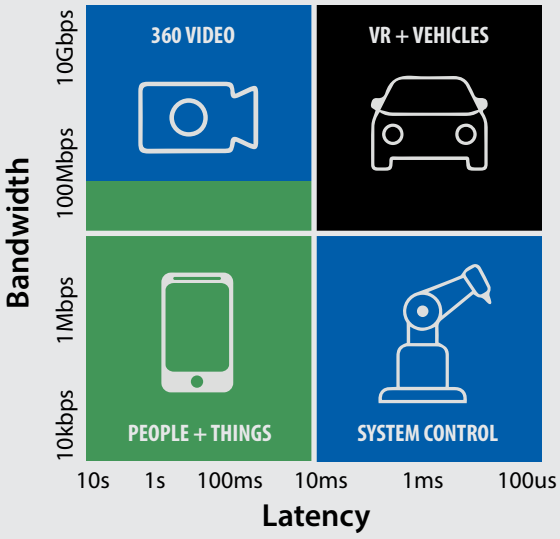
Industrial-grade networking requirements

USE CASE		AVAILABILITY	CYCLE TIME (milliseconds)	PAYLOAD (bytes)	# OF DEVICES	SERVICE AREA (metres)
Motion control	Printing machines	>6x9s	<2	20	>100	100
	Machine tools	>6x9s	<0.5	50	~20	3
	Packaging machines	>6x9s	<1	40	~50	3
Mobile robots	Cooperative motion control	>6x9s	1	40-250	100	<1,000^2
	Video-operated remote control	>6x9s	10-100	15-150	100	<1,000^2
Mobile control panels with safety functions	Assembly robots / milling machines	>6x9s	4-8	40-250	4	10
	Mobile cranes	>6x9s	12	40-250	2	50
Process monitoring		>4x9s	<50	variable	10,000 devices per km^2	

Latency and bandwidth mapped against industrial use cases

"For 1ms latency, LTE won't get you there. It will get to 10ms, but not much lower. But, then, 10ms will serve 85-90 per cent of use cases"

Manish Gulyani, Vice President, Enterprise Marketing, Nokia



Source: Nokia

millisecond, okay. But that emergency stop button has to work every time. You need to prioritise three sets of information in different ways. You need that determinism."

LATENCY AND BANDWIDTH

Actually, the LTE-versus-5G debate is less about reliability, and more about network latency and its flipside-measure, network bandwidth, claims Nokia. "There are two aspects to this, really: speed and throughput," says Gulyani. Another slide, which turns up variously in its presentations, maps network latency and bandwidth against sundry industrial applications (see graphic, left).

LTE, privately managed, gets you to latency of 40-50ms, it reckons; 5G, with tuning, will go further, eventually, to closer 1ms. Release 16 says time-critical industrial applications might require latency of one millisecond, packet delay variation (or 'jitter') of one microsecond, and reliability requirements of 99.9999 per cent.

But these URLLC use cases are rare, it seems, judged against the near-term scope of industrial applications. Nokia reckons on roughly the same ratio of LTE use cases as Deutsche Telekom. "If you want ultra-low latency, at 1ms, LTE won't get you there. It will get to 10ms, but not much lower. At the same time, 10ms will serve a lot of use cases, actually – 85-90 per cent," says Gulyani.

"The deal-breaker for factories is TSN, giving deterministic performance. Certain characteristics have been introduced in LTE,, but it is a URLLC specification, in Release 16, available with standalone 5G from 2020/21"

85% *of industrial apps can be served by 10ms latency with LTE, says Nokia*

Networking architecture impacts the need for out-of-the-box speed, as well. The emergence of powerful edge-compute capabilities – bringing the analytics closer to the action, and sorting the wheat from the chaff for data processing – complements and alleviates the latency and bandwidth demands of cellular networks.

Gulyani draws back. "You can't just sell this stuff; you have to walk through the use cases. No one goes all-in, at once," he says. "You try things out – you connect your video cameras, find they work, make adjustments, and move to tracking goods, perhaps, with an LTE module on an AGV. The use cases build."

And what about the view from the factory floor? Has Audi, with test frequencies under its belt and a licensed tranche of prime 5G spectrum in the offing, worked out a set of industrial applications in its labs that will shift to LTE right away, a different set that will attend an early version of 5G at the end of the year, and a third set that will wait on URLLC-flavoured 5G in 2020/21? "Unfortunately, I'm not allowed to tell you," says Löser.

But he maintains the story that everything is on the table in terms of the application (as well as the management) of industrial LTE and 5G networks. "We test in the lab, make sure it works in the lab, and then take it into a production environment

Industrial network control: *Whose line is it anyway?*

"We have a huge divide at the moment in the industry, in the country, [about] how operators can serve industries best. There are lots of complaints about how operators have served industry so far, which has probably something to do with the fact our networks are consumer centric. But we don't believe they should be like that in the future. As operators, we want to embrace our industry partners to serve them in the right way..

"Customers need a public layer, but they need a private one too, because they want to keep their data [on site]. We would like to offer both. And we have started that, based on LTE, and going into 5G... You can use any kind of spectrum for public [networks]. As an operator, we can use this spectrum for public usage, and we can also use the same spectrum for private networks. The advantage we have is we can play with these frequencies."

Antje Williams, Executive Programme Manager for 5G, Deutsche Telekom (pictured)

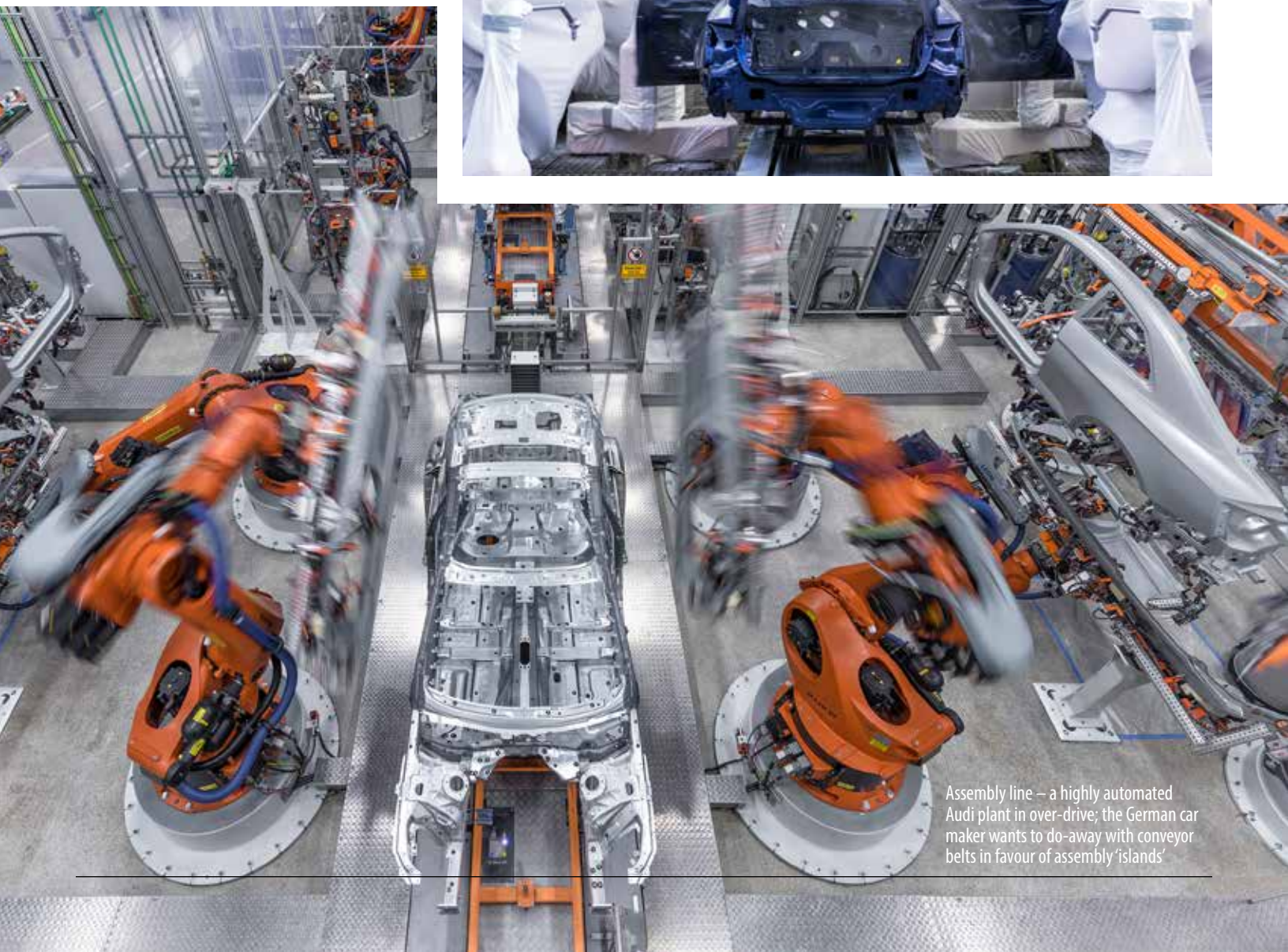
– in very careful steps. That is the way. The rule is to take into account availability and security – trying the solution in a small area first, then running in pre-assembly, in some low-volume car production, and finally working out how to transfer to our higher-volume lines."

He adds: "Because there is so much we need to do with this new technology – technology that is new for us, anyway. Right now, we don't really know how to run a cellular network flawlessly."

KPMG brings the narrative home. For now, there remains a lack of 5G devices, as well as a lack of standalone networking. Ethernet and wi-fi still go a long way, and factory infrastructure of any kind is expensive to replace. Corlis says: "If they can deploy 5G, they will – it is less costly than deploying ethernet on the factory floor. It won't be massive adoption immediately, but you will see some of the larger manufacturers – in aersospace and defense, and even in automotive – start to make moves in certain areas. But it will take two or three years before the massive deployments."

"There is so much we need to do with this new technology – technology that is new for us, anyway. Right now, we don't really know how to run a cellular network flawlessly"

Henning Löser, Head of Production Lab, Audi



Assembly line – a highly automated Audi plant in over-drive; the German car maker wants to do-away with conveyor belts in favour of assembly 'islands'

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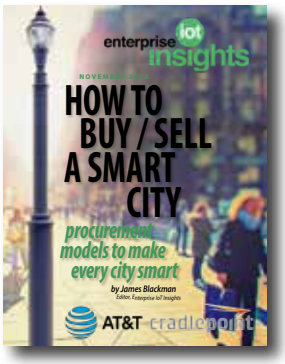

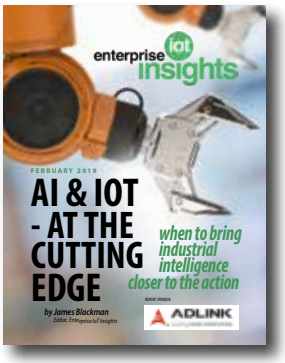

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