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Signals set for growth – how OEMs can be successful in a digitized rail infrastructure

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Key insights

The global rail infrastructure technology industry, a EUR ~36 bn global market each year, has its signals set for stable growth until 2025. Yet, we also see considerable change to come in the industry's three core segments train control and signaling, electrification and digital customer solutions. Nine key trends will significantly shape the future of the global rail infrastructure technology industry over the coming decade along the three dimensions of industry dynamics, customer landscape, and technological change. In addition to their effect on the industry as a whole, these nine trends will have a direct and significant impact on each industry segment.

Over the last 12 months McKinsey has conducted in-depth research, including more than 50 interviews with industry experts representing a range of rail infrastructure manufacturers to rail operators as well as scientific institutions and digital ventures. We have used the findings from this to create a comprehensive picture of the current and future state of the industry, and to sketch a strategic roadmap for rail OEMs to respond to the opportunities and challenges ahead in rail infrastructure technology.

Train Control and Signaling

The roll-out of the ETCS advanced signaling upgrade program across Europe presents a solid growth outlook for rail players with an aggregate market potential of ~EUR 35 bn until 2030. Software solutions enabling real-time train-to-train and train-to-network communication together with infrastructure components for autonomous driving technology are driving both technology development and overall growth. However, product standardization and intensified competition on a global scale are also pressuring established rail players to re-assess their strategic positioning as scale becomes ever-more important to remain competitive against players from lower-cost environments, especially China. Global revenues are set to grow to ~EUR 19 bn p.a. until 2025 in real terms, up from ~EUR 17 bn p.a. today.

Electrification

Traditional rail electrification technology is fairly mature and selected smaller new-built initiatives are scattered across several regions providing for low but stable growth. Yet, alternative propulsion technologies like battery-powered rail solutions or fuel-cell technologies become relevant, especially for urban transit. As these enable increasingly higher performance at lower costs, players should prepare to complement their urban infrastructure portfolios with e.g., advanced battery-powered rail solutions. Like the observable dynamics in the train control and signaling segment, achieving sufficient scale can help rail electrification players to remain competitive in the future amid intensifying global competition. Global electrification revenues are set to grow to ~EUR 10 bn p.a. by 2025 in real terms, up from ~EUR 9 bn p.a. today.

Digital Customer Solutions

Digital B2C solutions mark the strongest growing segment for rail players over the years to come. Global revenues are set to grow significantly to >EUR 15 bn p.a. by 2025 in real terms, up from ~EUR 10 bn p.a. today. Fueled by all-encompassing connectivity, data availability and an ever-increasing demand for information, end-to-end mobility solutions and other use cases around the passenger interface create significant new business opportunities in

B2C. Consequently, multiple players from the rail ecosystem and beyond are expected to compete for the passenger interface as the basis for future revenues. Hence, developing a strong stance in these digital solutions with access to the passenger interface needs be at the heart of the rail infrastructure technology industry over the coming decade.

These developments in multiple aspects of the market present several opportunities for growth but require rail players to act now if they wish to succeed in an increasingly digitized rail infrastructure. These industry-level developments are happening in the context of two broader trends. First, as rail infrastructure becomes increasingly connected, cyber-security becomes a more and more important issue. Industry players must build adaptive, responsive organizations to stay ahead of an evolving cyber-security threat. Second, rail operations are on the path toward becoming fully autonomous, particularly in urban transit. Industry players hence need to complement their portfolios with solutions enabling autonomous train operations as these have several positive implications for network capacity, safety and cost of operations.

There is certainly no standardized approach to adapting the current business model of established rail players so that they can capture the new growth potential effectively. However, our observations of players in the rail infrastructure technology industry – and in adjacent industries that have successfully adapted their business model to tap into new revenues pools, particularly those including technological disruption – reveal a set of approaches and perspectives that have proven effective. Specifically, we have identified actions in 5 key areas that aspiring OEMs might consider taking:

Cost consciousness. To strengthen the future competitive positioning, sufficient scale, design-to-value initiatives, and low-cost locations could be the key to reducing costs particularly in procured parts, R&D/engineering and manufacturing.

Customer and project-centric organization. More global market accessibility and a significant uptake in urban rail developments have made the customer landscape more complex and demands a more tailored sales setup.

Value-chain positioning in B2C. Looking beyond their traditional B2B orientation, OEMs need to decide on which value-chain parts they want to operate for the largest growth segment in the infrastructure technology industry – digital solutions for the passenger interface.

Innovation and technological standards. To successfully capitalize on the disruptive technology trends around advanced signaling, automated operations, battery technologies and digital customer solutions, innovation is key and requires sufficient internal and/or external capabilities.

Partnerships. OEMs should evaluate opportunities for further cooperation across and beyond the industry in order to form scalable ecosystems and profitable alliances. The viability of individual partnership options depends on each player's starting point.

Introduction

As an industry, infrastructure technology has been a distinct aspect of the overall rail sector for more than 100 years. Given the rise of global megatrends and new technological opportunities, infrastructure technology is expected to become even more significant in the years to come. The automation of vehicles and developments in vehicle-to-infrastructure communication will result in more high-tech equipment and safer processes. Global population growth, increasingly limited resources, and a growing awareness of the environmental implications of sustainability will increase the number of urban transit systems, especially in emerging countries. Digitization and connectivity will make the rail system more transparent to passengers and enable a level of interaction that helps them manage and optimize their end-to-end mobility.

The structural changes, geographical shifts and technological disruptions on the horizon mark an important turning point for the players in the rail infrastructure technology market.

This publication aims to shed light and give an integrated perspective on the imminent challenges and trends in the rail infrastructure technology industry, make them more tangible, and provide answers to questions that are looming large in the industry:

- What forces are shaping the current structure of the global rail infrastructure technology markets?
- How will the global rail infrastructure technology markets develop over the coming years, what are the drivers of growth, and how will these developments affect the customer landscape?
- How are the business models of rail infrastructure technology OEMs impacted by new technologies, digitization, and inter-modal mobility solutions?

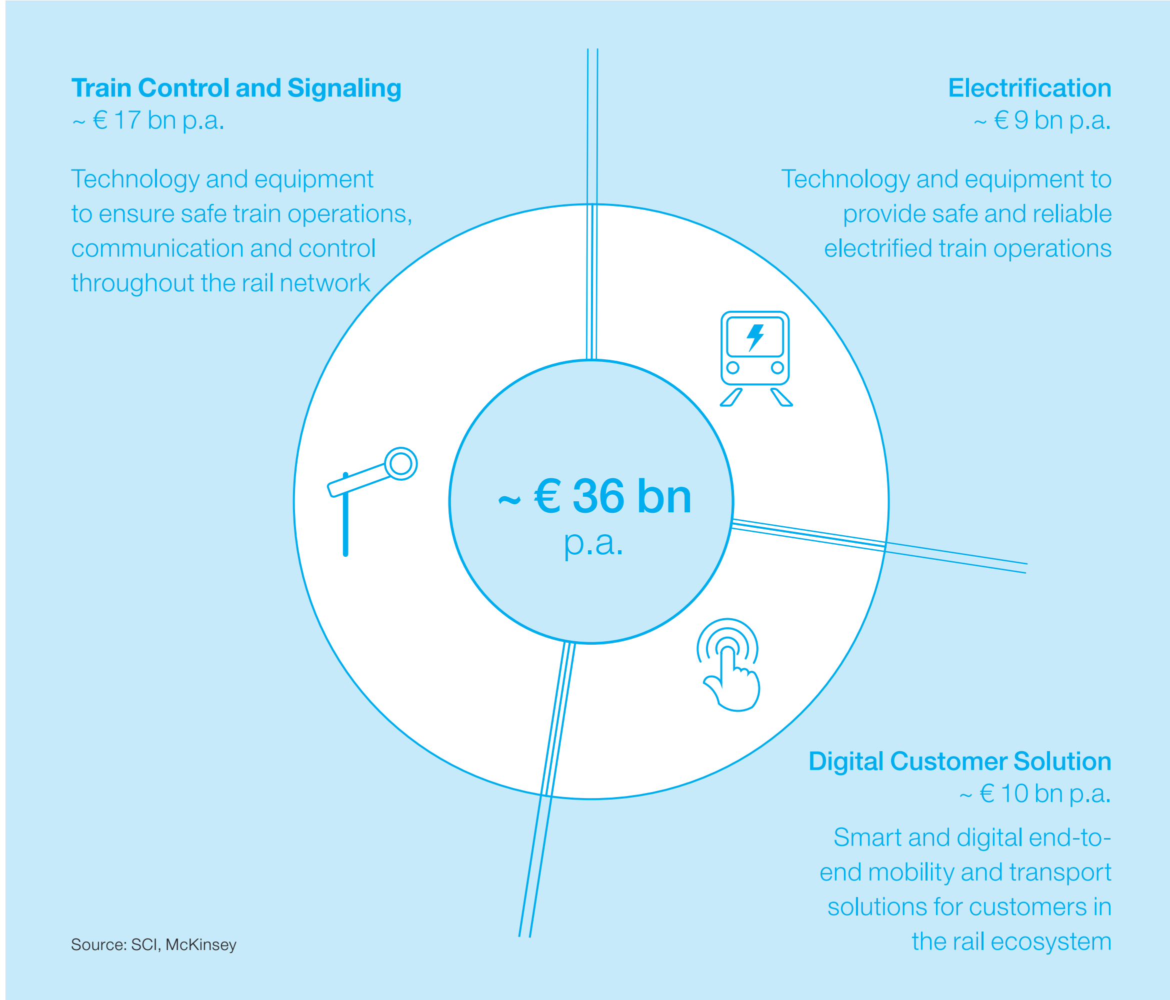
In discussing the sector's recent, current, and imminent key trends, we draw upon proprietary analyses, our industry expertise, and insights from client discussions.

We will also quantify the implications of these trends and highlight the shifts they will lead to in the revenue pools for rail infrastructure technology players over the coming years. Based on the expected shifts, we identify associated key challenges and growth opportunities in the areas of advanced signaling technology upgrades, maintenance solutions and digital customer solutions. We then offer recommendations for how the current industry champions might adjust their portfolio and business models.

We conclude with a set of pragmatic and tangible recommendations on how rail infrastructure technology players can best capture the new growth potential and prepare their business models for future success.

I. Industry overview

Exhibit 1: Size of the rail infrastructure technology market



Source: SCI, McKinsey

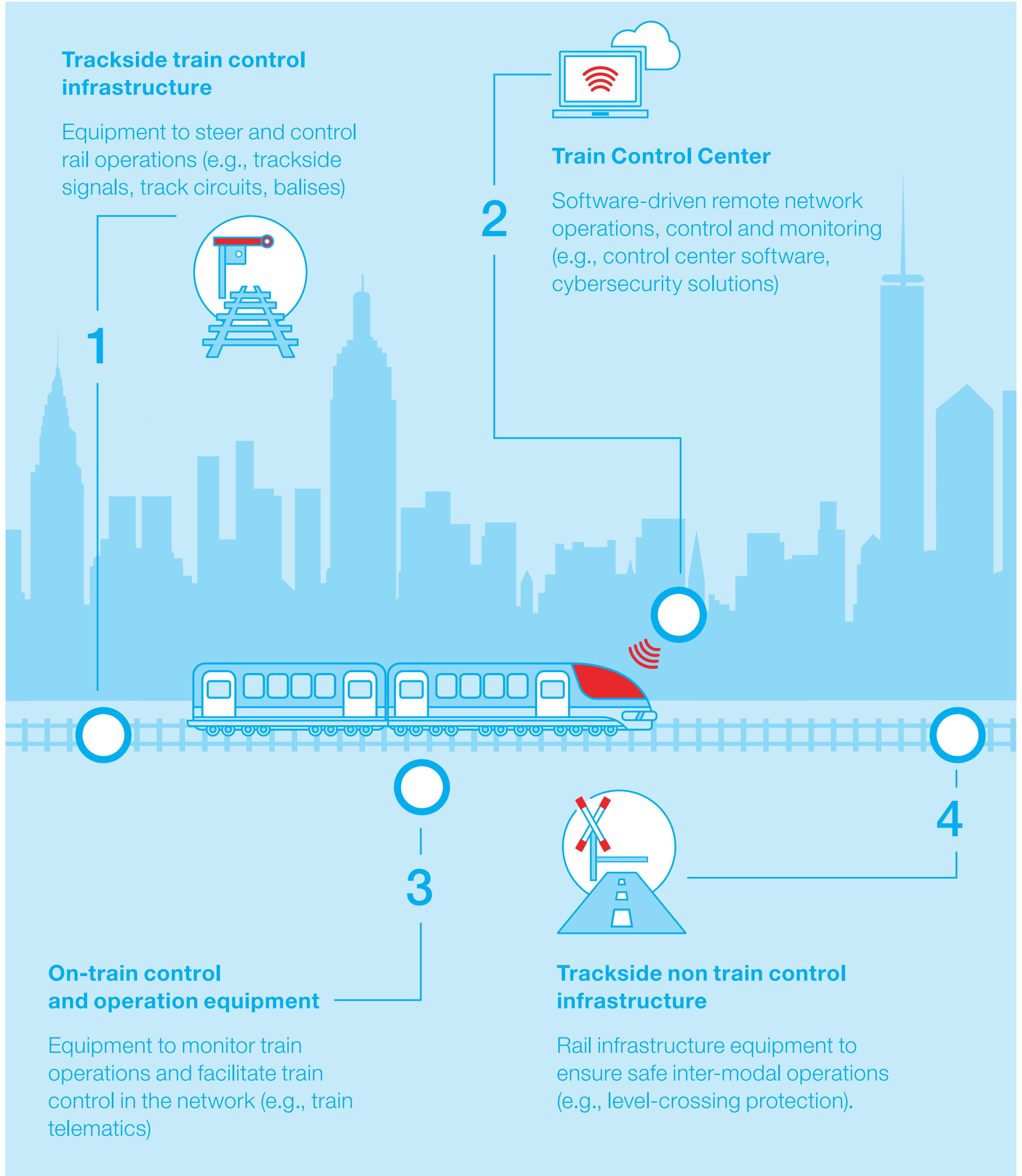
The rail infrastructure technology industry is comprised of three segments – train control and signaling, electrification and digital customer solutions – that combined account for annual revenues of around EUR 36 bn globally. We distinguish rail infrastructure technology from tracks, tunnels or other low-tech infrastructure components.

The train control and signaling segment is the largest of the three segments, accounting for about half of the industry's total annual revenues (EUR 17 bn). The signaling segment is characterized by steady real growth of about 2.5% p.a. over the past decade stemming from selected regions that cyclically undergo new development (particularly China) and upgrade programs (e.g., North America in past years).

The electrification segment totals about EUR 9 bn in annual revenues. Over the past decade, real growth of ~3.5% p.a. was fueled by increases in the global electrified track length particularly from investments into new urban and mainline rail infrastructure in Asia.

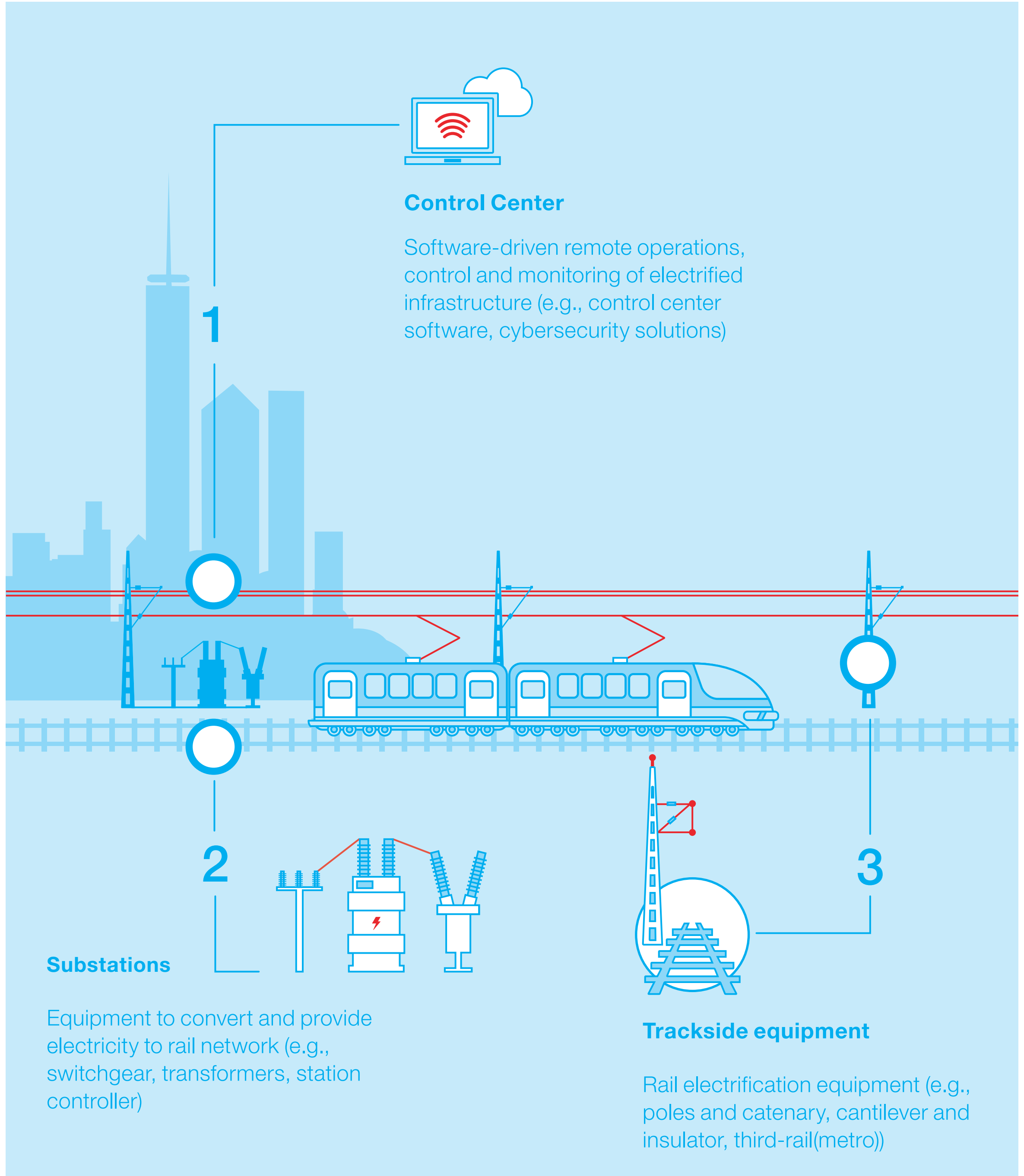
The digital customer solutions segment generates approximately EUR 10 bn annual revenues. This segment has become the most disruptive and dynamic segment of the technology industry as various players from the rail and non-rail ecosystem are pushing into the market with innovative solutions for the passenger and freight customer interface and end-to-end mobility solutions.

Exhibit 2: Overview of the train control and signaling industry



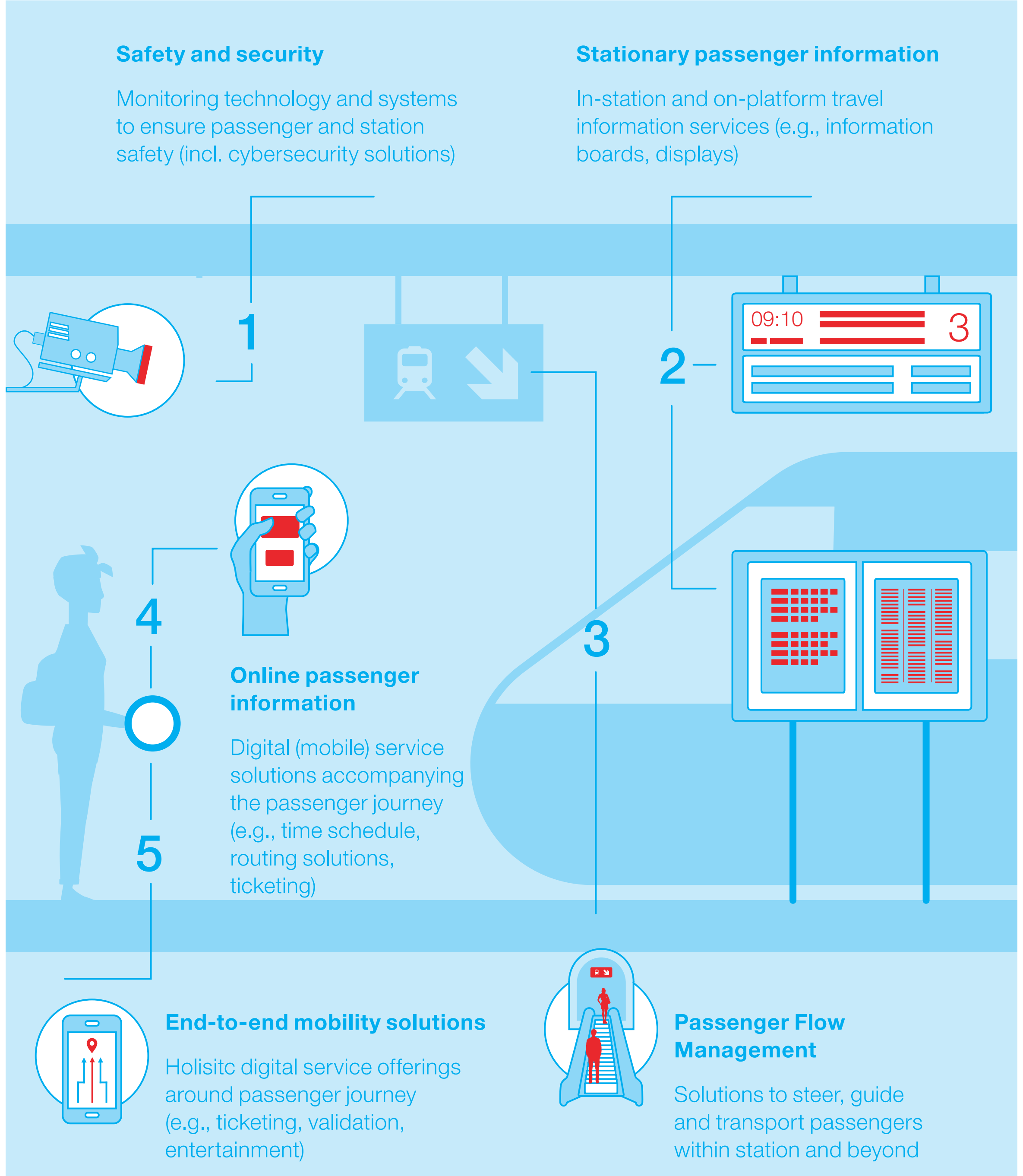
The train control and signaling segment provides all elements to safely operate and monitor a rail network and to utilize the infrastructure capacity efficiently. The signaling product space is highly complex and includes various physical assets along the tracks, within trains, and in remote control centers – all of which need to be inter-connected. While today, the high variety of an OEM's product portfolio is determined by national standards and requirements for signaling technology, efforts are being made to continue to standardize products in the future to improve inter-operability. The signaling industry is increasingly shaped by software solutions and real-time data transmission between train control centers and the trains themselves.

Exhibit 3: Overview of the rail electrification industry



The rail electrification segment is comprised of all elements to convert and deliver electric energy directly to trains. Substations convert energy from national networks into the right frequency and voltage used in rail operations. For energy transmission along the track, two main systems dominate – catenary in mainline operations and third-rail in metro systems. Control centers face the challenge of always providing the right amount of energy and stabilizing the network. The electrification equipment is fairly standardized and inter-changeable. Modern electrification systems also help to further reduce emissions as they can provide energy recuperation from e.g., the trains' braking process.

Exhibit 4: Overview of digital customer solutions



Digital customer solutions primarily emerge around the passenger interface of travel, but various applications for rail freight customers also exist. Digital customer solutions encompass stationary and online passenger information, entertainment solutions, safety and security systems, intelligent passenger flow management as well as a wide range of end-to-end mobility services. A multitude of online and offline services are provided along the entire passenger journey incl. real-time (re-) routing, digital ticketing, contactless ride validation and many others. In addition, data-driven solutions can help operators to manage passenger flows and increase safety and security within stations as well as on trains.

II. Trends in the global rail infrastructure technology industry

To provide insights into the changes ahead and how they will affect OEMs, the industry landscape, and the overall value chain, we have identified nine trends along three key dimensions:

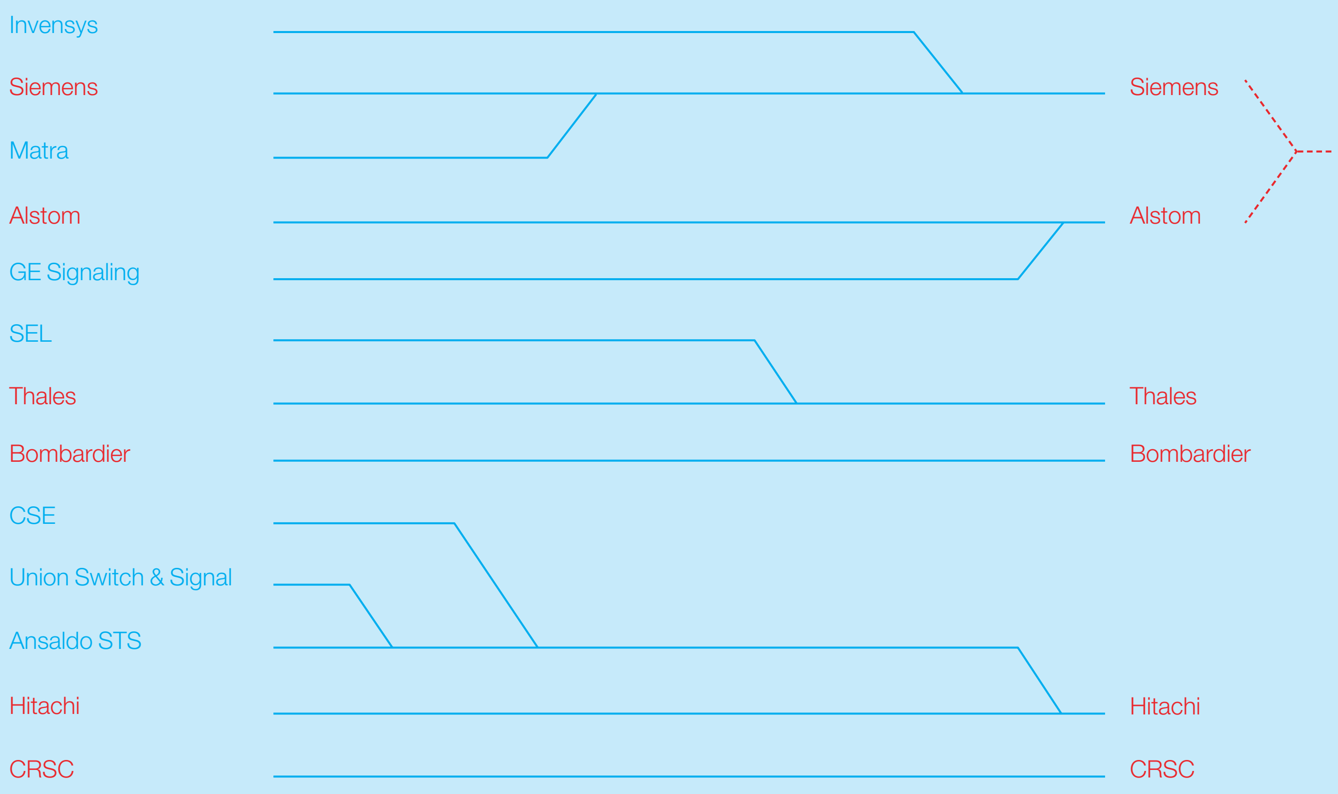
A: Shifts in industry and competitive landscape (A1 to A3)

B: Changes in demand and customer landscape (B1 to B2)

C: Technology-driven disruption and growth opportunities (C1 to C4)

The train control and signaling industry has become more and more concentrated over the past decades

Selected key merger examples – not exhaustive



Margin pressure for smaller rail infrastructure players with full portfolio

A1 Growing consolidation in rail infrastructure technology

Global train control and signaling players have consolidated significantly. Recent examples include the Siemens-Invensys merger in 2012 and the Alstom-General Electric Signaling merger and the Hitachi-Ansaldo STS takeover both in 2015. Combined, these mergers represent annual revenues of ~EUR 8 bn. The top five signaling players nowadays hold ~80% combined market share, up from ~65% in 2007.

Historically, signaling players have been focused on their domestic markets which were often kept national for economic as well as strategic infrastructure reasons. This led to very limited competition in most markets. Nowadays, competition has increased a lot driven by three key factors:

- Increased market liberalization, especially in Europe (EU-wide tendering)
- Higher sophistication of (security) requirements demanding scale in R&D
- Standardization of systems (ETCS, PTC) to ensure interoperability, making market access easier

The standardization of requirements increases competition and will render costing even more important as customers become increasingly price sensitive. In particular, we see three areas of synergies: procured parts (~50% of costs), R&D/engineering (~10% of costs) and manufacturing (~10% of costs). In future years, the medium- to long-term strategic choices for signaling players must center around one of the following dimensions: Achieving sufficient scale to be cost efficient in global markets through scale effects especially in procurement, R&D/engineering and manufacturing or covering a specialized value proposition for niche products and technology.

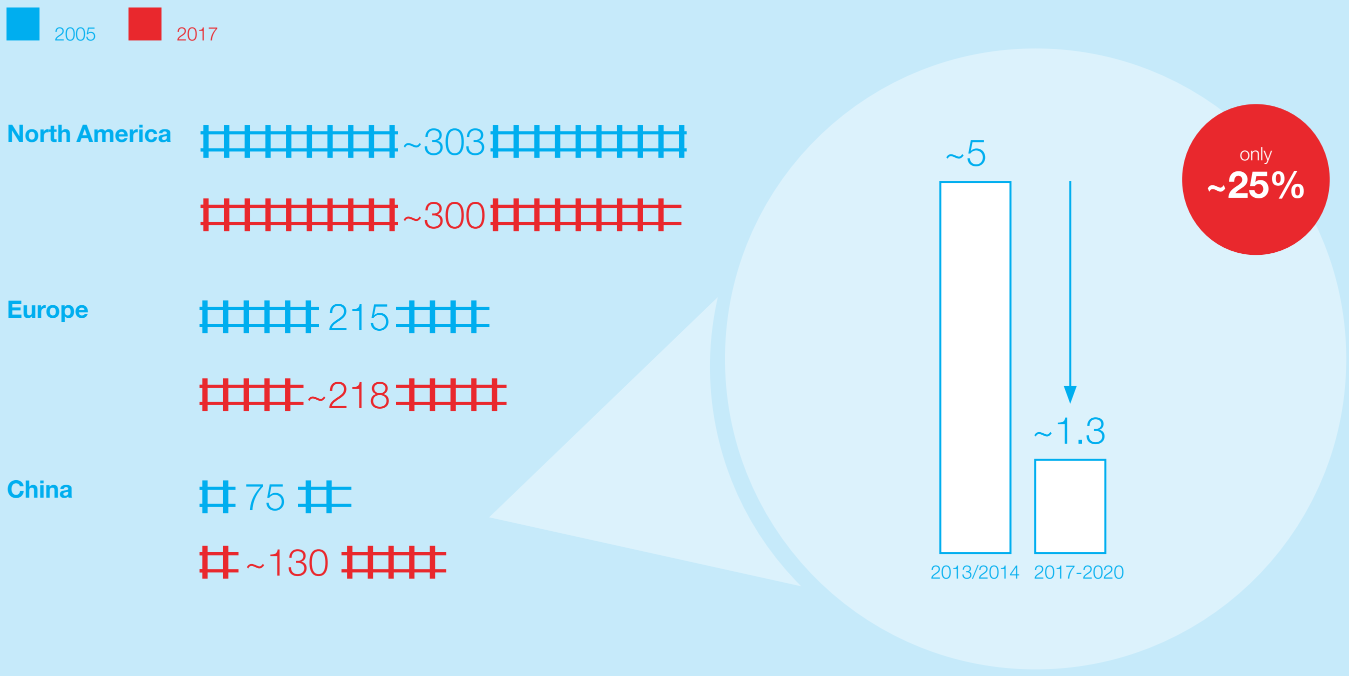
Out of these considerations we foresee continued consolidation in the global signaling industry with multiple likely scenarios. Yet, anti-trust considerations will be an increasingly important factor given that 80% of the market is already shared among just 5 players. Possible future industry scenarios include – but are not limited to:

- Large-scale full portfolio player with global growth ambitions acquires a smaller-scale full portfolio player to gain market access in a foreign market
- Smaller-scale full portfolio players join forces with other regional small-scale full portfolio players to achieve sufficient scale
- Specialized niche players are taken over by large-scale full portfolio player wanting to broaden their technological capabilities

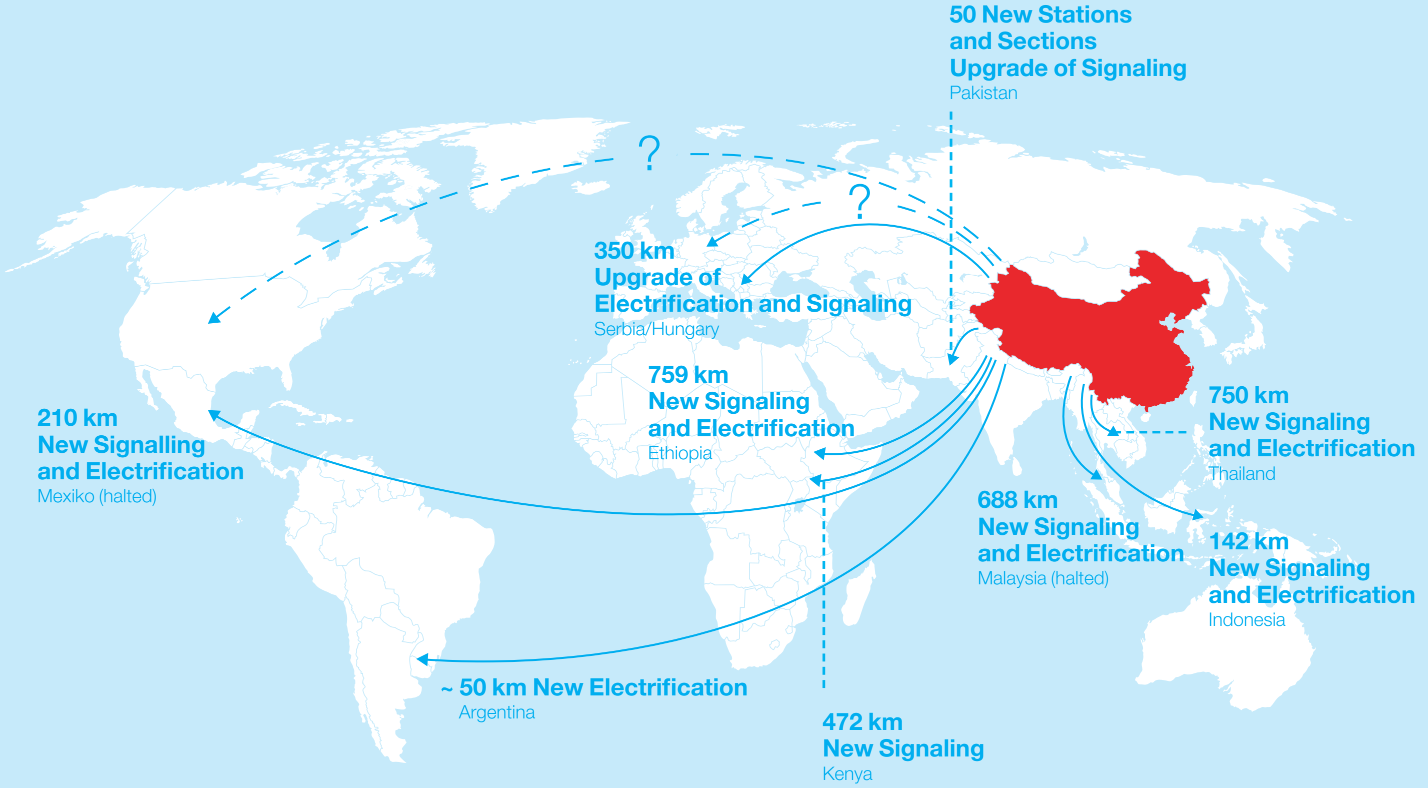
Besides size, profitability and technology, a highly relevant factor in mergers will be market accessibility incl. national approval processes, especially between Europe and Asia.

Development of rail network length by region
Line length in km

Annual new opening of dedicated high-speed passenger lines in China
Thousand line km, per year



Examples of China's exports in rail infrastructure technology



A2 Chinese players have gained market share and push for exports

In recent years, Chinese rail infrastructure technology players (CRSC, CREC, CRCC) experienced the strongest growth of all global players leading them to hold 20-25% market share in the global rail train control and signaling and electrification markets today. The sources of growth are rooted in the massive expansion of Chinese rail infrastructure over the past decade. China's rail network grew from ~75,000 line length in 2005 to ~125,000 km today. While China's rail network length almost doubled in the past decade, the investments in Europe and North America were stagnant.

Going forward, however, the expansion program is expected to slow down. Between 2017 and 2020, only ~1,300 high-speed line kilometers will be built each year, which is only ~25% of the peak years 2013 and 2014, where >5,000 new high-speed kilometers were constructed each year. Another area of future growth in China will also be the expansion of urban transit systems, especially metro systems (~5% real growth) driven by China's development towards the "urban billion" expected by 2030 up from ~600 million urban citizens in 2010. Yet, the growth from metro systems, additional upgrades, and maintenance of conventional lines only partially compensates for the reduction in new line investments and hence, export markets come into stronger focus for Chinese players in order to avoid underutilization of existing plants and labor.

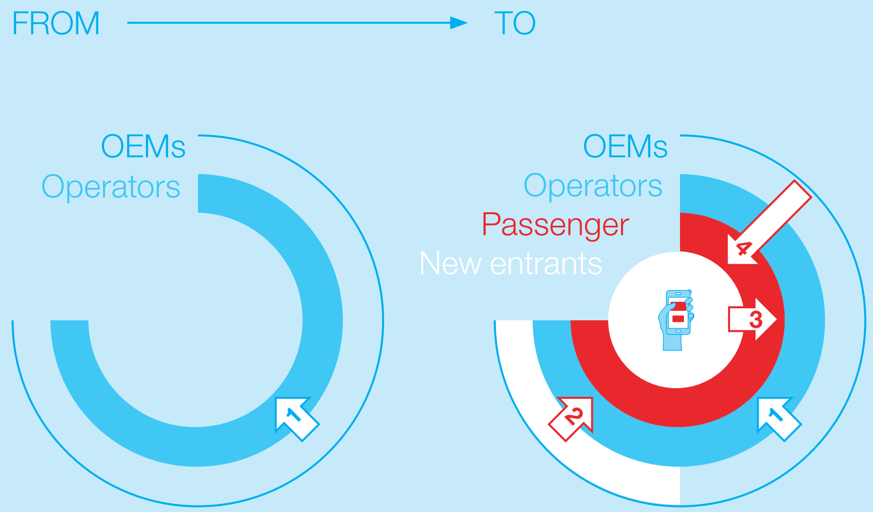
To date, exports only account for a small fraction of total rail infrastructure technology revenues for Chinese players (<5% in 2015). These exports have so far been mainly directed at developing markets like the newly built, international Addis Ababa-Djibouti mainline with ~750 km of track or the capacity and speed upgrade on the Beograd-Budapest mainline with ~150 km of track.

The growth of these players is complemented by government-backed financing packages for comprehensive rail systems (complete infrastructure incl. construction and rolling stock). An example of this is the inclusion of the building of the seaport and marine basis in the Ethiopia-Djibouti project. These offerings are often accompanied by low interest rates and limited payback in initial years.

One can observe a similar market dynamic in the rolling stock industry, which is a couple of years ahead in industry dynamics given fewer market entry barriers. In that industry, the Chinese players could often bid at a price point that was up to 20-30% lower than the nearest competitor in recent tenders.

Going forward, we expect to see increasing Chinese exports also into mature rail infrastructure markets like Western Europe and North America, which will introduce price pressure into these markets. Nonetheless, homologation in the rail infrastructure technology industry might still impose some challenges for the export ambitions. Growth options might also include inorganic moves.

The industry dynamics are shifting considerably with an increasing focus on the passenger interface



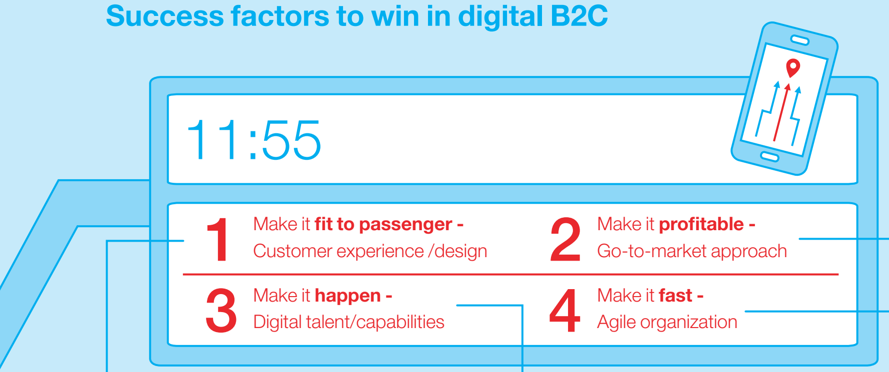
1) B2B
Established **rail technology players** with B2B services for **rail operators**

2) B2B
Technology players, mobility providers and start-ups with intelligent B2B solutions for rail operators

3) B2C
Technology providers and mobility app providers with direct link to passengers through their B2C information solutions in proprietary ecosystems

4) B2C
Established rail technology players develop new B2C business models for the passenger interface

Success factors to win in digital B2C



Clear strategy and implementation plan incl. definition of offering and value-chain positioning

Focused marketing and launch strategy to gain relevant (pilot) passengers

Truly user-centric, preference-based products based on passenger use-cases

Leverage external expertise and involve customers early in the development process

Identify, recruit, retain and develop key in-house talent with new skills and ways of working

Build dedicated HR strategy with new paths and incentives for key roles

Enable fast and continuous innovation for customer solutions through agility across the organization

Break down hierarchies and define product service teams to achieve short update- and release cycles

A3 Emergence of new players in rail information systems around passenger/B2C interface

In today's world, connectivity and digitization open endless new technological solutions and service opportunities across industries, and the rail infrastructure technology industry is no exception. Passengers demand an increasing amount of information, entertainment and multi-modal end-to-end mobility solutions. This partly also applies to the rail freight ecosystem with solutions to increase visibility and efficiency for shippers and receivers.

In the past decade the rate of investments into mobility solutions has increased nearly six-fold, and around 60% of investment volumes went into large, industry-shaping deals. Notably, these investments focused mostly on the technologies underlying the changes in mobility, not on products. Investors, hence, are betting on an ecosystem. Consequently, multiple players from the rail and non-rail ecosystem are expected to compete for the passenger interface as the basis for future business models.

- Technology players with capacity to integrate multi-modal travel data in their proprietary solutions
- Mobility providers offering platforms for on-demand, door-to-door transportation which could integrate rail services
- Start-ups and new ventures innovate through data integration in price comparison, ticketing, travel booking and many other customer interfaces
- Rail operators as proprietors of up-to-the-minute train data providing journey and (re-) routing services to customers
- Rail technology players with new ventures in digital customer solutions

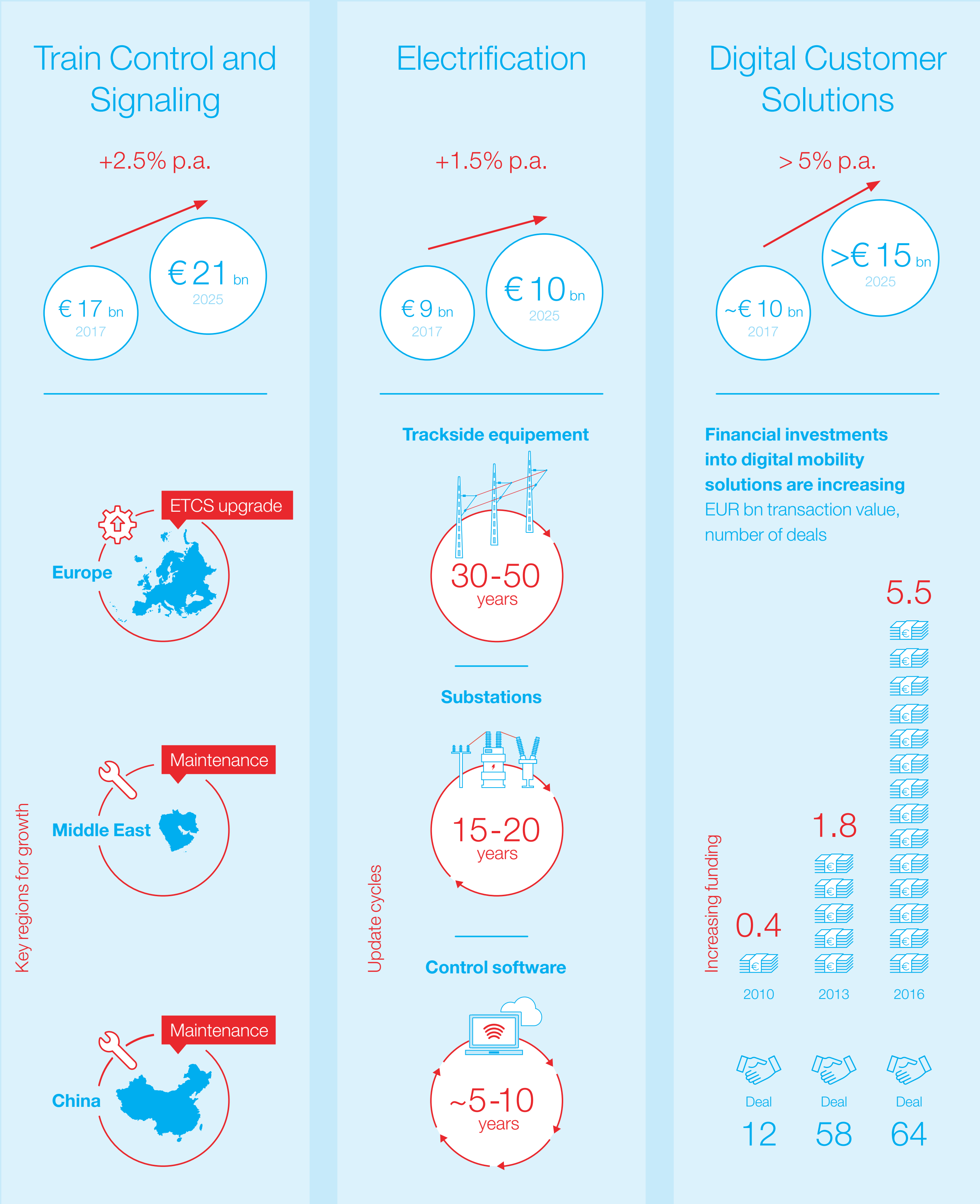
Non-rail players will push their proprietary ecosystems to the passenger, implying loss of a direct link to customers and their travel data for the current gateway, which today is still largely the operator. As a response to the opportunities inherent in these new digital solutions, players from the rail ecosystem must be inclined to enter the market for information systems and solutions. They need to be strategic about where along the value chain they would be best positioned, weighing synergies on the customer side against limited compatibility with the existing traditional rail business. For rail OEMs, we foresee organic and in-organic options to grow into the market for digital customer solutions.

- Organic growth – Developing key passenger service solutions on their own (e.g., Siemens "Be-in"-"Be-out" ticketing solutions, Thales eTicketing System, Deutsche Bahn Vertrieb Quixxit)
- In-organic growth – Acquiring key technology providers for digital customer solutions (e.g., Siemens' acquisition of software-solutions provider Hacon in 2017, Alstom's acquisition of Nomad Digital for passenger end-to-end solutions in 2017)

We will describe different archetypes of digital solutions and resulting business models in trend C1. To succeed on these new digital playgrounds, aspiring OEMs should be adamant to reflect four key success factors around go-to market strategy, customer experience and design, digital talent and capabilities and agile organization.

All market segments are growing while growth drivers vary by segment

EUR bn and % in 2017 real terms



B1 Solid, global market growth with technology upgrades and maintenance in focus

Global rail infrastructure technology is currently a ~EUR 36 bn market annually.

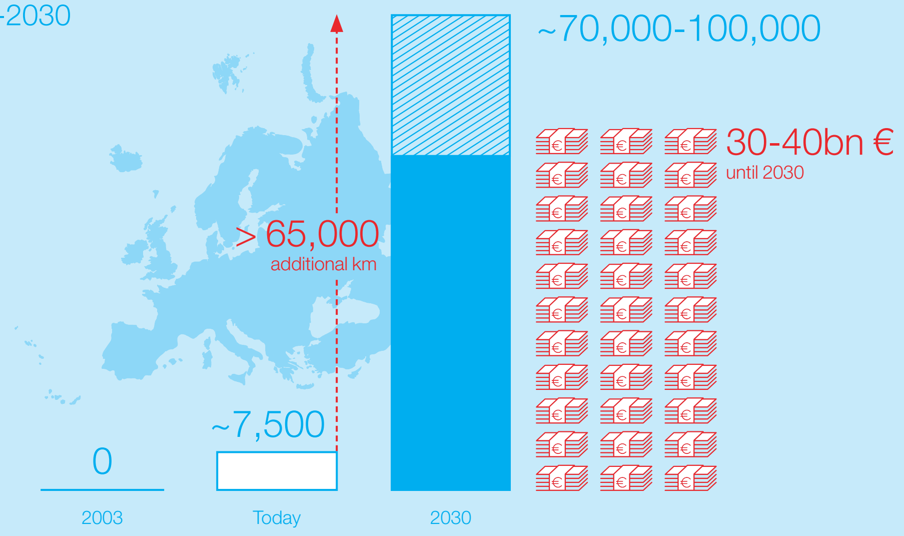
The train control and signaling industry is the largest segment of the market at ~EUR 17 bn p.a. which is set to grow by ~2.5% p.a. in real terms until 2025. Market growth stems from selected regions that cyclically undergo dedicated rail infrastructure new development or upgrade programs. In particular, until 2025, we will see a shift from new development activities (mainly China and Middle East, decline of ~2 to 2.5% p.a. in real terms) towards advanced signaling technology upgrade programs (particularly ETCS in Europe, real growth of up to 4% p.a. until 2025). In addition, the renewal and maintenance business is a strong growth segment (3-4% real growth until 2025) along the recent installed base growth, particularly in China and Middle East as well as shorter renewal cycle times driven by higher share of software components. Growing business opportunities in more lifecycle-oriented contracts will also be observable (e.g., Siemens 25-year CBTC contract for Copenhagen Commuter Rail system (S-Tog), Alstom and Thales CBTC contract with Hong Kong's metro operator MTR).

Rail electrification is ~EUR 9 bn of the ~EUR 36 bn per year infrastructure technology market. This segment is set to grow by ~1.5% p.a. in real terms until 2025. Selected electrification programs across Western Europe (UK, Denmark), North America (light rail business) and India do not compensate for the phase-out of real growth from China's mainline, new-built investment program. Therefore, we expect to see a slight shift in the electrification business towards renewal and maintenance (real growth of ~2 to 2.5% p.a. until 2025), which is driven by increasing technological complexity in rail electrification systems and shorter update cycles through shift towards software-components. In addition, we expect the market for traditional electrification in urban transit systems to come under pressure in the long run as innovations and improvements in battery and charging technology become more widely available.

We estimate the market for digital customer solutions in rail information systems to be around ~EUR 10 bn p.a. today. This will be the strongest-growing segment in the rail infrastructure technology business over the coming years. We observe a significant amount of capital flows into new ventures in the fields of rail automation, track and trace, and digital platforms as well as into collaboration & supply chain optimization solutions already. In total, more than 300 transactions have taken place and around USD 5.5 bn in capital investments have been made in 2016 alone. These solutions, hence, get considerable attention and funding from venture capital firms which will further spur start-up activity.

Development of ETCS deployment in Europe

Line length in km, 2003-2030



Source: ERTMS deployment statistics, UIC ERTMS Conference 2003, national railway information, McKinsey

Outlook on remaining ETCS deployment in Europe

Line length in km by country

	ETCS deployed km of total line length by country Line length in km, 2017		**Target year full ETCS deployment** Estimated	**Annual deployment** km per year
Germany	~250	38,828	~2040	~1,750
France	~2,750	28,765	~2040	~1,190
Poland	~300	18,510	~2050	~570
Italy	~650	17,041	~2050	~520
UK	~200	16,209	2044	~625
Belgium	~500	3,607	2030	~260
Denmark	0	2,552	2023	~510

Source: ERTMS deployment statistics, UIC ERTMS Conference 2003, national railway information, Eurostat, McKinsey

B2 Replacement of European signaling systems along ETCS

Among the key growth drivers in the global train control and signaling business are the advanced signaling technology upgrade programs currently being rolled out across mature markets like North America and Europe. Such advanced signaling technology brings several advantages:

- Increased inter-operability within and across countries
- Commercial advantages for both buyers (increased competition with positive impact on pricing) and producers (increased cross-border market access)
- Increased capacity utilization in the rail network through, e.g., moving-block technology with lower investments than new built tracks
- Improved safety through standardized products

While the roll-out of the PTC (Positive Train Control) upgrade across North America is already well advanced, the roll-out of Europe's ETCS (European Train Control System) upgrade program is taking off triggered by increasing cross-border train operations and regulatory efforts targeting the harmonization and EU-wide compatibility of control systems. Despite a high degree of visibility on ETCS-conforming product specifications, it will remain challenging due to:

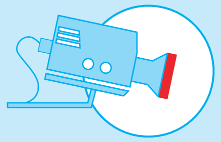
- High degree of complexity as the homologation of systems needs to be in place for every country – often we still see national specifications, e.g., Siemens and Thales systems in Germany, Alstom and Ansaldo STS technology in France
- High degree of granularity as upgrade contracts are often awarded per traffic control center or smaller line segment
- High degree of integration effort and interface management with existing systems during transition period while running operations need to be upheld
- High degree of uncertainty with respect to implementation timeline given dependence on public decision processes, e.g., in 2003 forecasts by the International Union of Railways indicated that already by 2008 ~8,000 km of line length was to be ETCS deployed

ETCS rollout-out follows several specification levels. Level 1 ensures inter-operability and cross-border train operations, level 2 has additional potential to reduce rail infrastructure costs due to less trackside equipment, and ETCS level 3 has the potential to bring capacity improvements to the network. However, to date, level 3 specifications are still being developed.

While the implementation remains challenging, ETCS also bears huge potential for growth. With more than 65,000 additional kilometers in line length to deploy under the ETCS regime across Europe until 2030, one can derive a cumulative market potential of ~EUR 30-40 bn for advanced signaling technology players. On an annual basis, the ETCS program hence contributes around 4% real growth p.a. to the European train control and signaling market. Several countries with smaller rail networks such as Denmark are early-movers targeting full ETCS deployment by 2023, while implementation plans for larger network countries span out to well beyond 2030.

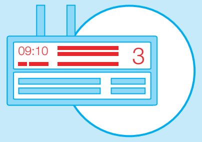
Ample digital business model opportunities in passenger information solutions

Digital archetypes with business model opportunities and use-cases



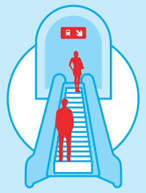
Safety and security

- Advanced security equipment and scanning solutions
- Passenger and station surveillance systems
- In-station track safety monitor (e.g., sensors)



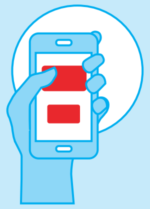
Stationary passenger information

- Real-time travel updates and information
- Data intelligence for real-time re-routing
- Digital ticketing hardware and systems



Passenger Flow Management

- Dynamic traffic and human flow management solution
- Emergency traffic and human flow management systems
- Advanced on-platform guidance systems



Online passenger information

- Digital ticketing solutions for single mode of transport
- Real-time re-routing information
- Smart price search and comparison
- Passenger on-train infotainment
- Targeted digital advertising

End-to-end mobility solutions

- End-to-end ticketing across travel modes
- End-to-end routing across travel modes
- Fare optimization and minimum fare calculation
- Intermodal ride validation
- Dynamic pricing and revenue management systems

C1 New business models in digital train operations and passenger experience

The megatrends of digitization and all-encompassing connectivity bring disruptive change to today's infrastructure networks and how individuals move within them. Over the coming years, wireless connections and an ever-increasing degree of machine-driven and autonomous steering logic will shape the rail infrastructure technology industry.

Digital solutions for train control and operations under the advanced signaling upgrade program ETCS (trend B2) and autonomous operation technology (trend C3) are the future for signaling OEMs. In addition, digital twin solutions and advanced maintenance services around sensor technologies offer attractive opportunities in signaling business. Smart grids (e.g., energy recuperation and balancing) as well as predictive maintenance solutions based on sensor data and remote monitoring (e.g., catenary supervision) are relevant for electrification players. Hence, digital solutions in these fields create new business opportunities for OEMs, yet these also bear new risks, e.g., from cyber-attacks (trend C2).

Clearly the most disruptive field will be passenger- and customer-centric digital solutions. One can expect players from the rail ecosystem and beyond to compete for solutions related to passenger interface (see trend A3). Specifically, use cases and business model opportunities arise around the following 5 large archetypes:

Safety and security solutions including equipment such as security scanning (e.g., luggage scans on Spanish high-speed trains), surveillance, track safety sensors (e.g., multi-sensor obstacle detection in Nuremberg metro) as well as cybersecurity solutions

Stationary passenger information with a focus on providing passengers with real-time updates, information and corresponding re-routing options, incl. alternative modes. Additional opportunities will open in the field of digital ticketing and validation systems

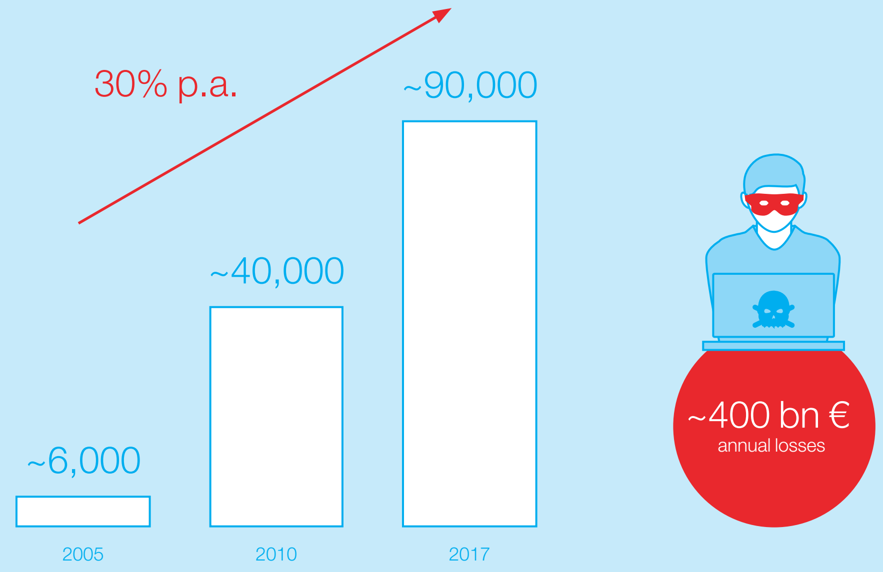
Intelligent passenger flow management solutions to dynamically reduce station congestion and increase passenger comfort (e.g., re-routing to another train or free seats in Thameslink in UK or the Hamburg subway). These passenger flow management solutions also need to cover management of emergency situations and can generally be accompanied by smart on-platform guidance systems like illuminated platform edges.

Online passenger information systems such as digital ticketing, incl. fare optimization and real-time journey updates in the case of delays. Additionally, business opportunities arise around passenger infotainment throughout whole journey, including personalized marketing (e.g., Eurostar entertainment offering).

End-to-end mobility solutions including advanced digital ticketing and/or routing solutions across transport modes, intermodal ticket validation and minimum fare calculation (e.g., Dutch OV-chipkart solution covering all public transport modes, advanced "Be-In/Be-Out" ride validation systems tested in Switzerland). In addition, operators might be interested in solutions around dynamic pricing and revenue management.

Cyberattacks have soared over the past decacde and can have significant monetary impact

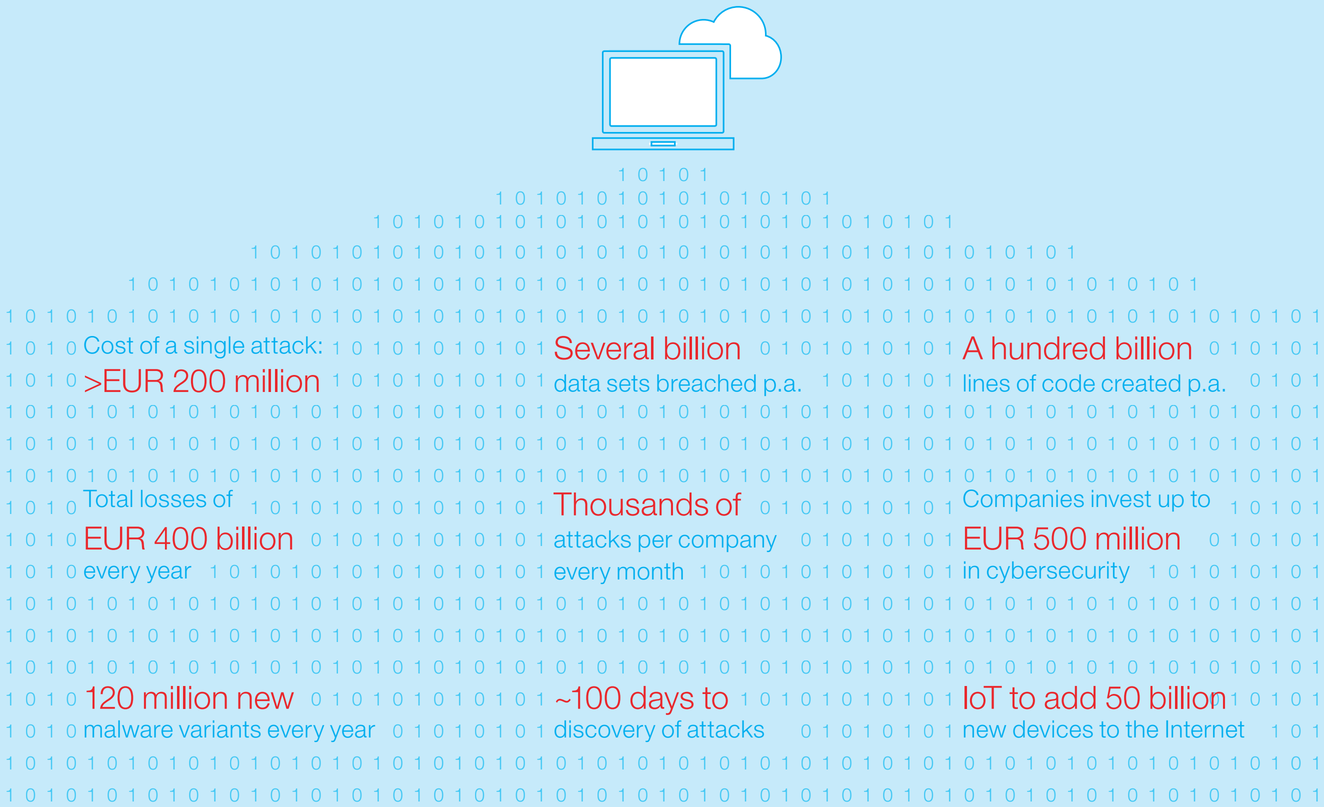
Number of incidents



Source: US-CERT, McKinsey

The threat is growing

Facts on cybersecurity



Source: McKinsey Cybersecurity and Cyberrisk service line

C2 Cybersecurity as driver for adoption of digitized solutions

Consensus is that the ever-increasing sophistication of cyber-attacks poses a core challenge to infrastructure networks and connected organizations. Over recent years, with around 120 million new malware variants each year, the level of sophistication of attacks has evolved into organized cyber-crime capable of threatening national security. The cost of a single attack can amount to more than USD 200 mn. Consequently, the market for cyber security solutions as a whole is expected to grow by ~8% p.a. throughout the coming years. Such attacks span across all relevant transport sectors and examples include

- Deutsche Bahn station information system being struck by the "WannaCry" ransomware in May 2017 causing a temporary breakdown of passenger information
- Control over connected passenger vehicles while driving like Chrysler's Jeep being taken over by hackers interfering with critical driving technology already in 2014
- Maersk global freight systems being struck by the "NotPetya" ransomware in August 2017 causing operations stoppages at 76 ports worldwide at a total cost of up to USD 300 mn

Mobility companies are acting on the imminent cyber risks, evidenced by the "Charter of Trust" for greater cyber security and promotion of digitization signed by Siemens, Daimler, Airbus and six others at the 2018 Munich Security conference. This agreement focuses on coordinated actions around, among others, certification of critical infrastructure solutions and ownership for cyber and IT security.

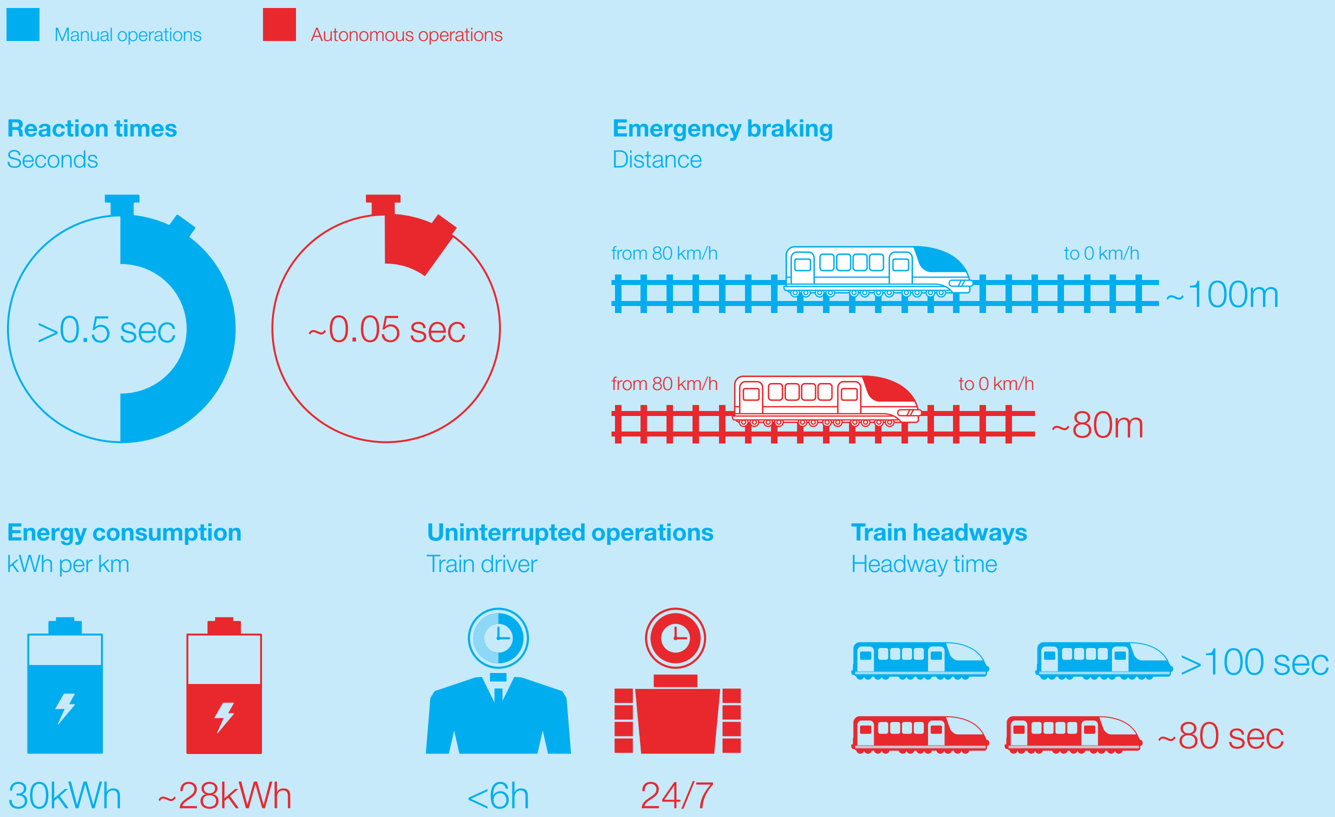
Global megatrends like the increasing digitization of the value chain are making rail infrastructure players even more vulnerable to attacks especially on the interface between operational technologies (OT) and information technologies (IT) there are vulnerabilities from connected legacy technology. While to date no cyberattacks causing major threats with respect to infrastructure technology have been recorded, it is nonetheless important to prepare and safeguard existing and new technologies, e.g.

- Interference and manipulation of critical rail operations technology causing operational incident or even trains collision or derailment
- Malicious control software causing breakdown of electrification or signaling network
- Manipulated sensors or control software causing destruction of components of the rail infrastructure technology

Rail infrastructure technology players need to ready themselves for all-encompassing connectivity by following a more adaptive, holistic and collaborative approach to cyber security incl. prioritizing assets and risks by criticality, implementing differentiated controls and processes.

Regulation will also increasingly demand cyber security standards for new technologies in this critical infrastructure sector while it will be vital to clarify liability risks for cybersecurity solution providers. In addition, network operators need to ensure that state-of-the-art cybersecurity requirements are already reflected in new built or upgrade tender processes even beyond current regulation. Successfully embedding efficient cyber-security technology in their end-to-end solutions for customers hence can serve as a differentiator for rail infrastructure technology providers and could justify a price premium.

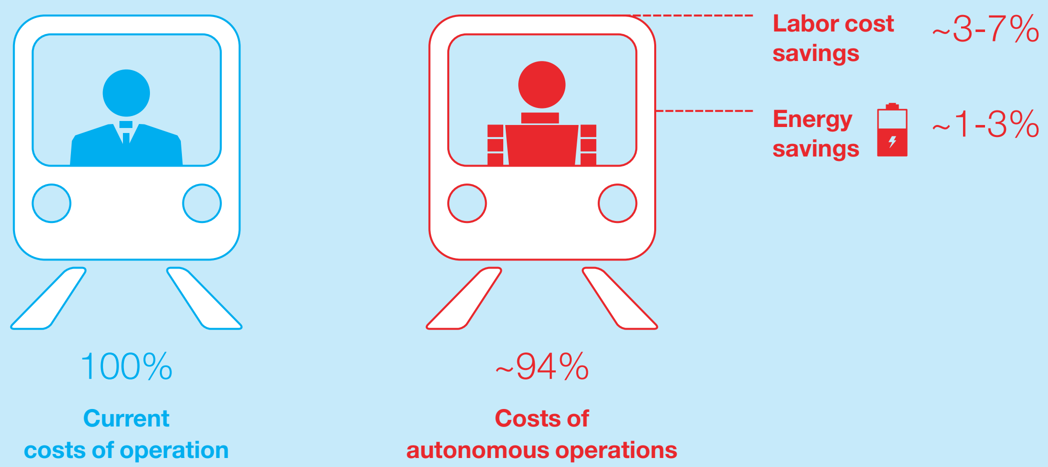
Autonomous operation technology is superior to human behavior



Source: McKinsey

Economic potential of autonomous train operations is relevant for customers

Indexed costs for train operation



Source: McKinsey

C3 Increasing automation of total urban (rail) infrastructure

Deployment of fully-autonomous rail operations will become wide-spread due to three main developments: safety improvements, operating cost reductions, and capacity enhancement.

Autonomous operation systems interact more efficiently with existing safety and control technology than human drivers ever could. Technological advancements and wide-spread deployment of autonomous driver assistance systems (ADAS) are set to reduce traffic fatalities by up to 90% with the potential to save ~USD 200 bn (incl. automotive) each year in public health costs associated, such as the fatal Amtrak train crash in South Carolina in 2018 or the head-on collision of two passenger trains in 2016 near Bad Aibling, Germany.

Autonomous train operations have the potential to significantly improve the cost efficiency of train operations as both control officers and train drivers could be substituted by autonomous technology. In the long run, this could amount to annual savings in operations costs of up to EUR 7.5 bn based on the ~150,000 train drivers alone currently employed in Europe. First, fully autonomous pilots might be seen on dedicated freight lines, like in Australia, where salaries exceed EUR 120,000. Mining giant Rio Tinto, for example, is already on track to operate fully autonomous heavy rail transport together with Ansaldo STS leading to >10% capacity increases in shipped iron ore. Additionally, driving efficiency (i.e., optimized acceleration and braking) will increase fostered by driver assistance systems, such as LEADER by Knorr-Bremse or FASSI piloted in S-Bahn Berlin. These systems can be seen as a step towards fully autonomous operations and have a cost-savings potential of up to 10%.

In addition, autonomous driving technology will increase network capacities as autonomous trains can run in shorter intervals resulting in up to 25% higher capacity on existing tracks. With limited space and significant costs associated with the expansion of rail infrastructure (second "Stammstrecke" in Munich expected to cost EUR 3.5 bn for ~11 km), such capacity improvements can help to tackle the challenges of an ever-increasing urban population. Successful examples include the fully autonomous Paris metro line 1, which has already realized a capacity improvement of ~20%. Success here triggered the retrofit of the city's Line 4 making it fully-autonomous as well. In addition, German rail operator Deutsche Bahn digitizes train control technology in their "Digitale Schiene" initiative targeting capacity improvements of up to 20% each year.

We have identified three key elements of autonomous train technology that are central for rail infrastructure technology providers to obtain.

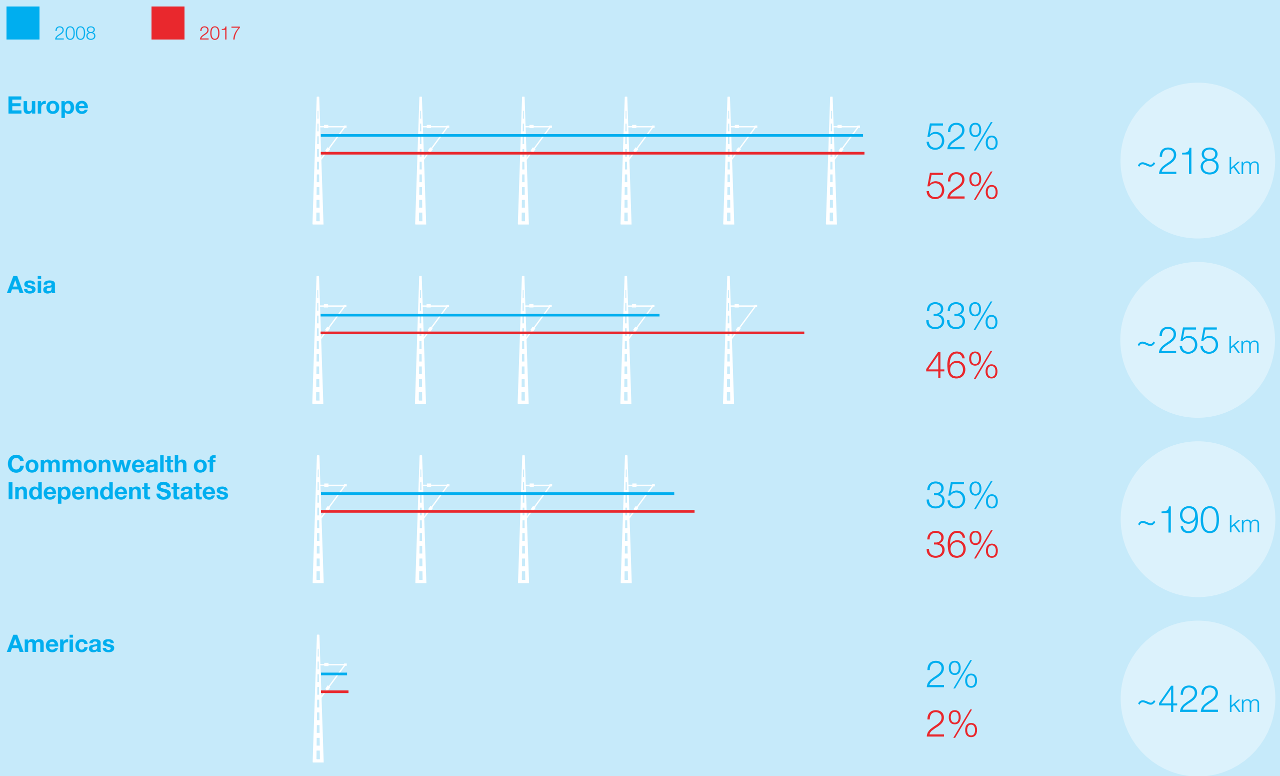
- Protection– ensuring train-to-train/network interactions like distance control
- Operation– providing entire driving-critical features like braking or door opening
- Supervision– enabling communication with remote control center for network steering

Rail infrastructure technology providers might consider partnerships with players active in autonomous operations in automotive given their leadership in a complex ecosystem and the high level of applicability across multiple forms of transport.

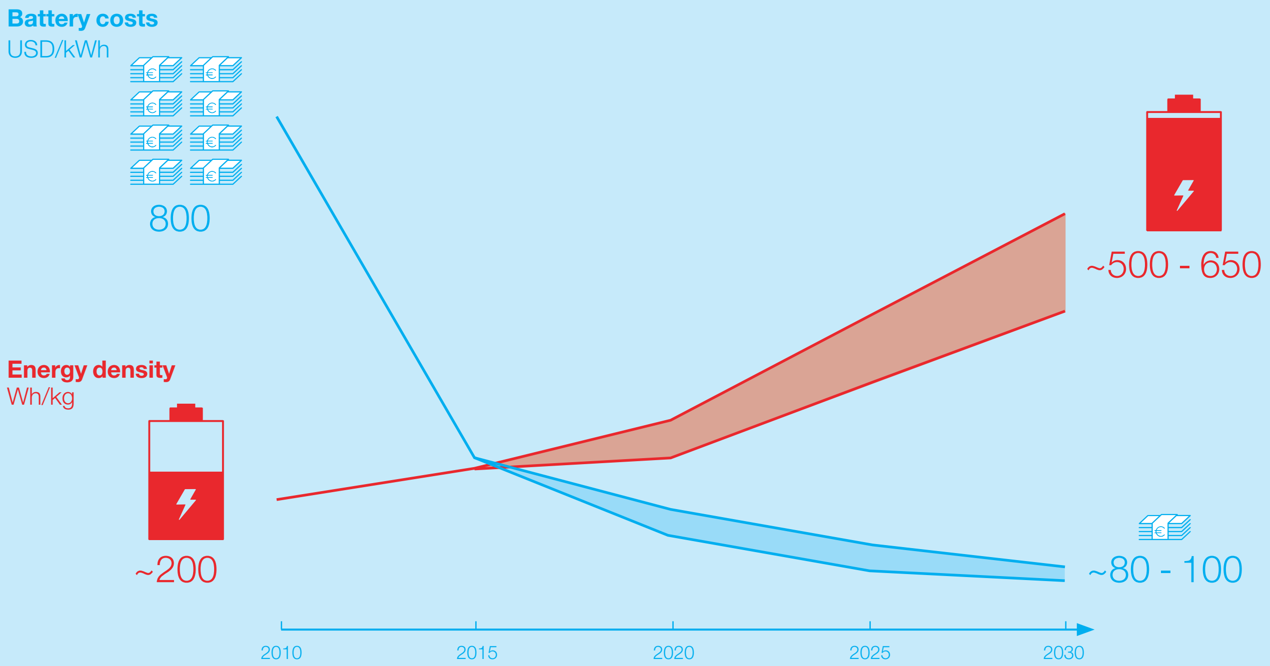
Length of the global electrified rail network has increased significantly over the past decade

% of electrified rail network by region

Total network length in '000 km



More performant battery technology becomes available at lower costs



Source: BNEF, Bernstein, Goldman Sachs, SNE research, Avicenne Energy, Credit Suisse

C4 Innovation and improvement in battery and charging technology

In the wake of an ever-increasing public discussion about sustainable mobility solutions and the environmental need for emission regulation, electrification of the overall traffic and rail infrastructure has become common. Conventional electrification is a very mature technology. Recent improvements to effectiveness and efficiency comprise more stable operations in very high-speed networks through and energy recuperation in smart grids respectively.

In Europe, around 50% of the rail network is electrified, driven by economic and sustainability considerations, with more than 90% of traffic volume running in the electrified network. In recent years, Asia has expanded its electrified rail network by ~50% driven by new-built investments into the high-speed network. America traditionally shows low electrification rates due to low train frequency and a primary focus on freight transports. From an economic perspective cost-benefit analysis needs to be done. We typically observe costs of EUR 500,000 per kilometer of conventional rail electrification.

Another aspect of cost efficiency in rail electrification is the utilization of battery technology instead of conventional direct energy transmission from the grid. For battery technology, the first attractive use cases can be found in the urban rail infrastructure, where charging can happen continuously at station stops. These early successful examples include – but are not limited to:

- Pantograph-based charging during stops at stations only, while routes no longer need electrification. Two technological alternatives can be distinguished. While batteries have longer charging times, they power vehicles over longer distances (e.g., Nice tramway system), super-capacitors can be charged in less than one minute for short operation between stops (e.g., Seville light rail system).
- Induction-based contactless charging of electric motors or battery/super-capacitor during stops and potentially dynamically during acceleration, e.g., Nanjing tramway.
- Braking energy recovery systems to re-use energy using traction engines of the vehicle to recuperate energy while braking. This energy is re-used for traction, HVAC or feedback into grid. Examples are manifold and can be found in most advanced urban transit systems (e.g., Brussels metro).

Going forward, energy density will further increase while cost per battery will further decrease making battery technologies economically feasible for large-scale operations. For cost-efficient application of battery technologies in rail, OEMs might consider partnership models with experienced players from other ecosystems, e.g., automotive. In the medium term, the focus will lie on developing solutions for urban transit with less distance and more stops.

Beyond battery driven propulsion systems there are also further systems piloted such as fuel cell technology, e.g. by Alstom in Germany (Coradia iLint) or CRRC in China (FCveloCity). This technology might achieve even higher specific energy density.

III. Revenue pool quantification – shifts, challenges, and growth opportunities

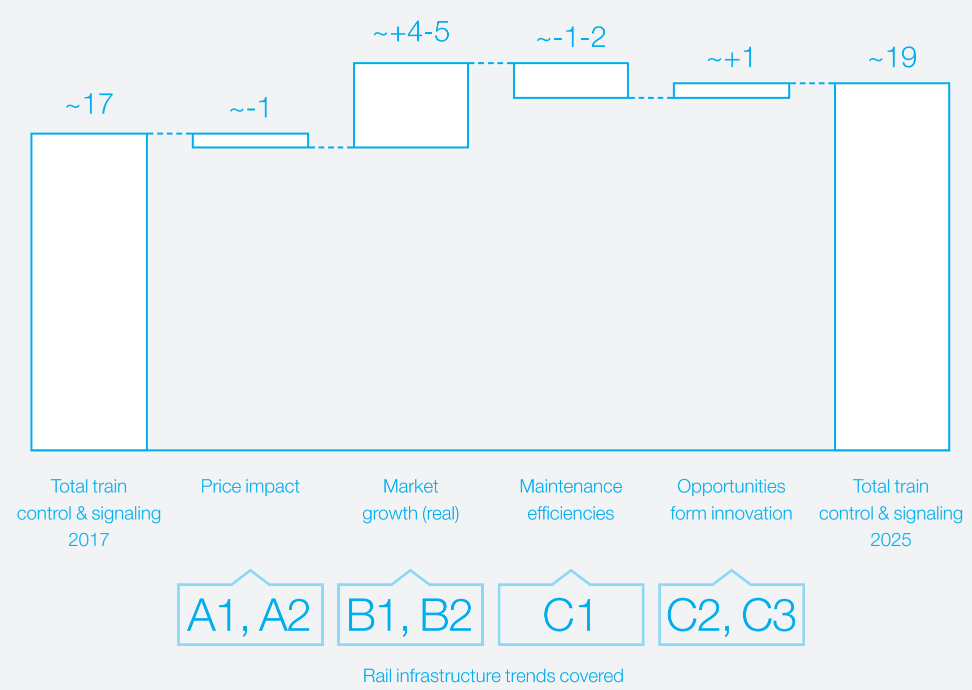
The trends, challenges and resulting growth opportunities are quite different in rail infrastructure technology's three segments train control and signaling, electrification and digital customer solutions. Importantly, the strongest growth opportunities for rail infrastructure technology OEMs arise in the field of digital customer solutions.

Train Control and Signaling

The annual global revenue pool for train control and signaling players is set to grow slightly from EUR 17 bn today to EUR 19 bn by 2025 in real terms.

The real market growth of ~2.5% p.a. brings additional annual revenues of ~EUR 4-5 bn driven by the ETCS advanced signaling upgrade program and increasing maintenance business (trend B1). Price pressure from technology standardization (trend B2) and intensifying competition (trends A1 and A2) lead to a reduction in annual revenues of ~EUR 1 bn. Increasing numbers of software components, new digitized solutions, sensor technology, predictive maintenance and remote monitoring enable up to 15% more efficient maintenance regimes reducing annual revenues by ~EUR 1-2 bn (trend C1).

Exhibit 5: Revenue pool development: Train control and signaling until 2025
EUR bn p.a. in 2017 real terms



While these shifts, such as the one toward predictive maintenance, imply a smaller revenue pool, it remains to be seen whether value pools from the service business shift from operators to OEMS. Innovations on the cyber-security solutions front (trend C2) and autonomous rail operation technology (trend C3) present opportunities for OEMs to tap into an additional annual signaling revenue pool of ~EUR 1 bn.

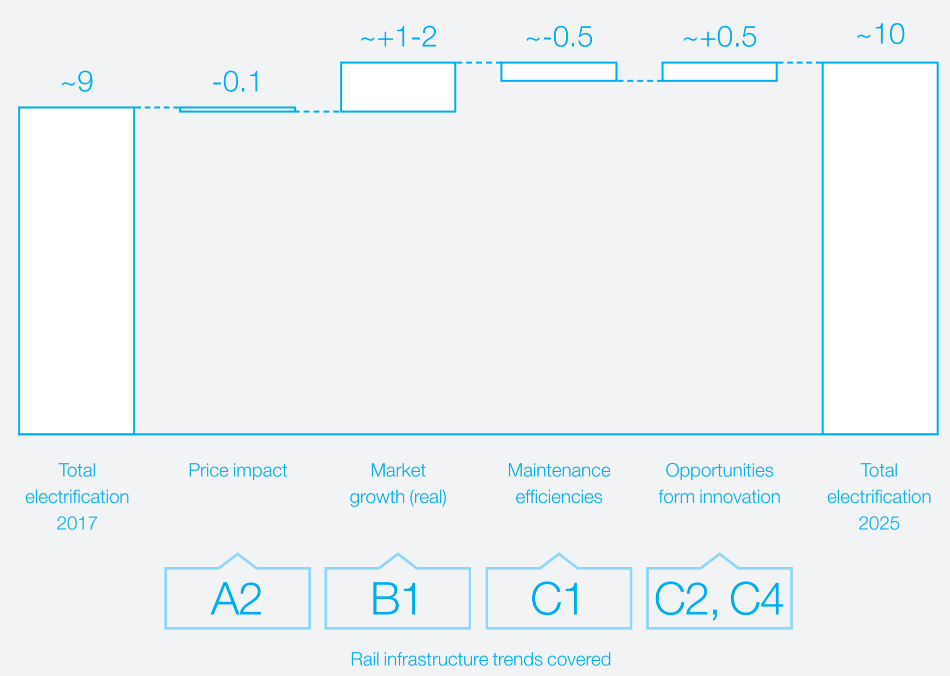
Electrification

The global annual revenue pool for railway electrification solutions is set to grow slightly from EUR ~9 bn today to ~EUR 10 bn by 2025 in real terms.

The slowing real market growth of ~1.5% p.a. brings additional annual revenues of ~EUR 1-2 bn (trend B1) driven by selected electrification programs and maintenance. Price pressure from intensifying competition (trend A2) leads to a small reduction in annual revenues of ~EUR 0.1 bn. The 15% greater efficiency in maintenance regimes – enabled by more software components, new digitized solutions, sensor technology, predictive maintenance and remote monitoring – will also likely reduce annual service revenues by ~EUR 0.5 bn (trend C1). Here, innovation on the cyber-security solutions front (trend C2) and battery technology (trend C4) present opportunities for OEMs to tap into an additional annual revenue pool of ~EUR 0.5 bn.

Exhibit 6: Revenue pool development: Railway electrification until 2025

EUR bn p.a. in 2017 real terms



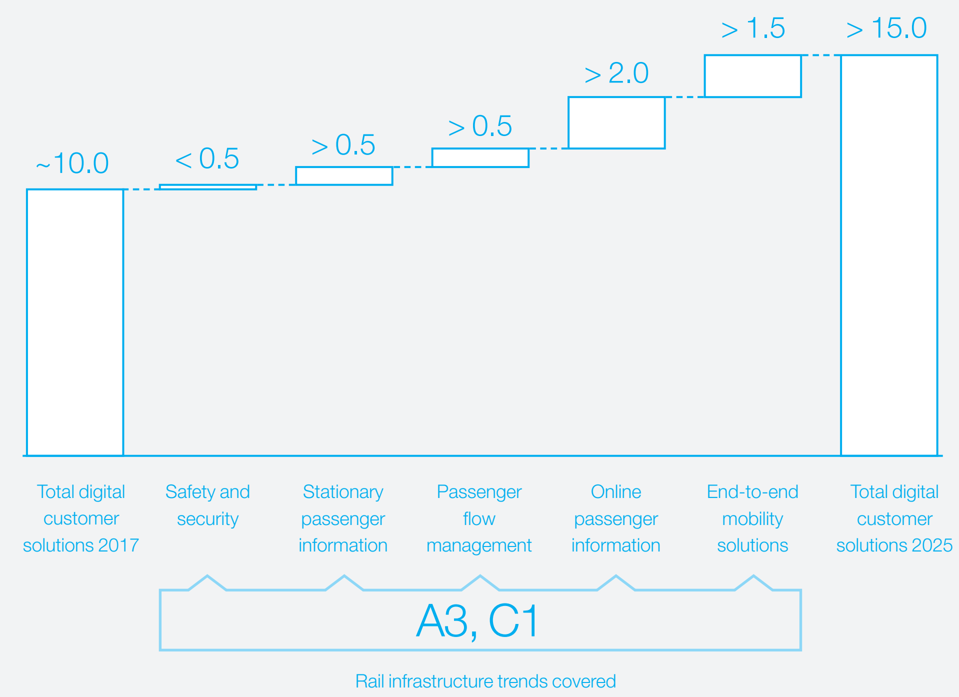
Digital Customer Solutions

The global annual revenue pool for digital customer solutions is set to grow strongest from EUR ~10 bn today to more than EUR 15 bn in 2025 in real terms.

The disruptive nature of all aspects of digital customer solutions makes it a hard to quantify market segment in general. Clearly, the strongest growing segments will be online passenger information (EUR ~2 bn) and integrated end-to-end mobility services (>EUR 1.5 bn) with a multitude of business model opportunities for established rail infrastructure OEMs (trend C1). Several successful digital customer solutions like Trainline for integrated trip planning and ticketing based on minimum fare or of course Uber in the ride hailing market have proved that integrated platform solutions form the basis of success in these segments.

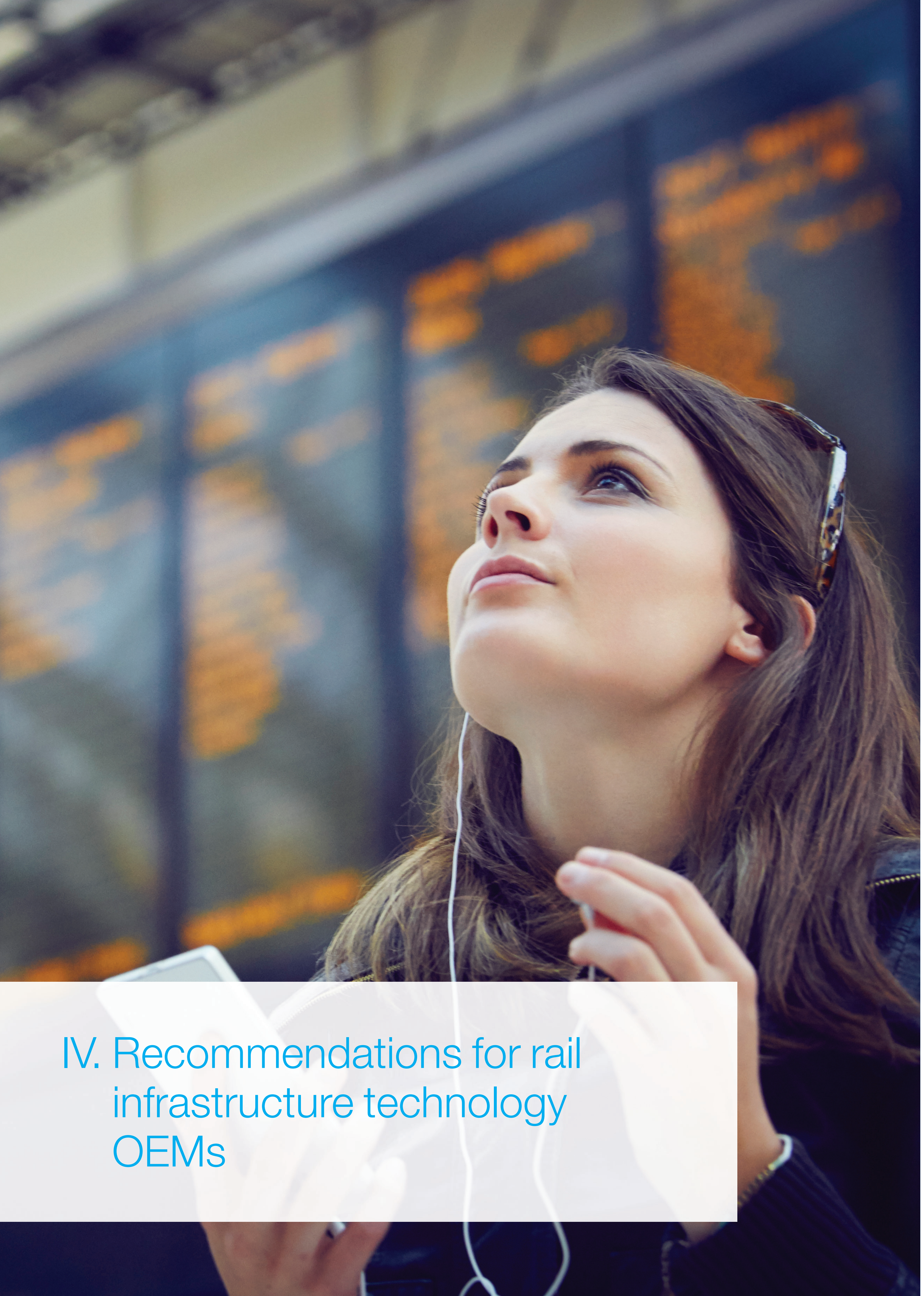
Exhibit 7: Revenue pool development: Digital customer solutions until 2025

EUR bn p.a. in 2017 real terms



Opportunities in data management for real-time information or human flow analytics, digital ticketing systems or advanced station guidance drive growth in the stationary passenger information and passenger flow management segment (~EUR 0.5 bn each). The safety and security segment does not necessarily follow similar market mechanisms as growth can be spurred through tragic events, attacks or political decisions.

Yet, competition with players from within and beyond the rail ecosystem will impact the ultimate value pool share in digital customers solutions that established rail infrastructure technology players can attain (trend A3).



IV. Recommendations for rail infrastructure technology OEMs

Based on the trends and revenue shifts ahead we recommend that OEMs consider the following actions

Reduce costs
OEMs need to work on their cost base to strengthen their competitive positioning in light of intensifying competition, growth in emerging markets, and increasing price-consciousness. These efforts might be targeted at what are typically the largest three cost components: purchased parts, R&D/engineering and manufacturing.

- Purchased parts – OEMs can benefit from scale in procured parts negotiation overall and specifically for carry-over parts
- R&D/engineering – OEMs can reduce costs through Design-to-Value initiatives and by leveraging scale
- Manufacturing – OEMs might rethink footprint localization to low cost environments

Build customer- and project-centric organization
OEMs need to adjust to new customers located in emerging countries and to growing diversity of the project-business landscape. For example, out of the 33 new metro systems opened after 2010, 26 systems are located in China, India and Iran, but only 2 systems in Europe and none in North America. OEMs hence need to tailor sales activities to an increased number of different customers, particularly in urban transit where there are many players in each country in contrast to (typically) one key mainline customer.

Decide on role in the B2C value-chain
The largest growth segment of the industry includes innovating the passenger interface. While OEMs in the past have typically solely focused on the B2B business model, a digital strategy – including a decision on which control point in the value chain OEMs want to operate – is required for future success and realization of business model opportunities.

Drive innovations and technology standards
As a response to increasing product standardization paired with opportunities from technology upgrades, OEMs need to invest in continuous innovation of their products and services. To succeed in continuously innovating, OEMs need to ensure access to and development of the right talent and capabilities and investigating potential strategic partnerships are viable options.

Leverage partnerships
Digitization, connectivity and autonomous operations are disrupting the industry. Given that the rail infrastructure industry is still smaller than other industries like the automotive industry, it might make sense for industry players to leverage the product innovations of others instead of taking on the task themselves. These partnerships in the areas of both hardware, e.g., sensor systems, and software technology, e.g., in routing, can either be collaborative or via in-organic moves.

□ □ □

The global rail infrastructure technology industry is facing significant shifts in the market, including increasing competition, changes in customer demand, heightened cyber-security threats, the emergence of technology standardization, and technology-driven disruptions such as autonomous operations. These developments demand new digital business models, e.g., for the passenger interface, and new value propositions. Some of the key trends and corresponding shifts in the revenue pools may not manifest immediately. Nonetheless, since adapting the business models is a multiyear process, it is imperative that rail infrastructure technology players start preparing now. This is especially important since the major growth areas are centered on innovation, new technologies and local requirements, which demand new business models, new customer interactions, and also probably new talent in rail infrastructure OEMs' organizations. OEMs might continue looking at leveraging external partnerships and establishing cross-functional teams equipped with the skills and open mindset required for experimenting and innovating to remain competitive in the long run.

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